University of Salford MANCHESTER

Engineering Better Social Outcomes through Requirements Management & Integrated Asset Data Processing

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Baz 1941-2015

Abstract

The needs of society are no longer serviceable using the traditional methods of infrastructure providers and operators. Urbanisation, pressure on global resources, population growth and migration across borders is placing new demands which traditional methods can no longer adequately serve. The emergence of data and digital technology has enabled new skills to emerge and offer new possibilities as well as set much higher expectations for the younger generation who have only known lives in the digital age.

The data describing the physical properties of built assets have been well understood and digital methods such as Building Information Modelling are providing levels of access and quality historically unknown. The concepts of human perception are not so well understood with research only being documented over the last forty years or so, but the understanding of human needs and the impact of poor infrastructure and services has now been linked to poor perception and social outcomes.

This research has developed and instantiated a methodology which uses data from the delivery and operational phases of a built asset and with the aid of understanding the user community's perceptions creates intelligence that can optimise the assets performance for the benefit of its users. The instantiation was accomplished by experiment in an educational environment using the "Test Bench" to gather physical asset data and social perception data and using analytics to implement comparative measurements and double loop feedback to identify actionable interventions.

The scientific contributions of this research are the identification of methods which provide valuable and effective relationships between physical and social data to provide ''actionable'' interventions for performance improvement and the instantiation of this discovery through the development and application of the ''Test Bench''.

The major implication has been to develop a testable relationship between social outcomes and physical assets, which with further development could provide a valid challenge to the least cost build option that is taken by the vast number of asset owners, by better understanding the full implications on people's perceptions and social outcomes. The cost of operational staff and resources rapidly outweighs the cost of assets, and the effective motivation and productivity the right environment can provide improved or inhibited performance and social outcomes.

Chapter 1

Introduction

1.1 Introduction

Chapter one provides an overview to the background and rationale of the research in relation to the phenomena which effects physical asset performance and social perceptions of the built environment and the services provided by it. The chapter builds on this by reviewing the emerging opportunities brought by new technology to establish a data driven approach to managing requirements using structured data describing physical and perceptive feedback. It then concludes with encapsulating the key challenges facing the providers of assets in providing better performing assets in a set of research aims and objectives.

1.2 Background

Leaders in the public and private sectors now realise that the approach to urban development currently being pursued by society is not sustainable in the long term. The social problems that are arising from this lack of sustainability are becoming obvious and are creating concern in the mind of the public at large. The Federation Internationale des Ingenieurs-Conseil, (FIDIC 2011), quotes “we need to respond in many ways to make better use of our finite resources and to deliver the best possible opportunities for our population to lead fulfilling useful lives”.

The UK Government's stated objective in the Construction Strategy (GCS 2011) was to deliver a national infrastructure to service public consumers. The impact of national infrastructure not performing has gross implications on society and our ability to perform basic day-to-day tasks as well as to maintain a competitive national economy. Best practice identified by the UK Government (GCS 2011) supports the acceptance and adoption of the asset by ensuring end users' expectations and perceptions are met. Schemes that have failed to address these issues are characterised by lack of planning, management, design, integration and delivery with designers, contractors and stakeholders. As technology develops and matures, finite resources diminish our historic approach needs to evolve. The digital revolution has come at a very timely moment in history with growing awareness of our impact on the planet, realisation that our continued use of finite resources will have consequences and a recognition of the impact of those consequences on society.

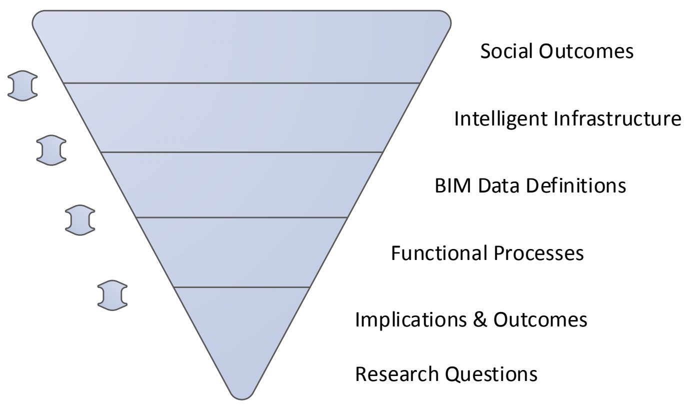


Figure 1.1 - Literature Review – Funnel Strategy

The relationship between people and the built environment is complex and multi aspect. To contextualise this a model is described in Figure 1.1 which demonstrates the key areas of interest. This framework is a variation of the funnel principle described by Bailey (2003) and provides a useful point of reference to focus the research.

At the mouth of the funnel the user or subject interacts with the environment. In recent years the impact users have had on the environment has been described by FIDIC (2011) as unsustainable. The emergence of "sustainability" as a concept has been rapid in the last decade. For the purpose of this research we will be utilising the definition provided by BS EN 15643-3:2012 (2012), which defines sustainability as the "ability of a system to be maintained for the present and future generations", in the context of "environmental, social and economic aspects". We are familiar with the cost and environmental elements of this all-encompassing subject and much progress has been made in the sector to formalise methods and measurements, but have these started to deliver improvements? The evidence around carbon according to the RAE (2010), is at best unreliable, due in the main to poor data quality or inconsistent or incomplete processes. The third and less well documented element of sustainability is the impact on people and society that the built assets have and the perceived impact upon users and consumers.

The demands of society on both built and social infrastructure continues to grow in step with the increasing rates of urbanisation. According to the United Nations - World Urbanisation Prospects Report (UN 2014), 54% of the world's population now lives in urban areas, compared to only 30% in 1950. It is forecast that by 2050, 66% of us will live in an urban area. This also means we are now spending more time inside buildings. The impact on our wellbeing, happiness and state of mind is critical to maintain the fabric of society and prosperity. This research contains a review of research in this area and demonstrates the potential scope for improvement such work is vast, but suffers from a lack of standardised measurement and commercial imperative.

The construction sector is responsible for providing accommodation and spaces for life functions, but is faced with many competing variables including cost, time and quality which need to be balanced against the needs of a client and most importantly the users of an asset. Users have been challenging builders since the beginning of time; the difference now is that, for the first time in the construction industry we are seeing the beginning of a digital revolution, (NBS 2016) indicates that this has crossed the half way point with 54% of businesses aware of and using BIM, with a further 47% having an awareness. Useful structured data and transactions are starting to become used and better understood, these are seen by many as a potential way forward, providing a clear and transparent trail of transactions and relationships. This new environment is enabling a whole new area of analysis and study of data that is being generated around us. The emergence of "Linked"

"Open" and "Big" Data is enabling us to provide insights into things to discover new properties about our built environment. This research is focused on harnessing this information during the asset design and delivery phase and effectively using it to provide better places for people to use, delivering better social perceptions, wellbeing and outcomes.

1.2 The Research Problem

There are two key problems identified in providing better performing assets, the first is related to the poor consistency of delivery and production inside the construction supply sector, brought about by least cost pricing, low barriers to market entry and massive fragmentation. The second is related to the lack of transparency of the implications of such actions inhibiting feedback and learning leading to poor incentivisation to change behaviours and make improvements.

1.2.1 A Lack of Effective Methods and Alternate Agendas

The models of engagement between the asset owner (the need or demand), the funder, the delivery teams and the users are disparate and fail to encourage learning (through feedback) and adequate long term focus on the needs of users.

The industry employs Victorian engagement methods and contracts that are not designed to align needs through the value and supply chains. This provides fertile ground for disputes and poorly aligned contracts and agreements with differing agendas due to individual commercial positions and perceived needs. The developer is typically keen to deliver at the lowest capital cost and have early occupation to ensure cash flow and profit. The delivery team want to enhance the specification and extend the delivery process to enhance profits and users want more and better service for less rent. This position is then enhanced with a lack of common engagement methods, poor data and market fragmentation. By example, there are too many approaches across the various programmes including Building Schools for the Future and other strategic programmes which, with hindsight, were expensive and did not deliver the schools that were needed, according to James (2011). He went further to state "the design and procurement process for the programmes were not designed to create either high and consistent quality or low cost. Procurement started with an amount of money rather than a specification, designs are far too bespoke and there is no evidence of an effective way of learning from mistakes." This has been further echoed in the heritage regeneration sector by ACG (2008) who have identified "the distinct lack of quantitative evaluation concerning social impacts and perception through both heritage and general regeneration projects", with inadequate resources and ability to evaluate the outcomes. James (2011) also identified that the school's capital allocation process is complex, time consuming, expensive and opaque. Devolved funding processes do not deliver efficiently the objectives that they were established to achieve. Multiple funding streams diverted funds to those most adept at winning bids rather than necessarily to those most in need.

1.2.2 Lack of Understanding of Implications and Incentives to Improve

The lack of effective methods promotes a lack of useable data. This means that there is no transparency of holistic performance and it becomes very difficult to demonstrate the implications or to set an incentive strategy to encourage behaviours that provide improved performance and user outcomes.

James (2011) said: "A lack of expertise on the client side meant that there was little opportunity to improve building methods in order to lower costs over time." He also said that central mechanisms to engineer better solutions were too weak. He identified that maintenance was critical to controlling the lifetime cost of schools and the quality of maintenance across the estate is extremely variable. This is exacerbated by the fact that no good quality data is collected on the condition of the estate. ACG (2008) identified that there is little quantitative evaluation of the benefits of regeneration on social capital. They go on to identify that a community or area with strong social capital should have a heightened sense of personal or social responsibility and be inclined to respect social values (Paxton et al 2002). To enable a measurement process, they use the Inter-Organisational Committee on Guidelines and Principles 1994 definition of Social Impact: "By social impacts we mean the consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organise to meet their needs, and generally cope as members of society." This allows them to create a relationship between regeneration, deprivation and health. However, the lack of methods to link these is repeated as is the difficulty in creating a relationship between commercial development programmes and social wellbeing.

To illustrate these problems, the following examples are typical of the challenges involved when faced with the task of providing assets which provide effective environments for people and communities to thrive.

The Building Schools for the Future (BSF) programme as described and reviewed by James (2011) was defined as a key enabling strategy in the employer's desire to create an "educational transformation" across the country. This was a far-reaching programme which, at its peak, was the largest single programme in the Governments portfolio. However, as part of the James (2011) review, a key view identified was that there was almost universal consensus that "while no one doubts that children deserve to learn in safe and pleasant environments – and that significant parts of the school estate were and are in an unacceptable state – there is very little evidence that a school building that goes beyond being fit-for-purpose has the potential to drive educational transformation. The generally held view was that the quality of teachers and leaders has a much greater impact on attainment than the environment."

This lack of understanding or ability to measure the performance of the estate and its perceived social performance led the Government to allocate improvement funds in unpredictable ways, often based on local agendas or academic performance. This is evidenced by the example of the Simon Langton Girls Grammar School in Kent;

Case Study - Education

Simon Langton Girls' Grammar School in Kent has been rated 'outstanding' by Ofsted and 99% of its pupils achieve 5 A* - C grades at GCSE. The school building has been in significant disrepair for some years. In the last two years, large pieces of concrete have become loose and fallen from the building. The roofs of the main building are flat and have needed continual repairs for some years but are now beyond economic repair.

Kent received funding in waves 3, 4 and 5 of BSF, and was also due to be part of wave 6. Simon Langton is an example of the kind of school that was not a priority within BSF, despite the fact it is in need of urgent improvement. By the criteria applied to determine which areas should get BSF funding, the results at Simon Langton were too good and the pupil population insufficiently deprived.

“We are victims of our own success – schools which achieve outstanding results are not seen as being those which need any money spent improving their buildings, which is a public disgrace. They are not and never have been considered as a priority in terms of capital expenditure.”

Jane Robinson, Head Teacher, Simon Langton Girls’ Grammar School

At no time in the review of literature or the review of the asset delivery process was there a convergence of the widespread research into human perception and behavioural psychology and the provision of the environment. This is not limited to the educational sector - there are examples from across the breadth of the built environment.

Case Study – Housing

Shelter has spent a lot of time analysing the effects of poor accommodation on the life chances of children. They indicate that the “Housing Effect” is especially pronounced in relation to health. Children living in poor or overcrowded conditions are more likely to have respiratory problems, to be at risk of infections and have mental health problems. Housing that is in poor condition or overcrowded also threatens children’s safety. The impact on children’s development is both immediate and long term; growing up in poor or overcrowded housing has been found to have a lasting impact on a child’s health and well-being throughout their life.

Growing up in bad housing also has a long-term impact on children’s life chances because of the effect it has on a child’s learning and education. Homeless children are particularly disadvantaged because of the disruption to their schooling caused by homelessness. Living in poor or overcrowded housing conditions also affects a child’s ability to learn, which can have a lasting impact on a child’s chances of succeeding in life. Furthermore, the roots of later problems – such as offending and behaviour problems in adulthood – may be traceable to behavioural problems that emerge when children are growing up in poor housing conditions. Figures from 2006 indicate that poor housing accommodation leads to:

- Up to 25 per cent higher risk of severe ill-health and disability during childhood and early adulthood. There is a direct link between childhood tuberculosis (TB) and overcrowding. This also exposes children to a tenfold higher risk of contracting meningitis.
- Increased risk of conditions such as asthma and slow growth, which is linked to coronary heart disease.
- A greater chance of suffering mental health problems and problems with behaviour.
- Lower educational attainment, greater likelihood of unemployment and poverty.

1.3 Research Aims

The aim of this research is to develop a methodology which analyses data from the briefing, delivery and operational phases of a built assets lifecycle and combines user's perceptions of the assets performance, to provide insights that can assist in the identification of actions that can improve existing and future assets, to encourage a positive impact on people's lives.

1.4 Research Objectives

The key objectives of this research are:

1. To establish the nature and structure of data processed throughout an asset's lifecycle.
2. To establish the availability, nature and characteristics of human perception and methods for collecting data to record the perceptions.
3. To identify methodologies which allow social perceptions and built asset physical performance data to be usefully analysed.
4. To develop a methodology that can be used to systematically process physical asset data and social perceptions.
5. To determine how the outputs of such an approach can provide feedback which may be presented in an actionable format that could be used to improve existing asset performance and future briefing.

1.5 Research Scope & Unit of Analysis

The scope of this research has focused on the nature of the relationship between physical asset data and human perceptions. This is a vast scope and has been limited for the purposes of this research to the relationships between a limited number of variables in each domain in a single type of built environment. The physical definitions will be bound by areas (grouped into zones) and the measurement of values relating to atmospheric pressure, temperature, light, noise and volatile organic compounds. The communities of study will be limited to a comparison and experiment in a school environment (however this should not limit the approaches wide applicability to other asset types). All external influences not included in the research must be considered in the wider context and are referred in the conclusions and potential further research areas. Examples of these out of scope entities will include impacts of multiple assets and different combinations of assets, especially transportation systems, dependencies of immediate communities on other third party relationships and communities which may or may not be material in the influence of the asset under review. This would require access to much larger and broader scopes of data than would be possible in this research.

The research only refers to other areas of research or domains where there are specific interfaces. At these points the researcher has kept the interfaces and methods of data acquisition in scope but excluded the detail of how that data is derived in the third party system. This includes systems such as Building Management Systems or detailed sensor technologies.

This scope, when read in conjunction with the Research Questions forms a sharp focus on understanding what actions and behaviours asset owners and operators can make to enable the communities which use them to have better and more fulfilled and productive lives.

1.6 Research Approach

The research approach is designed to bring together two opposing philosophical views pertaining to the views associated with subjective and objective data generators. This identifies the need to use mixed methods and a pragmatic approach such as realism to create a balance between the extremes of view. The long term nature of built assets identified a need to balance the demands of longitudinal and cross sectional study. The overall approach of literature and cases study review or experiment was defined by the greater opportunity to identify new knowledge and that low level of literature in this domain.

1.7 Thesis Structure

This thesis is presented in nine Chapters; the structure is designed to accurately articulate the research flow.

Chapter One - Introduces the research and the work undertaken and describes the clear aims and objectives.

Chapter Two - Is a critical literature review looking at the "Physical Measures" relating to the operation of an asset. The way that data is generated, checked and used to gain a digital virtual description of an asset to enable comparisons of performance against design brief, best practice and potentially other "Complex Systems" including linked or adjacent assets.

Chapter Three - Is a critical literature review looking at the "Social Measures" relating to the "People" and their communities who are the users of the assets and how they perceive the environment and spaces they live and work in. The history and types of measurement are discussed and the challenges of using these unstructured perception datasets to assess human perception of spaces effectiveness and the potential relationship with the building physics information described in Chapter two.

The literature review is structured by the application of a funnelling strategy, as depicted in Figure 1.1. The strategy aims to provide greater clarity in the research boundaries as it focuses on the key issues to be researched and to show how this research interrelates to similar work in this area.

Chapter Four - The confluence of the two domains discussed in Chapters two and three is a complex domain. This Chapter discusses how these data types are collected and processed. At a data level we have the challenges of integrating quantitative and qualitative data. At a philosophical level they are very different too - the two domains require different approaches to understand and contextualise the responses and impacts. The results also bring new insights as to how communities and domains perform. With the exception of recent work looking at Soft Landings there has been relatively little research in the cause and effect of human perception to their built surroundings. This Chapter reflects on the existing literature and offers observations as to why and how the two domains can be brought together to enhance the user experience and their social wellbeing.

Chapter Five - This Chapter describes research methodologies and the rationale as to the research methodology selected. Research philosophy, strategy, description of the various methodologies and data sources which will be required for successful completion of the research are also documented.

Chapter Six – The development of methods and tools to create the Test Bench which is the key contribution to knowledge of this research is described in this section. The Test Bench is a system which has been developed and configured from new and existing systems and applications to enable a practical experiment to be undertaken as described in Chapter seven.

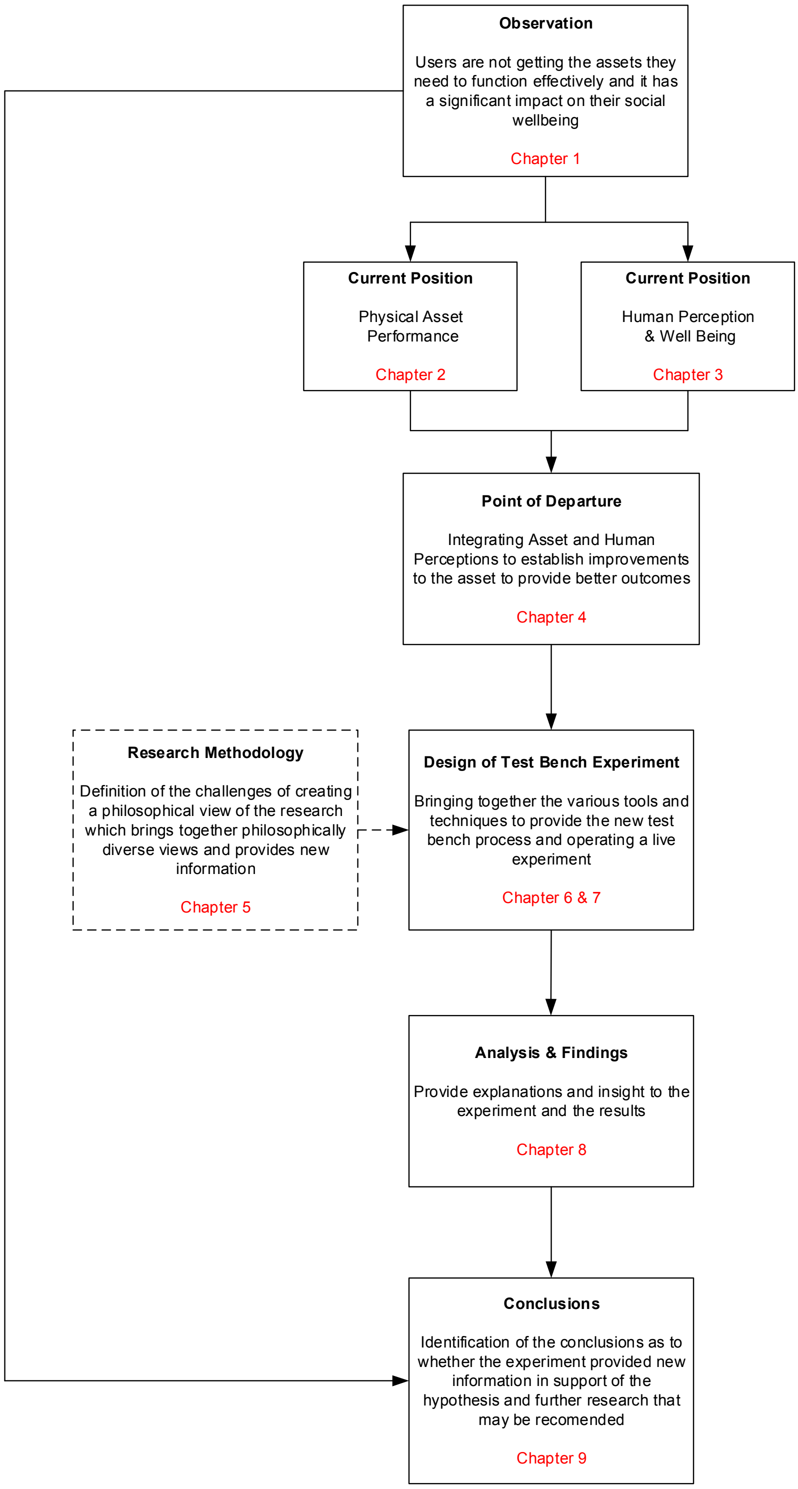


Figure 1.2 - Introductory Thesis Overview

Chapter Seven - Describes how the Test Bench methods and tools were configured and applied to a live experiment scenario. It describes how the target asset and community was selected for the experiment. It also documents the challenges and lessons learnt during the experiment.

Chapter Eight – The experiment produced a large amount of data. This Chapter describes the analysis process and the information elicited from the analysis. It presents the findings and the feedback process which enabled the identification of "actions" to improve the asset's performance.

Chapter Nine - The final section looks back over the research, provides observations and research conclusions as well as recommendations for future research.

The diagram shown in figure 1.2 describes graphically how the document flows through the following Chapters presenting the Test Bench, the experiment and the research findings.

1.8 Summary

The purpose of this chapter has been to introduce a summary of this research to pave the way to presenting the sequence of the research steps as explained through the thesis Chapters. Therefore, this chapter has presented the rationale for conducting this study, the research aim and objectives and also its main contribution to the body of knowledge.

Chapter two builds on the overview provided in the introduction to establish the current industry practice as to the delivery, operation and measurement of asset performance. This informs how data is created and managed and how it could be surfaced to enable a point of reference to assess the performance of assets in operational service.

Chapter 2

Current Practice & Emerging State of the Art for Asset Delivery & Operations Phases

2.1 Introduction

As described in Chapter one, the research problem is in an area where there is little applied theory which describes the basis of a link between the performance of a built asset and the performance or perceptions of the users and their well-being. Much has been written on the poor performance of asset delivery and Clive Cain in his forward to Murray & Langford (2003) summarised well the fact that the continuous stream of reports over the last fifty years has raised the same concerns about the industry's poor performance in terms of delivery and user satisfaction. There has also been much research in the areas of social and psychological thinking and perception, but it is somewhat surprising as to how little the ultimate customer base of built assets - the “users” - have been considered.

Chapter two sets out the current research and industry practice with respect to commercial and technical practice and future trends driven by the move to digital techniques. It further points to the future in terms of the procurement process for data specifically in the area of user and performance integration, feedback and analysis.

2.2 Background

Cain in Murray & Langford (2003) pointed to repeated warnings of cost performance and the consequences this has had on the competitiveness of other sectors. This long term lack of action proves the industry's continuing unwillingness to accept the messages of the reports and radically change its structure and culture in order to improve its performance and to deliver better value to its end user clients. Banwell (1964) was one of the first observers who identified that post war procurement and the operation of assets in the UK were allowing insufficient time and focus on the importance of value. He further identified the enormous risks taken by those who continue to regard design and construction as two separate phases: "In no other industry is the design so far removed from production". Kiviniemi (2005) identified the main problems in the provision of assets as being in the design process, with there being "no connection between requirements and design documents", "the impact of personnel changes and project duration", "the impact of "middle-men" in the process" and "the impact of direct and indirect requirements". The first and most critical part of the design process is briefing. This is described as "a process of refinement from a general expression of need to a particular solution", by Worthington & Blyth (2010). This separation of the design from the production process is also reflected in the design from operations and business needs and culture of the final asset end users. Worthington and Blyth (2010) identify the needs of understanding the users culture: "Issues such as culture and management strategies can radically affect the kind of building solution adopted". "The environment reflects the culture and can reinforce and communicate it through the way that space is designed, allocated, sub-divided and managed". However, there is always a conflict between what staff want and what they need. This is further complicated by the difficulty in understanding these needs across a community or business that occupies the asset. Communities act in different ways depending upon the environment and perceptions. The common thread across all of these observations is the introduction of human occupation, interaction and their influence on the delivery and performance on the built asset.

The impact of a well performing asset can be measured in many ways but at the lowest level this is normally through fiscal variables. There is sparse literature at the micro individual asset level of impact with most focus being at the wider macro impact of towns and conurbations prepared as part of the planning process. This is valid from a planning perspective but does make it difficult to optimise the performance of a single asset as its use and surroundings are constantly changing. The impact of an asset on its cost base varies depending upon its purpose, location, adjacencies and utilisation. If these impacts are analysed from the point of view of the figures from the UK Government Cabinet Office (UKCO 2015) and the Office of National Statistics, (ONS 2015) over an averaged asset base, a set of ratios can be developed as shown in Figure 2.1. The values shown in this analysis are generic across the entire public asset base and could be extracted to form either portfolio or geographic values. The value assigned to the design and build phase is 20%. Clearly for a complex asset such as a hospital this may be greater than for a highway, but the indicative relationship between the delivery phase and the operational phase (typically 80%) gives a valuable ratio when planning for whole life strategies and impacts.

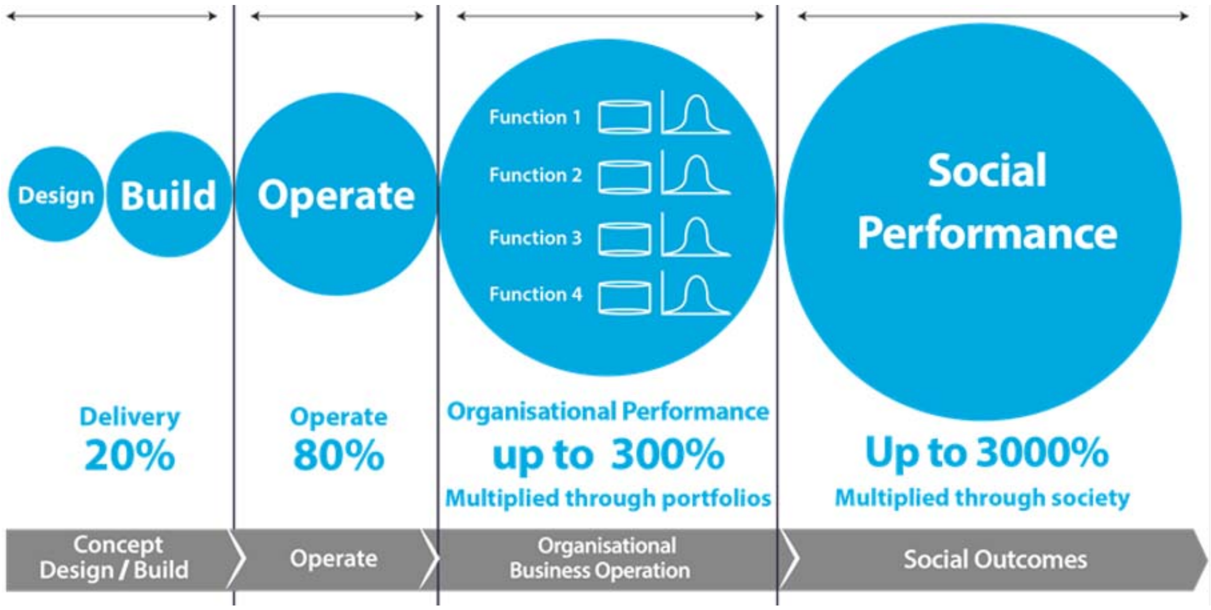


Figure 2.1 - Cumulative effect of assets from lifecycle to impact from a cost and outcome view. Adapted from Wolstenholme A (2009) with generic relative values from Cabinet Office (2015) and ONS (2015)

All asset investment is an investment in a business plan for an organisation to deliver services to its customers. Most businesses explore every option as to how their services are best delivered and often a built asset may be the last resort. The focus on the cost and design of the asset is dependent upon how well it can deliver better functional services to the organisation. These functional services can represent around 300% of the total cost base according to ONS (2015) and are represented by the functional activities that the asset provides. This by way of an example of a hospital may include:

- Car parks
- Waiting rooms
- Consultation rooms
- Operating theatres
- Recovery suites
- Wards
- Out-patients
- Boiler houses, etc.

The effective delivery of these functions depends upon the asset’s accurate brief, design and delivery being undertaken with due cognisance of the asset’s function and the dependency of each function on each other. These functions are a careful compromise between effective service, capital and operational cost and depend on both the client and the delivery team accurately articulating needs and requirements. An example of this would be the location of the operating theatres with respect to the building workflow (consuming operational labour costs) and the need to provide for highly serviced facilities which benefit from being close to boiler and plant locations (negating the need to move air, power and medical gases over long distances, thus incurring higher capital and operational cost).

These values are vital in the evaluation of the impact of assets on their surroundings and the wider social fabric or society, where social related impacts make up the vast majority of NHS and social care budgets. In Chapter three the potential relationships between the provision of poor built assets and these costs and impacts are explored. The functional costs are however in the scope of this Chapter. This has always been a challenge for designers as the ability for many clients to articulate their need is challenging and as Kiviniemi (2005) reminds us, people are also constantly changing. Until recently there have been only rudimentary ways of measuring asset performance and then normally through the use of "Building Management Systems" (BMS) which are often poorly specified and complex to operate. The current trend towards the internet of things (IoT) does promise the widespread possibilities of obtaining and using sensor technologies to track and measure any number of functional outcomes. There is currently no agreed definition of the IoT but the IEEE in their positioning paper (IEEE 2015) observes the emerging characteristics and architecture of the emerging technologies. Most definitions they identify are summarised by the IoT-A project (Bassi et al 2013). They describe IoT as an umbrella term for interconnected technologies, devices, objects and services". What is in no doubt is the potential for such technologies.

The effectiveness of a building also changes over time; this is described by Duffy & Henney (1989). Figure 2.2 taken from this work indicates how the impact of costs are hidden by the impact of time, including with operational costs. Further this was identified by the added complexity of this phenomena when projected over time by where Duffy & Henney (1989) identified for office products that if you add up what happens when capital is invested over a fifty-year period; the structure expenditure is overwhelmed by the cumulative financial consequences of three generations of services installations and ten generations of space plan changes, making the architectural input almost nugatory".

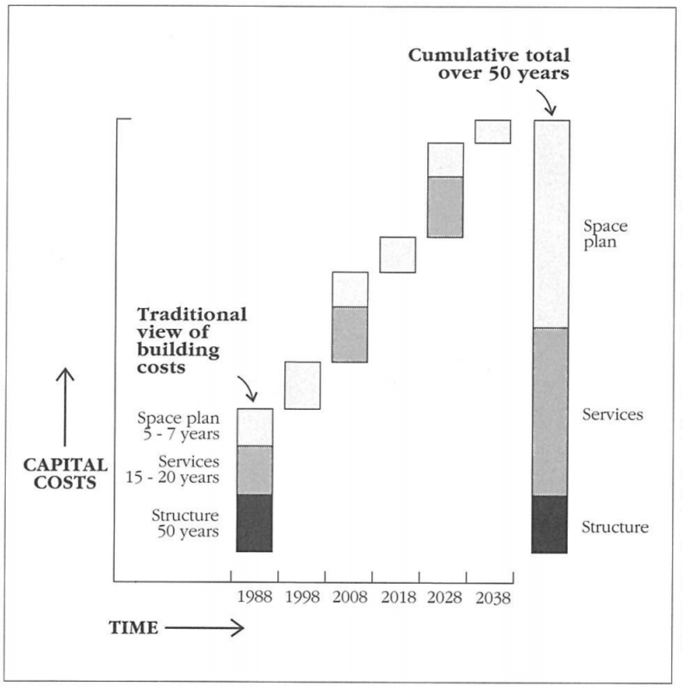


Figure 2.2 – Impact of time on cost. The Changing City (Duffy & Henney, 1989)

During the delivery process of an asset, data is collected either in traditional analogue paper mode or is delivered as part of a digital project using tools to generate electronic data and geometry. The data collected in these engineering based disciplines is typically of a quantitative nature and this allows for objective analysis of values. The market is mid-way through a very slow process of migrating from analogue techniques pioneered in Victorian times, to a full digital economy. The key constituent data elements BS1192: Part 2 Ad2 (2015) gathered during this process comprise the following:

- Data developed through the briefing process developed in cognisance of the perceptive performance of similar assets in the past (feedback) as part of the "Soft Landings" process
- Data developed during the design and construction process, including through the use of tools such as Building Information Modelling" (BIM)
- Data collected through the operational process, including through the use of tools such as "Asset and Facilities Management" (AIM), including maintenance schemes and data collection sensors
- Procurement and commercial constraints including legal and regulatory
- Current and emerging methods as to how asset data is being used to develop deeper understanding of how asset form dependencies and networks both from a physical and functional point of view, e.g. IoT devices, Building Management Systems or other telemetry sources
- The fiscal impact of each stage of a projects lifecycle and influence

2.3 Functional Process

2.3.1 Overview

The process for delivering a built asset is fundamentally common across the built environment. There are taxonomy and detail process changes depending up on the sector or region and different engagement models can be applied to different risk profiles. The process flow indicated in Figure 2.3 shows the high level delivery process this involves.

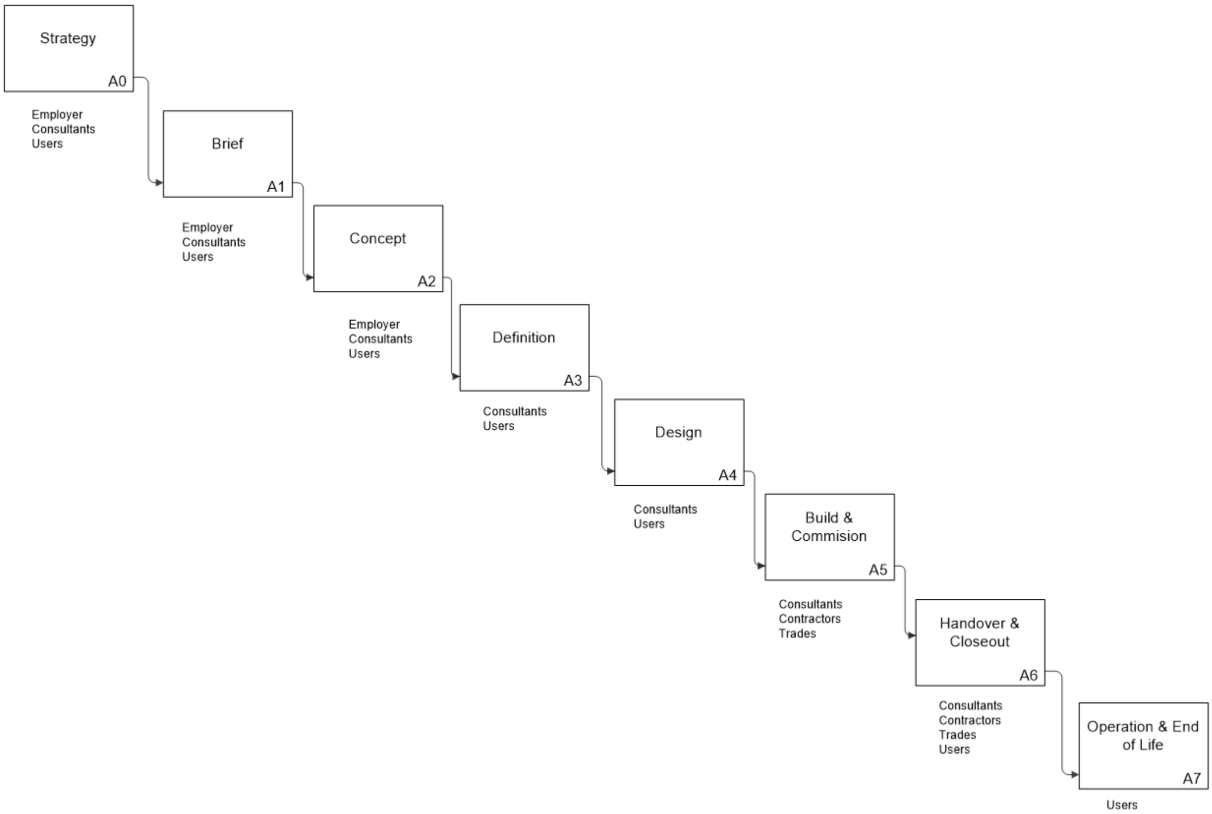


Figure 2.3 - IDEF0 Asset Delivery Process

The project delivery process for design and construction is defined by several documents including the various "Plans of Work" such as the (RIBA 2013) which "organises the process of briefing, designing, constructing, maintaining, operating and using building projects into a number of key stages and some generic cross sector British Standards as described below in Table 2.1.

Table 2.1 - BS and Other Level 2 Definition Documents

Document (Ref)	Description
PAS1192:2:2013	This document describes the production of co-ordinated design and construction (CAPEX) information.
PAS1192:3:2014	This document describes the same data and process delivery and use definitions as described above, but for the operational phase of the asset (OPEX
BS1192:4:2014	This document describes COBie-UK-2012 and its data definition and validation strategy.
PAS1192:5:2015	A document aimed at raising awareness and processes for securing data
BIM Protocol	A suite of BIM commercial and contractual advice documents and standard forms
Government Soft Landings (GSL)	A suite of documents describing Soft Landing policy and processes to ensure effective involvement of users and operators in the development of scope, design and delivery.
Classification System	A structured and standardised information classification system. (Uniclass 2015 for the purposes of this research)
The Digital Plan of Works (dPoW)	An industry standard method of describing geometric, requirements and data deliveries at key stages of the project cycle to enable clear definition for contractual deliveries of information

These documents detail the tasks and outputs required at each stage which may vary or overlap to suit specific project requirements". The RIBA Plan of Work itself is not a contractual document, but it directs readers to various tools and methods that can be selected. All of these selections have a material impact on the long term functional and operational performance of the asset. The definition of "process" offered by Kagioglou et al (2007) is useful as they point out the term can mean different things to different people depending upon sector, function and market. Talwar (1993) offers a definition as being "a sequence of predefined activities executed to achieve a pre-selected type or range of outcomes". Harrington (1991) says "any activity or group of activities that takes and input, adds value to it and provides an output to and internal or external customer". The Process Protocol Level II project (Kagioglou et al 1998) aimed to define a second level of detail to the generic Process Protocol, which sets out to define an improved design and construction process.

There are several Plans of Work, including specific models defined by organisations internally, for specific bespoke scenarios. The problem with these bespoke solutions is the ambiguity and challenge of supply chain businesses in developing their own internal processes and learning to cope with these new stages and taxonomy's all of which are a variation on a common theme. The diagram in Figure 2.4 demonstrates these common

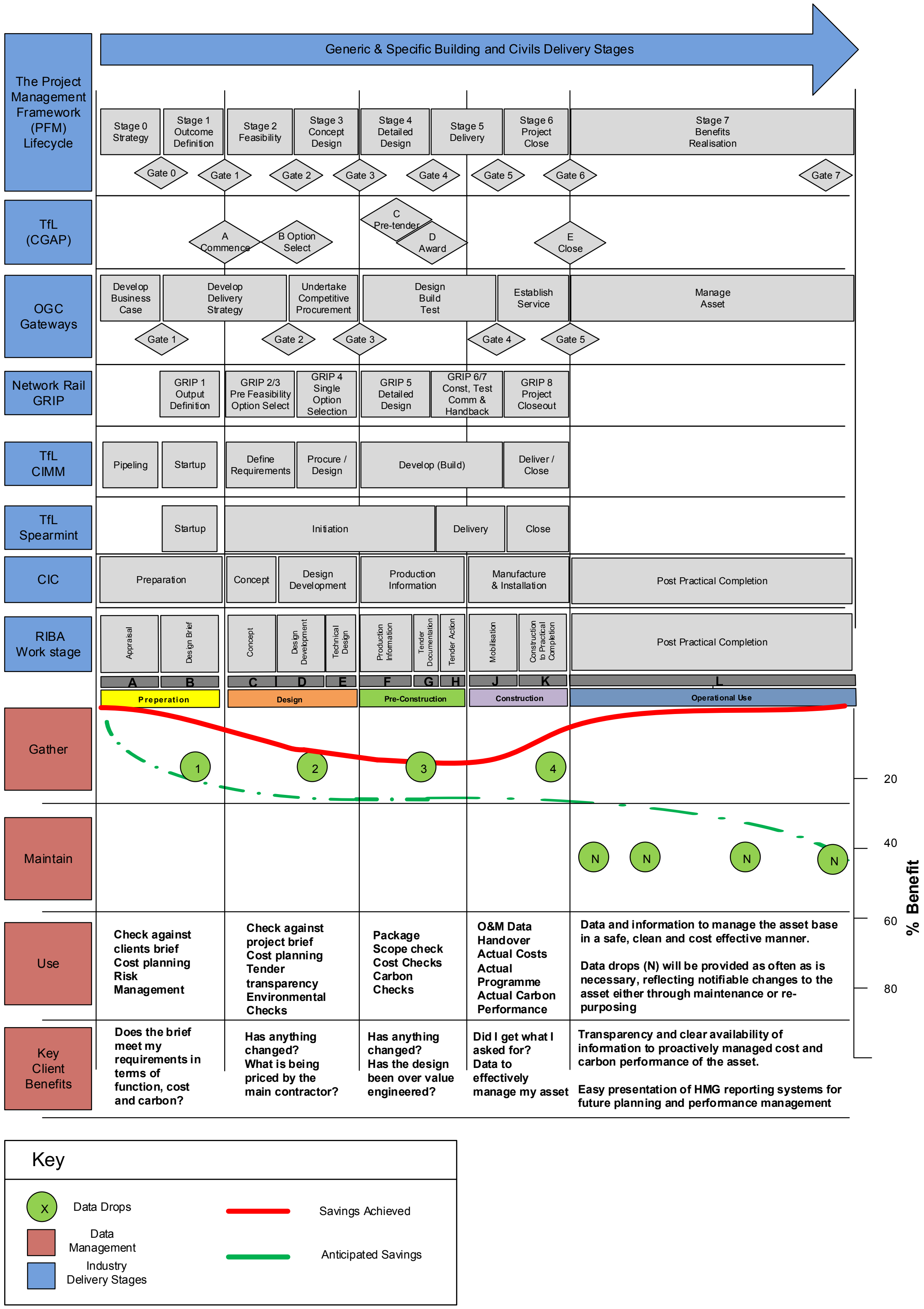


Figure 2.4 - Plan of Work Comparator

mythological alignments and shows how similar the key transaction points are. The purpose for discussing these alignments is to understand the commonality of data consumption by the client organisations (the need of which is identified by diamonds or gateways in some schemes and the exchange is indicated by green spheres). It is these data requirements which define the data procurement protocols, contracts and plans on any project.

2.3.2 Data Creation Tools and Instruments

To enable the functional delivery of data as well as geometry and documents (which has always been the traditional information delivery mechanism) it is necessary to gather all of the information normally found in schedules, documents, plans and calculations and attach the information to the geometry (either 2D or 3D). There have been over the past decade a number of technology developments which enable this activity. The tools are collectively called Building Information Modelling (BIM) tools.

Key to the concept of BIM is the ability for the digital objects to be able to describe themselves not only as graphical representations but also to be able to link to the extensive tabular datasets such as cost, materials, programme, logistics, identity, RFID for location/identification etc. It is these datasets and processes which are of key interest, especially when considered in the wider context of large quantities of externally derived data collectively known as “Big Data” being continuously developed by semi intelligent systems contained in the design of many assets, as well as individuals. The standardisation of these datasets is immature and models have been developed to scope useful activity. One such model is the Bew-Richards Maturity Wedge shown in Bew & Underwood (2010) & (BSI 2010) shown in Figure 2.5.

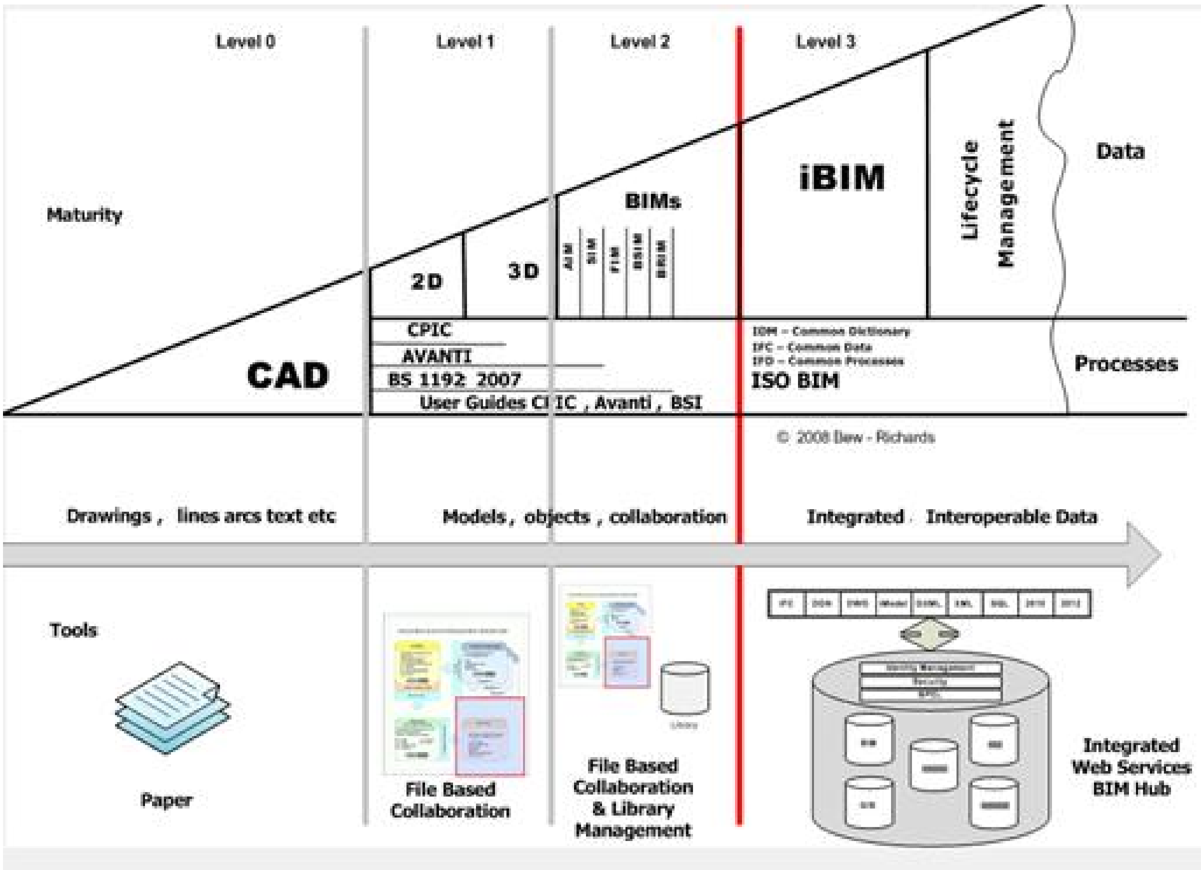


Figure 2.5 - Bew-Richards Maturity Wedge - Engineering Systems
© Bew-Richards 2008 IGI Global & BSi

The process of developing models is undertaken not in the traditional way of drawing lines, but by placing and configuring objects (groups of similar data) and attaching the geometric and data together. The data that is generated is shared using common open data standards and the transparency created between project participants improves collaboration and performance. The lack of collaboration and resultant data loss using traditional approaches was measured in the USA through the NIST Report, (Gallagher et al 2004). It identified US $15.8B per annum of waste through data loss in transactions. Similar measurements are now becoming available from the UK public sector work being delivered by the HMG BIM Task Group. They cite benefits of around 20% of capital expenditure for their Level 2 programme.

The emerging development of BIM to generate data is renewing interest in the optimisation of processes, including use of approaches such as the Process Protocol along with the application of Lean and Offsite manufacturing to further improve productivity, efficiency and data quality. The relationship between these processes and the Plan of Work is essential as the Plan of Work provides the commercial procurement structure for the processes to be executed. For any process to be effective the timely delivery of data through any process is dependent upon good management and governance of that process to ensure consistency of approach and delivery is assured. The model of managing construction information has a very long history and new approaches such as concurrent engineering (Anumba 2007) have yet to emerge on a widespread basis in the industry. The process of the delivery cycle can be divided up into a number of key stages such as those defined by the RIBA Plan of Work stages of preparation, briefing, specification, design, pre-construction, construction, and operational use.

One of the challenges for built assets to be truly high performing is their inability to learn. The process shown in Figure 2.3 demonstrates this by showing a linear process, without a feedback loop. An awareness of this is now emerging with "Post Occupancy Evaluations" (POE) now becoming more common, but these tend to be only carried out once not on a continual basis offering little use for objective review. There have been a number of attempts at implementing POE in the past but these have tended to fail either due to a lack of useful and reliable information to feed back or a lack of willingness through the contractual framework and commercial process, with performance guarantees always being difficult to negotiate at a reasonable cost.

As the BIM market has developed and matured the quality of data has slowly started to improve. This is now providing opportunities for the convergence of design, engineering, geospatial and commercial systems. This convergence was discussed by Bew & Underwood (2010) where they converged the principles of the maturity wedge diagram seen in Figure 2.6 which describes the engineering systems market and that of the commercial systems maturity, tracking the journey from analogue paper ledgers to full Enterprise Resource Planning (ERP) systems, which seek to integrate engineering data and commercial transactions into a single interoperable infrastructure for the lifecycle operation of a built asset. This integration provides opportunities to provide a much deeper and more complete understanding of an asset's performance through the integration of cost, time and performance information.

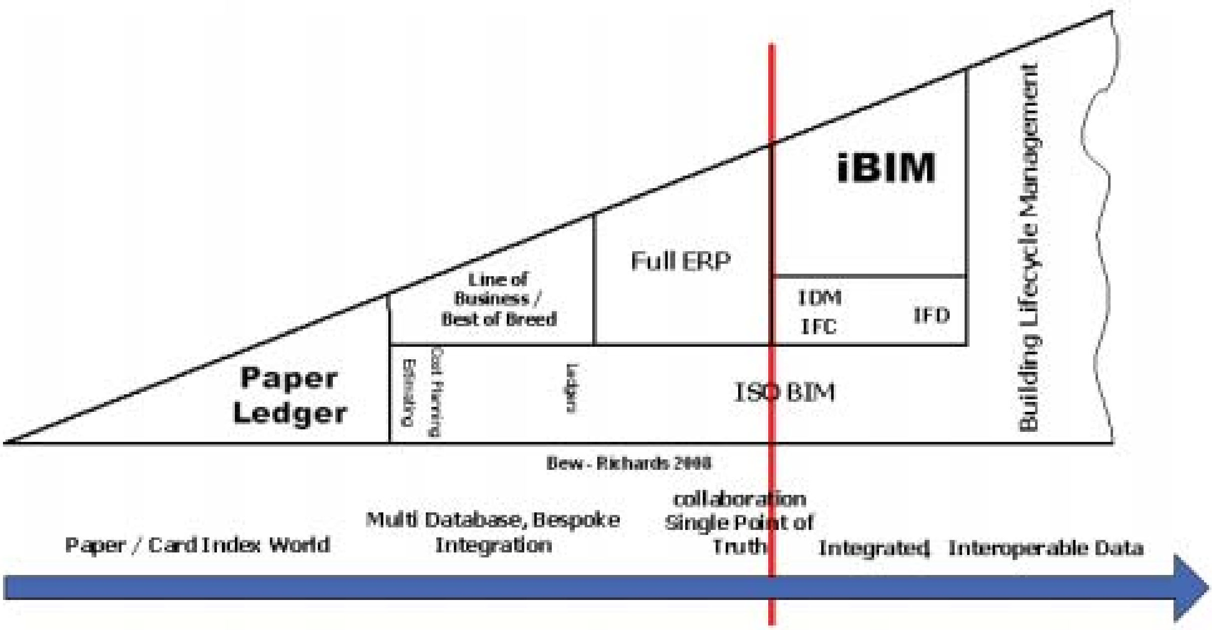


Figure 2.6 - Bew-Richards Maturity Wedge - Commercial Systems
© Bew-Richards 2008 IGI Global & BSi

Since the work completed by the Level 2 BIM Task Group and described by Bew & Underwood (2010) the realisation of the power of the Internet of Things has developed rapidly. (Feng et al 2012) identified that "we are witnessing the dawn of a new era of the Internet of Things (IoT), also described as the Internet of Objects. They refer to the IoT as the networked interconnection of everyday objects, which are often equipped with ubiquitous intelligence. IoT will increase the ubiquity of the Internet by integrating every object for interaction via embedded systems, which leads to a highly distributed network of devices communicating with human beings as well as other devices.

Figure 2.7 describes the parallel development of the IOT, with respect to the BIM maturity levels. It also shows how analogue sensors using semi-proprietary methodologies have been displaced by open IP based communications systems and architectures.

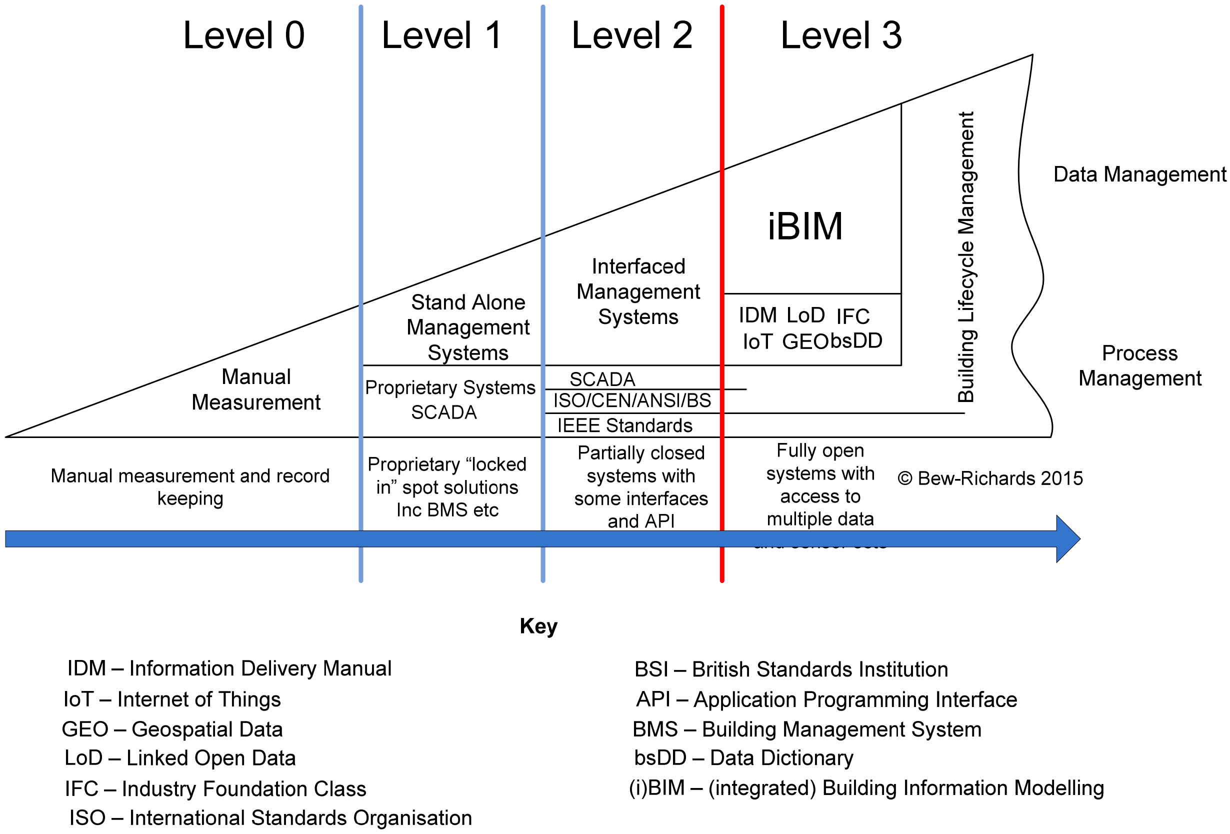


Figure 2.7 - Bew-Richards Maturity Wedge - Measurement Systems
© Bew-Richards 2015

Key to the widespread use of the BIM concept is the development of "interoperability" - the ability of any user to move data from application to application in a seamless and transparent manner. Clearly to enable this, a common data definition is required to enable sharing to take place at key stages of the process. There are two emerging standards in this area. The first at Level 2 is the COBie2 definition which is defined in the UK by BS1192:4:2014 (2014). COBie2 is a US derived exchange format which was developed as a single direction, limited repeat process primarily to ensure asset information was delivered to the client to more effectively enable post–occupancy management. The model is very straightforward and potentially limited by this original scope for the type of social attributes required for this research. Full definitions are described in BS1192:4:2014 (2014). Figure 2.8 indicates the high level data model for COBie2. The dataset is designed to be able to be transmitted using XL spread sheets, as wells as XML or SQL Tables, again demonstrating the focus on the data rather than the graphical elements. The figure also demonstrates the need for clear use of taxonomy variations between in this case domestic UK building and civil engineering markets, but wider across multiple languages.

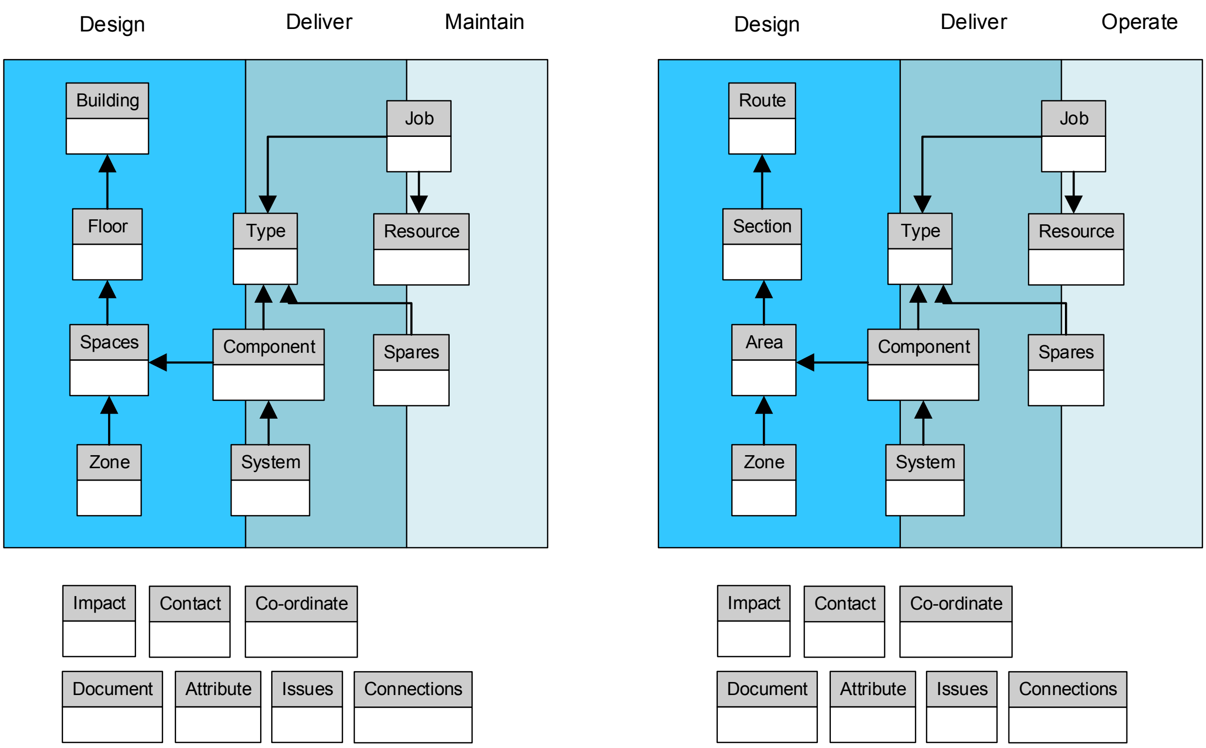


Figure 2.8 - COBie2
High Level Data-Entity Model (Building & Infrastructure taxonomy views)
© WBDG – NIBS 2011 (Adapted Bew 2013)

The Level Three stage of maturity makes use of open standard data and process definitions. The Industry Foundation Classes (IFC) data model is intended to describe building and construction asset data. It is a neutral and open specification that is not controlled by a single vendor or group of vendors. It is an object-based file format with a data model developed by Building Smart (International Alliance for Interoperability, (IAI)) to facilitate data interoperability across the industry on a global basis. The IFC model specification is open and is registered by ISO as ISO/PAS 16739 and is currently in the process of becoming the official International Standard ISO 16739.

Figure 2.9 - Building Smart BIM data and Process Standards
© Building Smart MSG 2008-2010

The process elements of the Building Smart portfolio are embodied in the Information Delivery Manual (IDM), or process definition. These specify when certain types of information are required during the delivery of a project or the operation of a built asset. It also provides detailed specification of the information that a particular user (user, specifier, architect, building services engineer etc.) needs to provide at a point in time and groups together information that is needed in associated activities, such as cost estimating, volume of materials take offs, procurement, project planning etc. Figure 2.9 is a Building Smart illustration designed to depict the relationship between the data schema, the processes executed over some or all of the data and just as in COBie2 the need to present defined terms in the form of a taxonomy to enable illustrates the relationship between the data, process and taxonomy standards required to make the processes and transactions understandable to users. The data schema is defined in an ExpressG format and differs from COBie2 in two key aspects - the ability (or intention) to provide a level of interoperability and the scope of the built environment covered by the definitions.

2.4 Procuring Data

The selection of appropriate contracts is described by RICS (2014) Appropriate Contract Selection Guidance Note. The subject is vast and out of scope for this research other than to observe that there are many type or forms of contractual agreement with which one can engage. Many of these contractual agreements are Victorian in structure and have done little to keep up with the demands of a digital world. This is most apparent when the concept of digital transactions or data provision are considered. All of the contracts provide a definition of what should be done (an input specification) rather than the norm for most digital transactions where outputs are both verified and acted upon. This therefore necessitates a need to specifically define all data deliverables as part of the procurement process.

The delivery of any built asset is a complex and time consuming activity, involving many stakeholders and resources. A typical school type asset may have up to sixty different suppliers and several hundreds of people working throughout its delivery. By comparison a complex asset such as a research laboratory or hospital could have up to twice as many. To achieve any chance of effective delivery a common set of processes or at least process interfaces are essential. This is undertaken by a series of common procurement strategies and contract forms. RICS (2014) describes a number of the more common approaches below in Table 2.2.

Table 2.2 - Common Procurement Routes

Procurement Route Name	Description
Traditional - Lump Sum	A project let on the basis of a design developed by the employer's design team. A selection is made on the basis of a single stage tender where the contractor proposes a methodology and commercial plan to deliver the project. This includes a fixed price for the agreed scope defined in the Contractors Proposals. Any lack of scope or allowance is absorbed by the contractor unless a variation is agreed to the contract.
Traditional - Re-measure or measure and value	As above but with the ability to change the agreed quantities based on agreement with the employer
Design and Build	A project where the employer tenders the project on the basis of a very outline design and employees the contractor to manage and develop the design to completion. These can be secured on either a single or two stage process.
Construction Management	This is where an employer places a contract with a supplier (normally a contractor to manage the design and delivery elements of a project. The contractor is employed on a fee basis and does not directly employ the trade contractors or designers these are employed by the client (employer) This approach is often used where the need for a rapid delivery

Procurement Route Name	Description
	is required or the design of the asset is changing quickly (such as pharmaceuticals and electronics)
Management Contracting	As above with Construction Management except the trades and designers are employed by the contractor
Partnering	A formal or informal agreement to work together, sometimes used interchangeably with Alliancing
Public Private Partnership (PPP) (PFI/PF2)	Any of the contract forms discussed above but with funding from join public and private entities.
Cost Plus / Cost reimbursable / prime cost	A rare form of contract over the last decade, where all works are paid for as used (including labour, plant and materials)
Target Cost	A form of Lump sum contracting where there is an extended period for the contractor to develop detailed designs and commercial solutions. These are also sometimes used with a “pain-gain” calculation where the target is is beaten or missed the client and contractor take a sliding scale of the pain or benefit, thus incentivising efficient behaviours.
Term Contract	A long term contract, normally comprising of many little short term contracts. This is a common approach for utilities operators.
Framework Agreement	An agreement often with a number of suppliers to service the needs of an employer over a number of projects (and or years). Often used as a route to short circuit EU and Prequal procurement processes.
Alliancing	See Partnering above
EPC Contracts	A form of contract derived from the Oil and Gas sector which covers the Engineering, procurement and construction elements of a project (Hence EPC).

A wide number of organisations provide standard forms of contracts through their publishing arms. Table 2.3 describes some of the common ones.

Table 2.3 - Common Contract Publishing Bodies

Contract Publishing Bodies	Description
The Joint Construction Tribunal (JCT) contracts	The mainstream construction sector procuring works such as new-build office blocks, office remodelling and refurbishments, hotels, new apartment blocks, fit-out of shops and office premises, accommodation projects, education projects, sports stadia and leisure facilities use these contracts. They are traditional in approach and often use old fashioned language. They are well proven and have a

Contract Publishing Bodies	Description
	large bank of proven case history. They tend not to encourage collaborative behaviours.
NEC contracts	The engineering and infrastructure sectors procuring works such as new roads and upgrades to the existing road network, new rail lines and assets, nuclear facilities, the London 2012 Olympics, and water utilities are increasing making use of the NEC form or contract. The time working with the client and delivery team working up the target design coupled with the various "pain-gain" commercial mechanisms provides an effective basis for collaborative incentivisation.
GC Works contracts	Although now experiencing a general decline in use, the GC Works contracts were previously used by central government and local authorities to procure a range of major building and civil engineering works, as well as more mainstream construction, e.g. new local authority office facilities. The use of GC Works contracts has declined as the public sector increasingly uses the NEC contracts and other collaborative forms of contract.
Infrastructure Conditions of Contract	The engineering and infrastructure sectors procuring works such as new rail lines and assets, tunnelling, ports and docks, energy and water utilities. Not commonly used as NEC is seen as more collaborative
IChemE contracts	The process engineering sector procuring works such as process plants and manufacturing facilities, and also other sectors such as nuclear, pharmaceuticals, water and tunnelling. Not commonly used as NEC is seen as more collaborative
FIDIC contracts	These are not commonly used in the UK, but have found use in the oil and gas sectors, and onshore and offshore renewables sectors (e.g. offshore windfarm projects), this form is out of scope for this work.
ACA/PPC2000 contracts	Can be used in the mainstream construction sector, but has found particular use by local authorities (e.g. term maintenance arrangements for housing stocks), housing associations and some central government departments (e.g. the Ministry of Justice and Department for Work & Pensions). This is a contract which does encourage and incentivise collaborative behaviour, it is also viewed as being simpler than NEC
CIOB's Contract for Use with Complex Projects	It is intended for use by companies and public authorities in the UK and in any other country where works comprise complex building and/or engineering which cannot reasonably be expected to be managed intuitively. It can also be used with a variety of procurement methods (including build only, design and build, and turnkey).
LOGIC contracts	These were developed for use in the offshore oil and gas sector in the UK. The contracts cover a variety of services and works including design, general construction and marine construction. With suitable adaptations, the LOGIC contracts have also been used for offshore

Contract Publishing Bodies	Description
	windfarm projects.
IMechE / IET contracts	These were developed specifically for electrical and mechanical work and consultancy, e.g. the design, construction and commissioning of anaerobic digestion plants or combined heat and power plants, and the design, installation and commissioning of complex automated systems in distribution warehouses. Therefore, those who are advising an employer on contract selection will need to factor the nature of the works and particular sector into the decision on which contract is most appropriate for the 35 particular project. Professional advisers should also familiarise themselves with which standard form construction contracts are most commonly used for particular works and in particular sectors.

Fundamental to the delivery of a digitally based project is the need to specify the data an organisation needs to manage its internal governance and wider processing activities. The alignment of data to key decisions is a fundamental activity which, if managed poorly, will guarantee poor business governance and performance.

The high level process flow shown in Figure 2.10 is an unpublished copy of an end to end delivery process for a generic target cost type contract. The process shows internal processes, Data Exchanges Points (Green Spheres) and key decision points (Red Diamonds). These are described in table 2.4. The curve indicates the level of maturity of geometric and attribute data required to provide adequate information to provide a safe answer to the question or decision.

The specification of data requirements is designed around the fundamental needs of the demand side (client) business. These "Plain Language Questions" define the strategic data required to service the business and are presented at the UK BIM Task Group Website www.bimtaskgroup.org by way of example. Table 2.5 presents an example indicating the key project stages and the likely sources that may be able to provide the data required.

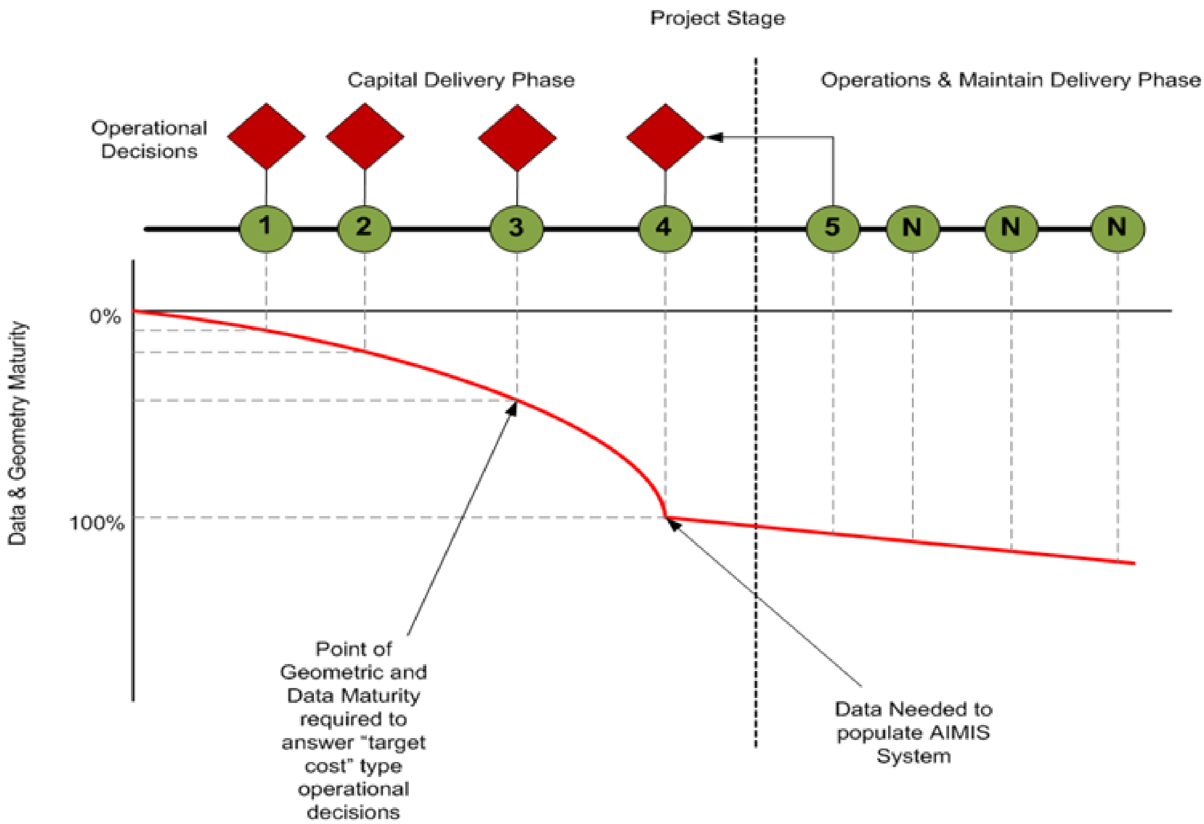


Figure 2.10 - Plan of Work to Data Delivery Model
© BIS HMG BIM Strategy March 2011

Table 2.4 - Process Activity Definitions

Activity	Description
Internal Processes	Any process which is executed in the business is indicated in a grey box. These are laid out in a similar fashion to those in the IDEF0 process modelling approach. Each process must have an input, an output, an owner and a description. (Indicated by a process box)
Data Exchange Points	A data exchange point is an identified stage in the project defined by the contract where data requirements specified in the contract are delivered and verified. (Green Sphere)
Key Decision Points	Key decision points are the high level governance stages of a project which require accurate timely data feeds to ensure high quality responses (indicated by a red diamond). The validated data is collected from the date exchange point and used for this purpose. The definition of the decision is often articulated as a plain language question (PLQ) to ensure clear definition, especially when converting into a data requirement.

Table 2.5 - Plain Language Questions (Generic Asset)

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
0 – Output Definition	1) Is the scheme likely to get Planning Permission?		x		
	2) What are the outline costs?				x
	5) Has Market research been carried to determine demand?		x		
	3) What is the likely revenue income?				x
	4) Have we got the resources to deliver the project?		x		
	5 What are the social imperatives the project seeks to achieve?		x		x
1 – Output Definition	1) What are the site extents?			x	x
	2) What is the Project type? –commercial, residential, mixed, transportation, maintenance operational		x		x
	3) What are the Site layout options? – Routes, adjacencies, servicing, building position and massing model			x	x

As data is developed through the lifecycle of an asset its fidelity and maturity increases. This signals the need to understand the concept of data "state". The state of data defines its suitability for a purpose or transaction. For example, the entities and attributes defining a space at briefing stage would not be useful for a commissioning or selling transaction as they would have changed as the design and construction phases develop, even if the same attributes were being employed. This is illustrated in figure 2.10 with the red trace increasing in development (maturity) by time, coincident with the data exchange points shown by the green spheres.

This theme is continued as the project moves into the operational phase and data is gathered through the sensors and building management systems. The data procurement strategies for sensor information is poorly defined with no useful literature describing how this should operate in the future. The IEEE have set up a series of working groups to explore potential solutions.

2.5 Preparation, Briefing & Specification

The start of the delivery process includes management of the feasibility, brief, scope and specification. These early stage processes are fundamental to the delivery of an effective asset. There is often poor visibility as described by Brown (2001), of the impact of early decisions on downstream activities such as operations, business outcomes and the cumulative impact of the asset (and others) on society as a whole, but the effect can be significant. The model shown in Figure 2.10 indicates the relative impacts and costs of a typical discrete asset during the design, delivery and operational lifecycle representing the capital and operational expenditure phases. The quality and quantity of data transferred between the delivery phase and the operational phase is typically very low. (Gallagher et al 2004) in their NIST Report discuss the quantum in terms of cost to the US economy. Further the data lacks the richness required to populate an effective asset management system without significant rework. This is due to a number of reasons including commercial and technical, but is often driven by a lack of strategic coherence between the development / delivery phase and operations, or a commercial agenda that fails to incentivise whole life optimisation. There is also a low uptake of standard processes such as ISO55001 or PAS55, which set out the standard process for optimising operational and whole life considerations. These should form a part of the business and project strategy and will inform the data requirements to be placed in the contract.

The amount of tabular data rather than graphical/geometric data grows as the relationship between the unstructured data currently held in document form now starts to be integrated with the graphical elements of the BIM models. The progressive accrual of data, where and how it should be stored and used is described by (Jackson 2009). Indications of volumes and rate of accrual are shown in figure 2.10. The delivery cycle described here is configured to demonstrate the specifics of various procurement routes (NEC/JCT in this case).

To enable the integration of data being derived from a number of sources it is desirable to maintain open access to data through the use of open formats (publicly defined) rather than proprietary data formats which encapsulate data in forms that cannot be reused without the use of specialist tools. Level 2 uses the COBie2 data set which forms an open structured data schema which is a sound basis for the understanding of the atomic build-up of an asset and its constituent parts. If there is a requirement to extend the dataset for key specific tasks (as there will be in this research) COBie2 allows within its structures extensible capabilities.

2.5.1 Key Briefing Considerations

There are many considerations made during the delivery process which affect the direction of the briefing process. Kiviniemi (2005) discusses the impacts of external influences and impacts in the delivery of the emergent design from the original brief, through his articulation of “Requirements Management”, which he defines as “the process to maintain and update project requirements after the requirements capturing process”. He also said “Regardless of the capturing method, the requirements, depending on the project type, consist of more or less detailed information about the required Properties: net area, activities, connections to other Spaces, security, appropriate or desired materials, and conditions, such as daylight, lighting, temperature, and sound level. Many requirements also "cascade," i.e., create “Indirect Requirements” for building elements bounding the space and systems serving the Space. Moreover, an important part of the design process is that some requirements can be in conflict; the project team must often prioritise and make trade-offs between different requirements, which creates the need to update the requirements and thus, manage and document the changes to the requirements and the design solution.”

The industry has grouped the effects of Social, Economic and Environmental impacts under the all-consuming label of “Sustainability”. This has led to ambiguity in the industry as discussed in the Royal Academy of Engineering – *Engineering a low carbon built environment* report, (RAE 2010). To avoid this and to ensure a focus on scope, for the purpose of this research each of the three elements will be dealt with discretely with a focus on economic and social outcomes and their relationships with the design process as seen from a data and processes perspective. This does not diminish the importance of these other aspects, but serves to scope this research.

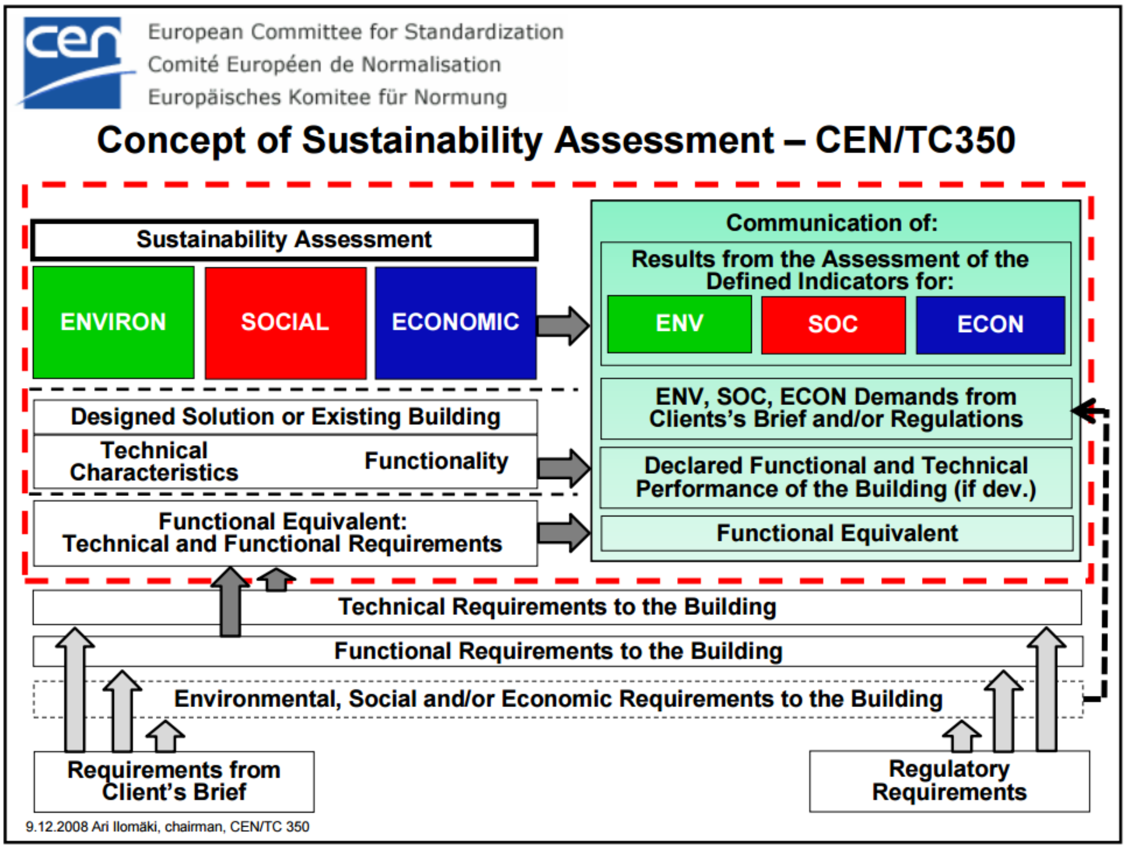


Figure 2.11 - Concept of Sustainability Assessment
© CEN/TC350 July 2012

Figure 2.11 is a model developed by the European Standards Body CEN to illustrate how social, economic and environmental issues are managed in the context of the project lifecycle. CEN (2012) describes the Sustainability of Construction Works – Assessment of Buildings. Part 3: Framework for the assessment of social performance from where this model is derived.

To digitally manage the briefing process a data set will need to be created to describe the functional and spatial elements of the facility. In effect a digital specification to which the emergent design can be checked against to verify its validity to both provide an effective solution and contractual compliance. Kiviniemi (2005) describes a candidate data schema which forms a basis for the design schema to match back to the work described in the emergent design.

The schema described by Kiviniemi (2005) does offer process management design ideas but these are limited to the testing rather than development processes. In practice several factors make it virtually impossible for all participants to know and remember all relevant requirements and especially their relationships to each other and to the design solutions. Some of these are exampled and described in Table 2.

Table 2.6 - Data Schema Potential Considerations

Criteria	Considerations
The volume and complexity of project information	Even small projects may have up to fifty separate organisations providing information, data, services and management. This diversity requires strategic management.
The duration of projects	All projects have multiyear durations, personnel and technology change and intelligence is lost over this time.
The need for designers to work simultaneously on many projects	The concepts of concurrent engineering brings significant technological and cultural challenges. The norm in construction is to allow disciplines to work in parallel rather than concurrently and to use the common data environment to manage concurrency of information
Changing stakeholders in different project phases	See project duration above
Shifting design focus, e.g., moving from overall problem solving to detailed technical solutions	Often different teams are employed to resolve different phases of design delivery. Professionals are normally used at the early stages developing design schemes and strategies with trade specialists developing the design on for delivery. This shift of focus and personnel has a significant impact, with professionals tending to focus on design integrity and performance and trades on cost.
Differing user needs from single assets	The impact of users on single and multiple assets is a complex phenomenon and requires careful analysis and understanding and can be modified through perception.
The impact of human perception	Human perception plays a massive part on the response a user will provide to a design proposal or facility. Appropriate measures should be taken to normalise this.

Most of these criteria are manageable in the context of the design process but all contribute to the “shifting focus” effects which are described by Kiviniemi (2005) and are developed in Figure 2.. The key decisions and PLQ's described above have a "shifting" influence on the design process through the delivery process as they provide a focal point for information to be contextualised and used to make decisions. The quality of the decisions (which has a material impact on the quality of the eventual design) is demonstrated through the concept of the "briefing window" which is the widening tolerance of error that can be better (or worse) managed through the use of better requirements data. The size of this briefing window is derived by the amount of ambiguity that there is at any time during the design and delivery process. This is demonstrated in figure 2.12 by the delta between the light and dark blue key decision bands. The availability of appropriate data to minimise the size of the light blue window is a fundamental consideration. The better the quality and availability the smaller the window and the less the potential detrimental impact on the decisions and therefore design shift.

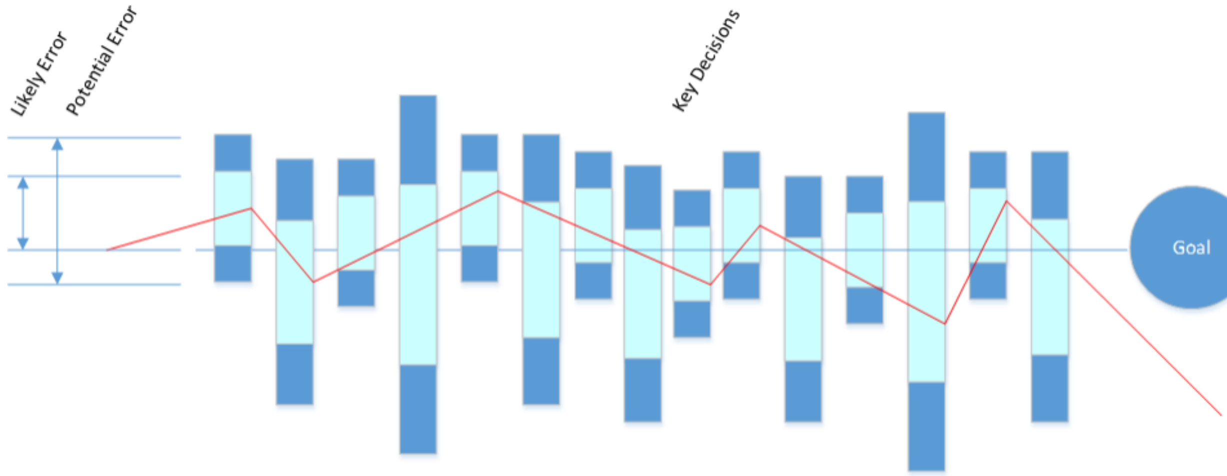


Figure 2.12 - Design Shift Away from Original Goal
Adapted from Kiviniemi (2005)

The last two criteria in Table 2.4 refer to the needs of users and the perception of those users to the design or physical built asset. The management of issues which are seen through the lens of the perceived view of a human stakeholder or user always require careful consideration and management as they are difficult to measure accurately and consistently. Further to this they provide a greater degree of tolerance and uncertainty to the error in the briefing window described in figure 2.12.

2.5.2 Soft Landings

Soft Landings are a process designed to assist the construction industry and its clients deliver better buildings. Soft Landings helps to solve the performance gap between design intentions and operational outcomes, through the careful and structured engagement of users and operators. The core process is defined in BS 8536-1, BS8536 (2015), where the authors have identified the importance of "promoting the early involvement of the operator, operations team or facility manager as appropriate. A number of organisations including HM Government and BSRIA have developed their own solutions based on the guiding principles of the British Standard. The gap in performance can emerge at any stage in a project including:

- At inception and briefing, where ambitions and requirements are set but may not be informed by experience and feedback from other projects
- At design, where specific performance targets are set and regulatory compliance achieved, but those targets are neither re-visited nor reality-checked during detailed design
- During construction, where budget shortfalls may compromise the best of intentions, and variations are made to the building and its technical systems that change how the building will be used
- During handover, when commissioning and end-user training may be rushed or abandoned to meet deadlines
- During initial occupation, where not enough support is available to occupants and the managers to ensure the building is set up for the long-term.

Soft Landings provides a step-by-step process for clients and their project teams to follow in order to avoid these pitfalls and deliver a better-performing product. It aims to create virtuous circles for all stakeholders and activities. No matter whether your project is attempting to achieve exemplary environmental standards, or is a simple extension or retrofit of an existing building, the Soft Landings process can be applied to ensure outcomes match the client’s intentions.

2.6 Delivery Process

Once an asset is briefed and has gone through the procurement process it is normally the responsibility of a main contractor to take responsibility for the delivery of the project. The details of this process will vary in small ways with the procurement route selected, but the need for the main contractor to procure and manage trade designers and suppliers using the same processes as described above in Table 2.1 and Table 2.2 continues. The main contractor must do this and ensure both design integrity and commercial reality both in terms of time to deliver and cost. There are many tools and techniques that have emerged to achieve this but they can be categorised as shown in Table 2.7.

Table 2.7 - BIM Tool Types

Tool Type	Description
Briefing and Checking	Ensuring the emergent or procured asset is the one that was originally procured and required.
Common Data Environment (CDE)	Technology providing information storage and management services (as defined by PAS1192:2 & (2007)). Information production and concurrency control provided for “Work in Progress”, “Shared”, “Published” and “Archive”
3 D	Development of 3 dimensional Geometry (drawings) and the use of this geometry to support the briefing, design and delivery process, through information management, spatial and clash management and awareness raising to brief Soft Landings
4 D	The addition of time and programme logic to the 3 D geometry
5 D	The addition of cost and value data to the 3D geometry
6 D	The addition of Facilities and Asset management data to the 3D geometry

There is an open market for these tools but the selection and use of these tools is outside the scope of this research.

2.7 Handover, Operations & Maintenance

Once an asset is constructed and delivered it may be assessed through a number of methods. These are collectively known as “Post Occupancy Evaluations” (POE) and may take place more than once to establish how an asset is performing. (BS 8536 2015) says “A formal post-occupancy evaluation (POE) of the building’s performance should be conducted at the end of Years one, two and three. The evaluation should include an end-user satisfaction survey, an energy-use survey and an assessment of the overall performance of the asset/facility against the agreed outcomes and/or targets and applicable benchmarks.

The owner's representative should compare actual performance with the required performance and comment on potential improvements, where appropriate, for the end-of-year review for each year of aftercare. When this annual analysis report has been completed, the operator, operations team or the facility manager, as appropriate, should request the attendance of a senior representative of each of the main disciplines within the design and construction team at a workshop with the owner's representative and the representative(s) of end-users. The annual analysis report should be considered against the owner's business objectives, project objectives and operational requirements and performance outcomes and/or targets as set in the Strategy and Brief work stages. The purpose of the workshop should be to consider recommendations on how the operational performance of the asset/facility can be optimised. The workshop should conclude with agreed actions necessary to achieve alignment with the objectives, outcomes and targets as closely and as quickly as possible." These methods are discussed and compared in Chapter four, but common examples of commercial POE tools include:

- Design Quality Indicator (DQI) is an example of a methodology for measuring three quality principles – functionality, build quality and impact – to provide objective evidence of achievement.

- The BUS methodology is an example of a survey that quantifies occupant satisfaction, reveals features of value or concern in the asset/facility and provides feedback.

- BREEAM In-Use is a scheme to help the owner, operator, operations team or facility manager, as appropriate, reduce the operational costs and improve the environmental performance of existing assets/facilities.

2.8 In-service (Operational) Performance Management

During the In-service and operational stages of an asset's lifecycle there are a number of operational datasets which are derived from assets during their day-to-day operations. These may include data from records being kept regarding maintenance and other interventions through to sensors or systems such as smart meters, turnstiles (London Transport Oyster), Building Management Systems or data from the myriad of Building or Asset Management systems in existence. This operational data offers countless clues as to how the building is being operated and used by the users and other stakeholders. The logical nature of this data in a managed environment is described by the BIM Task Group in their Level 2 vision and they include the summary diagram shown in Figure 2.13.

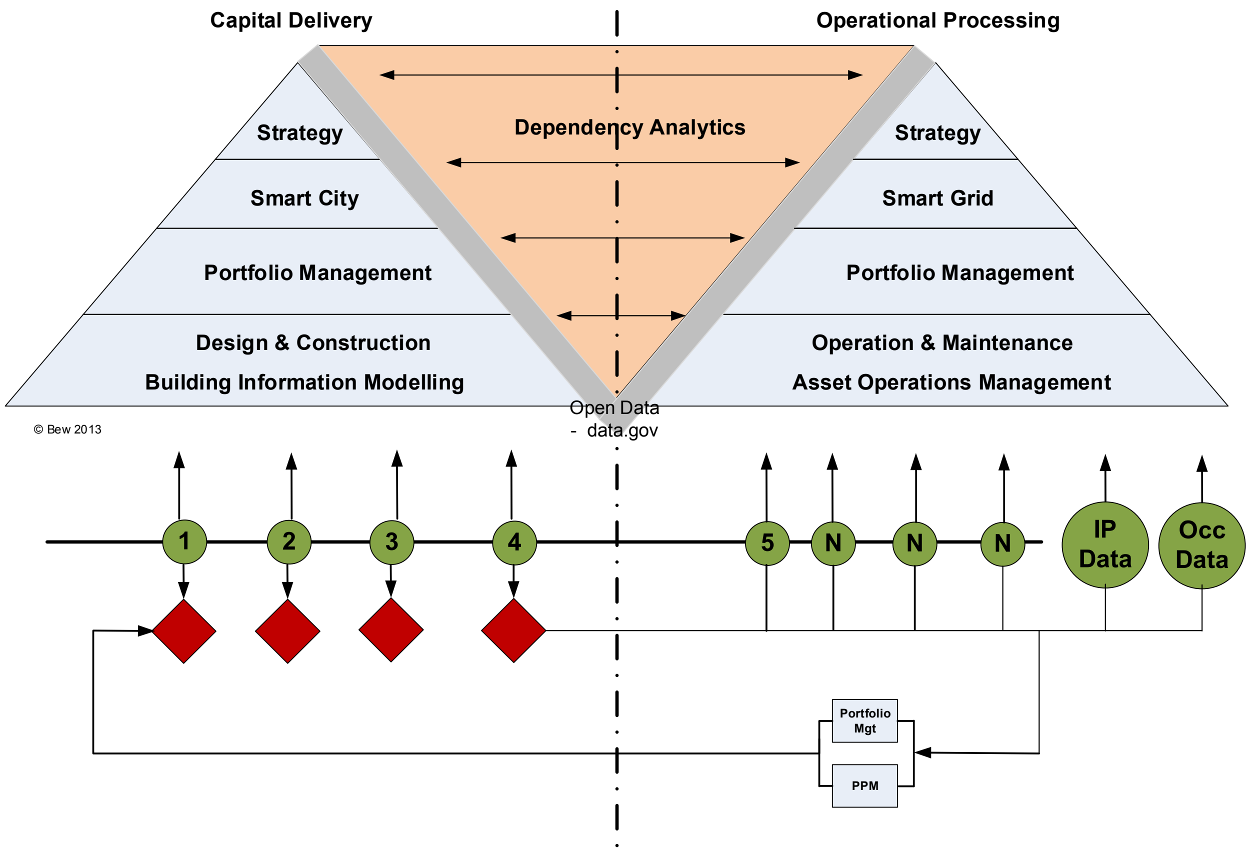


Figure 2.13 - HMG Level 3 BIM Data Vision
©Bew 2013

The diagram illustrates data being held in logical pyramids with horizontal layers indicating data purposes, ranging from the micro view "atomic" data available using BIM and Asset Management systems, passing up through combined asset portfolio views, geospatial "smart city or grid" services and at the macro view a strategic vision across entire budgets, states or nations. The data is logically held in separate capital delivery systems and operational asset/facilities systems. However, these may be physically one or many systems. The data capture process (contract) is indicated at the lower half of the image with the data exchanges and the red diamond “PLQ” data demands from the client.

The capture process of operational data is fundamental, as it forms the basis and information source that can form a feedback loop back into the review and briefing process. Applying these concepts into a process which we have defined as linear is also misleading, for the process is iterative. Daniel (2003) wrote “The building design is a deeply iterative process – constant dialogue between ideas, analysis, synthesis and evaluation. It is indeed as much problem setting as problem solving”. He further explains that the amount of iteration and conflicting requirements of stakeholders always increases the complexity of the process and decisions that are delayed are replaced by assumptions. This is described by Kiviniemi (2005) as potentially having have a significant negative impact on the emergent design with conflicting requirements and dependencies being missed or misinterpreted. He identified the main problems as being “no connection between requirements (the brief) and the design documents (a potential area for a feedback loop), the impact of project personnel changes and project duration, the impact of middlemen in the process and the management of what he defined as “direct and indirect requirements”. These are defined as the relationship between direct client driven requirements such as spaces or functional outcomes and the indirect requirements defining the services and technical elements of the design.

The use of structured data to provide feedback in this process is not well established in the built environment as it is in other high performance industries such as motor racing, aviation and automotive manufacturing. In all of these sectors market transformation has brought about dramatic improvements in reliability and performance. Rolls Royce are about to enter the second generation of remote diagnostics with their digital offering based on the Trent engine as described in their literature (Rolls Royce 2016). Motor racing and automotive have over the same twenty years gone through similar transformations. Cocco & Deponte (2008) discuss this in detail in their paper Metrology and Formula One Cars, highlighting the importance of feedback in the essential task of supervising the vehicles set up in terms of performance and setup. The principle of using active sensors to measure performance and comparing with a control value are discussed and encapsulated in the example offered for vibration management. Figure 2.11 shows the general arrangement of this approach, with the characteristic being measured (Vibration) providing active data to be compared and if falling outside a predefined tolerance, an intervention or "action" being taken. In this case it is a design modification or some adjustment to remove the anomalies.

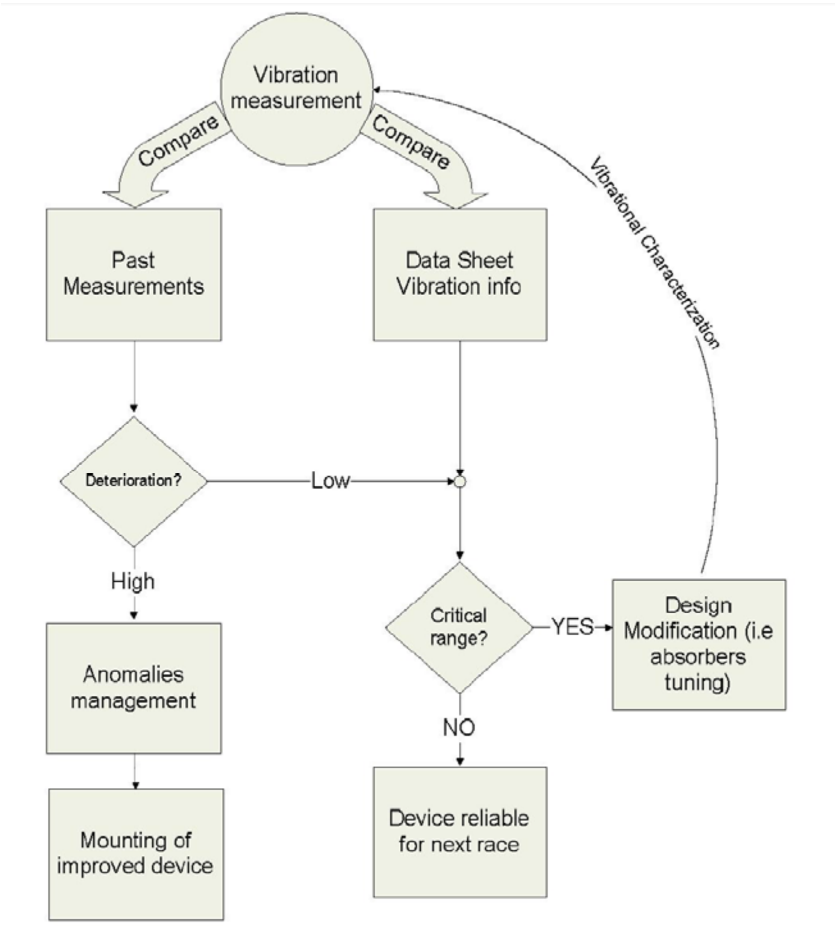


Figure 2.11 - Feedback model for vibration monitoring (Ferrari 2008)

If we apply these techniques to physical built assets using systems such as Building Management Systems and other forms of sensors such as Internet Protocol (IP) based telemetry it is possible to see how dramatic improvements could be made. There are a number of challenges that the built environment suffers with respect to instrumentation; firstly, the sheer size of the environment. The advantage of a car or plane is its finite (and small) scope - it should be noted that the example offered by Cocco & Deponte (2008) showed that a competitive Formula 1 car in 2008 had nearly 200 sensors. It is unlikely that many built assets would be able to support such an approach other than in heavily serviced areas.

The next challenge is around maintainability and commercial constraints. Many assets, especially infrastructure, are placed in inhospitable environments (e.g. large bridges) making the selection of devices and their servicing expensive and potentially unreliable. The final challenge is the market pressurising owners and customers to use their proprietary solutions. This, whilst understandable, creates closed access to vast amounts of data which users may be effectively locked out of as they cannot read it. The need for open standards here is critical if we are to achieve any useful sized data volumes. The area with the most activity, promise and literature by a long margin is the Internet of Things (IoT).

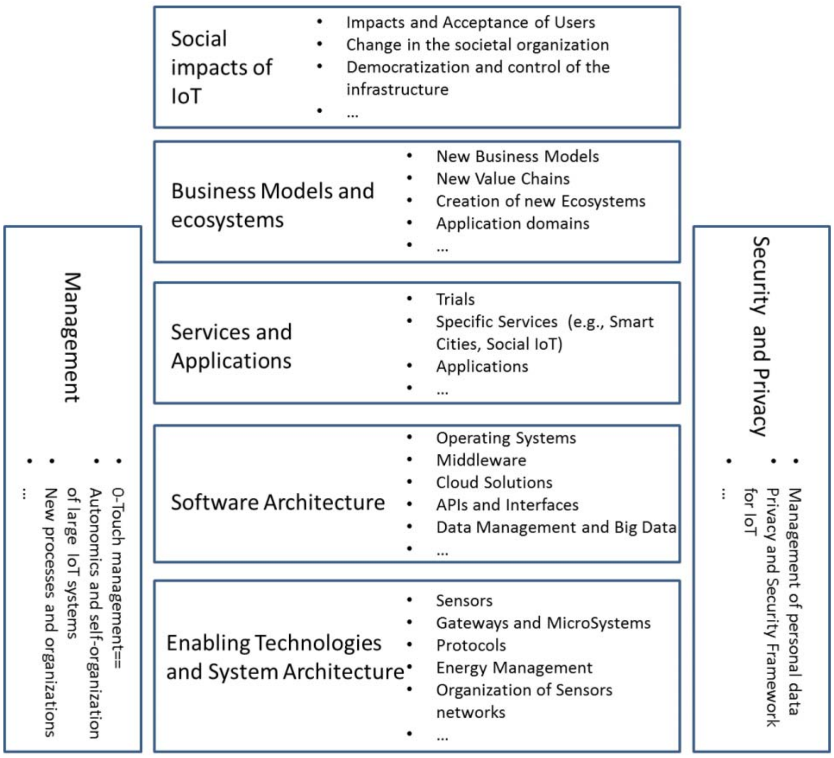


Figure 2.12 - Technological and Social Aspects Related to IoT (IEEE 5-15 (2015))

The IoT is a socio-technical framework to enable sensors to be accessed and used using existing technologies and internet protocols, thus providing and open access technical framework. The work undertaken by the IEEE already identifies the impact of these technologies on social aspects as described in (IEEE 5-15 2015). The model shown in Figure

2.12 shows the service layers from enabling technologies up to the interface with society and the ultimate customer.

The service layers cover the physical connections and protocols required to connect and access the devices, the next layer up describes the software architecture with both processing and access, storage and transport systems specified. The next level up is known as services and applications in this case to support smart city functions. These functions are specifically designed to support new businesses and ecosystems currently being hypothesised to develop smart city services, which are summarised in Table 2.8 from work described by IBM and Libelium, (Libelium 2015). The top level then describes the social impacts of the technology in terms of social change and impact. There is also a security and privacy element built in to protect personal and individual's data.

The IoT however only offers a transport and presentation mechanism for each data sensor type. The key decisions when it comes to developing a sensing and feedback strategy is which variables does one measure? There also some confusion as to at what level do you try and describe the service?

Table 2.8 - Service Descriptions, derived from Libelium (2015)

Service	Description
Smart Cities	Market description of a future state of built assets which operate in an active manner with asset (machine to machine) communications capabilities. They are also likely to exhibit self-learning or healing characteristics.
Smart Environment	Market description of a future state of environmental assets which operate in an active manner with asset (machine to machine) communications capabilities. They are also likely to exhibit self-learning or healing characteristics.
Smart Water	Market description of a future state of water assets and services which operate in an active manner with asset (machine to machine) communications capabilities. They are also likely to exhibit self-learning or healing characteristics.

Service	Description
Smart Metering	Smart metering is the provision of remotely read measurement devices to understand the domestic and commercial consumption of utilities. There are a number of implementation strategies such as CIBSE TM39
Security & Emergencies	The use of geospatial and traffic routing capabilities is now widespread within the emergency services as well as information regarding the layout of buildings to aid emergency activities
Retail	Retail analysis of demographics and footfall is critical to enabling high volume retail performance.
Logistics	The logistics sector is optimised through effective routing and utilisation of both drivers and capacity. All the time a lorry is empty or stationary it isn't earing revenue, the use of sensing data enables this optimisation.
Industrial Control	Smart machines and smart factories are all now in scope of the smart processes. Noise sensing to protect workers through to full automation and control are now all possible.
Smart Agriculture	Smart agriculture is now using sensor and satellite technologies to optimise machine movements and consumables distribution
Domestic & Home Automation	One of the earliest IP based remote sensing devices was the Google Nest which was designed to optimise the operations of domestic properties, which are a significant challenge in the delivery of cost reductions and carbon emissions
e-Health	The e-health market is a fast emerging and growing market using IoT and wearables technologies to monitor the activities and performance of patient health to pre-empt health issues.

These applications are derived from the ability to measure or sense a number of common variables including

- Temperature
- Light
- Noise
- Humidity

- Volatile Organic Compounds (VOC)
- Other Gas Combinations
- Movement

VOC's are organic chemicals that have a high vapour pressure at ordinary room temperature. Their high vapour pressure results from a low boiling point, which causes large numbers of molecules to evaporate from the liquid or solid form of the compound and enter the surrounding air, a trait known as volatility. They include both human-made and naturally occurring chemical compounds. Most scents or odours are of VOCs. Some VOCs are dangerous to human health or cause harm to the environment. Anthropogenic VOCs are regulated by law, especially indoors, where concentrations are the highest. Harmful VOCs typically are not acutely toxic, but have compounding long-term health effects, however because the concentrations are usually low, the symptoms are slow to develop.

2.9 Relationships and Dependencies with Other Assets

The built environment is not a single dimension phenomenon, but multi-faceted with every service and asset having potential dependency and impact on each other. As these dependencies relate, their impact on society is amplified and modestly small errors or failures can have a dramatic effect as demonstrated by the effect of poorly developed housing or transportation networks. Figure 2.13 shows a model developed by the UK HM Treasury to indicate some of the dependencies in the basic UK service infrastructure. What is shows is the total dependence and interrelationship with each other, i.e. ATM on communications on power all of which provide the money for basic subsistence and existence. Recently much work has been undertaken to improve the performance of these assets through the use of better information by technology organisations.

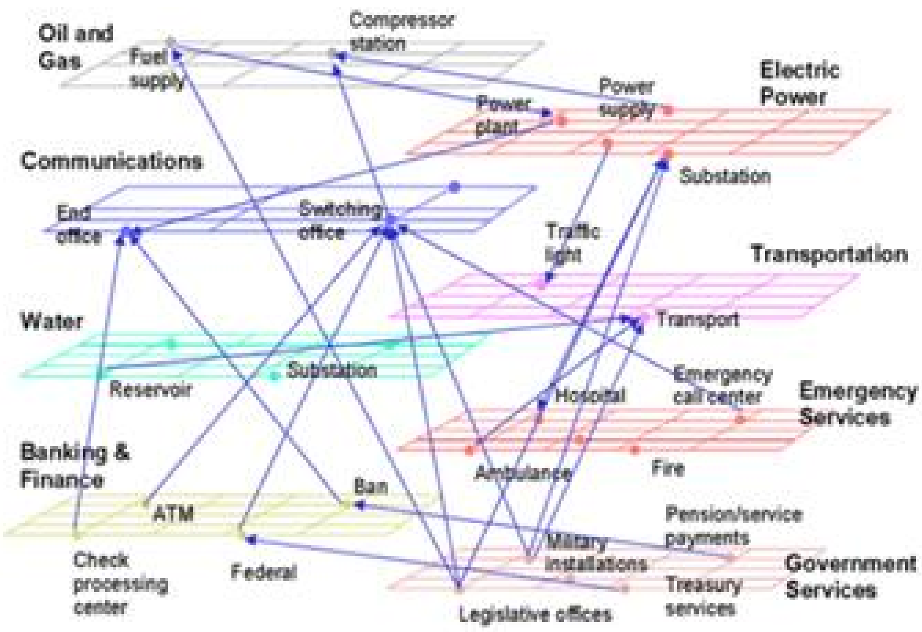


Figure 2.13 - Infrastructure Interdependency

Each infrastructure or asset can be viewed as a composite service where we can model impacts and effects, such as the effect of food distribution should we lose any or the entire road network. Similar models could be developed with respect to power and internet services and their potential impacts on the banking industries and the community.

As each infrastructure is broken down into its constituent parts it is clear that each service and infrastructure has its own internal dependencies and these can be very complex in their own right. Figure 2.14 demonstrates this complexity in the electricity generation and distribution service. In this example, we can see how many internal and external interfaces that are in place to deliver the service. Indeed, there are dependencies within the electricity delivery process as well as dependencies generated by the service the asset creates on other infrastructures. This is further contextualised by the management of the varied supply market which is made up of traditional generation, renewables and the regulatory control of the independent regulator balancing the demand of the domestic and commercial customer market.

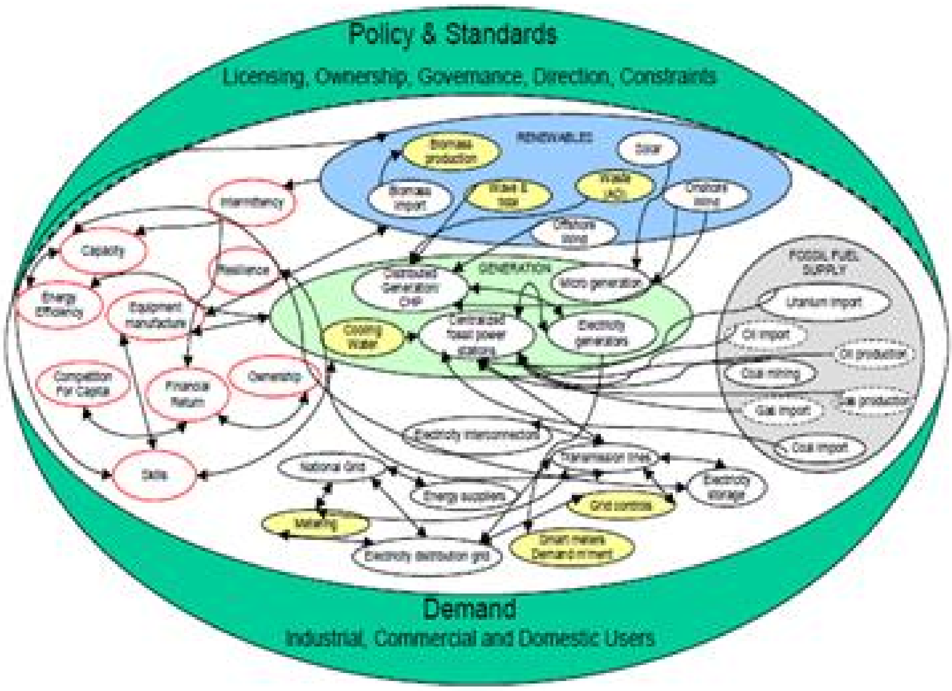


Figure 2.14 - Energy Infrastructure – Electricity Generation & Distribution Model
© UK Treasury Working Group 2010

The mass instrumentation of every asset and the analysis of each asset on each other and on society at large is known by the captive term "Smart City" or in the case of locations such as Singapore even more ambitious with the term "Smart Nation". These terms remain ill defined, but all describe the ability to measure and process data in the cloud to provide insights and services never yet dreamed of. Perhaps the longest and complete definition comes from the "Future Internet", Society for Brain Integrity, (Sweden 2010). The Society conceives the IoT as the "Future Internet" and gives the following definition.

“It means that any physical thing can become a computer that is connected to the internet and to other things. IoT is formed by numerous different connections between PC's, computers, human to human, human to thing and between things. This creates a self-configuring network that is much more complex and dynamic than the conventional Internet. Data about things is collected and processed with very small computers such as RFID tags (which are devices that use electromagnetic fields to automatically identify and track tags physically attached to objects). The tags contain electronically stored information. Passive tags collect energy from a nearby RFID reader's interrogating radio waves. Active tags have a local power source such as a battery and may operate at hundreds of meters from the RFID reader that is connected to more powerful computers through networks (or the Cloud). Sensor technologies are used to detect changes in the physical environment of things, which further benefits data collection. The network becomes more powerful when intelligence can be embedded to things and processing power can be distributed more widely in the network. Sweden (2010) have further defined the Future Internet as:

- Pervasiveness and Ubiquity: Digital content and services will be around us in not only ICT devices but in any physical objects as well, embedding computers into a physical environment creating a link between physical and digital worlds
- Network of Networks: The internet of the future connects networks of objects to the classic Internet. The result is a combination of different communication networks that can manage the complex communications of large amounts of information and enable new types of services as the structure of the internet becomes more complex and venerable to security threats
- Interoperability and Accessibility: Devices and objects are networked and work seamlessly together. Interoperability is implemented also in the level of the network architecture making the communication between services and applications also more fluent. Services and content can be accessed anywhere, anytime and with many different devices. Mobile devices will dominate globally as access points to the Internet
- Miniaturisation and Simplification: In IoT the computers at the end nodes of the Internet are small to the point of being even invisible to the eye when embedded in the environment. The purpose of this kind of miniaturisation is not necessarily to include the capacity of a full-blown computer in an even smaller scale device but to include only those functions like sensing, storing and communicating a limited amount of information normally to a smart device such as a mobile phone
- Context Awareness: Future Internet will be able to recognise different contexts by using different sensor technologies. On the physical level sensors gather information from the physical environment and on the digital level they gather information about the network and applications. When that information is combined with other input

data the network and applications can dynamically adapt to optimal processes at any actual moment

- Autonomy: Input of information into the Future Internet does not have to be made by humans alone. Machines will interact more and more with each other becoming more predominant than human-centric interaction. In IoT, sensors and actuators that are embedded in the environment can collect data automatously and transmit it to each other and the network
- Virtualisation of Resources: Virtualisation enables better exploitation of network resources with higher flexibility and security
- Semantics: These are an important part of the Future Internet. Using semantic or self-defining annotations linked to other information in the web locating information will become much easier, faster and accurate, as well as scalable and secure.

2.10 Summary

This Chapter has introduced the current practice and state of the art of the asset design using the UK Government "levels" of progress and maturity as an overall contextual framework. The data that is created and managed though the delivery process, especially that using BIM tools and standardised formats, can be used to understand how an asset may perform both virtually and in real life. The use of sensors to understand how the physicality of an asset performs is an exciting opportunity for the industry and forms a key part of this research, in establishing the relationships between physical and psychological wellbeing and high performance.

To enable this step however we need to understand how the effects of human behaviours and perceptions can be measured. This is discussed in Chapter three.

Chapter 3

Perception and Social Outcomes

3.1 Introduction

In Chapter two the approach to delivering and operating physical assets was described. The concept of a quantitative description of a physical asset held in the form of geometric and descriptive data sets. The process of converting virtual designs into physical manifestations is a long and complex process and can often fail to adequately consider the users of the asset or its services.

This Chapter sets out how users perceive the world they inhabit and explores potential methods for measuring and analysing perceptions and the impact of the built assets on social outcomes.

3.2 Background

The measurement of social well-being and outcomes is complex and defined in many ways (Altman and Rogoff 1987). The key complicating factor is the way in which humans perceive information and situations in dramatically different ways depending upon their environment and backgrounds. This perceived "reality" has various effects on their behaviours, which in turn effect or impact on their colleagues and community members in which they come into contact. It also has a physical impact on their built environment which could have been the cause of the behaviour in the first place, resulting in making a poorly performing asset perform even worse.

The composite result of these perceptions, behaviours and impacts has the effect of producing outcomes. Sometimes these outcomes are positive and lead to a well performing community who are well served by their built assets which provide secure, comfortable environments. More often the changing needs and personalities of the community will erode the effectiveness of the original design. Thought, perceptions and service demands change the needs of the environment and the shape of the community meaning the assets start to fail in the delivery of effective service capabilities and the community begin to suffer. Their outcomes start to diminish and fail to deliver a satisfactory environment. This can mean lower academic results from a school, poor success rates from hospitals or higher rates of mental illness from poor quality residential accommodation, (Feinstein et al 2008). At its worst this can look like compete breakdown of social fabric as was evidenced in the inner-city riots and industrial disputes of the 1960's and 70's.

Using Baileys funnel, (Bailey 2003) shown in Figure 1.1 as a framework it is clear from much of the literature that the challenge of achieving an effective asset is a careful balance between opposing influencers. Cost is almost always the dominant driver and has the largest impact on the completed asset. Poor building design and environment has been linked with poor social wellbeing and performance for many years as described by the BRE (2011). It is understood that the relationships between human and social wellbeing and the built environment are complex and multi aspect. All assets and infrastructure has an impact on each other in unpredictable and unexpected ways. The human user is often many layers away from the intent and desire of an asset provider and his perception of its performance can vary dramatically because of this. Many assets are dependent upon others to function and this develops and changes with time. This is illustrated in the Smiths Institute report by (Feinstein et al 2008) which tracked the relationship between housing and people’s circumstances and other life outcomes over a long term longitudinal study. Whilst it indicated that the link was not inevitable, the data showed that the socio economic and cultural factors had reshaped the residential market and they cite as a conclusion that "social housing has become an indicator for adult life chances, above and beyond what might be expected".

Churchman and Ginosar (1999), explore the theoretical basis for and approach to neighbourhood evaluation. They cite several theories; the first is Bronfenbrenner (1976,1979), which is described as an ecology of human development. This is contrasted by a transactional view from Altman and Rogoff (1987), which attempts to rationalise the complexity of any community. The fact that there are so many variables that can be measured at different levels is also considered as well as the fact that any measurement must be evaluated from the standpoint of the user of the facility. To explore the array of influences the following hierarchy of assets and dependencies can be considered.

As discussed in Chapter two the use of feedback into the operational and delivery phases of an asset's lifecycle can have a dramatic impact on the outcomes of that asset's performance. This use of feedback is nothing new in engineering or other high performing assets or in the design of manufactured products. The Social Construction of Technology (SCOT) is ascribed to Trevor Pinch, professor at Cornell University, and Wiebe Bijker, professor of Social Science and Technology at Universiteit Maastricht. The birth of SCOT is typically assigned to the 1984 workshop (cf. Section 10.2). SCOT is in a social constructivist tradition, but treats technical factors in a relativist fashion (Pinch & Bijker 1986). In The Social Construction of Technological Systems, Pinch & Bijker (1987) described how the influence of different social groups turned the bicycle from the "penny farthing" to the bicycle we know today. In SCOT, the developmental process of a technological artefact is described as an alternation of variation and selection. This results in a "multidirectional" model, in contrast with the linear models used explicitly in many innovation studies and implicitly in much history of technology (Pinch and Bijker 1987) and also resonates with a similar approach taken to the delivery of constructed assets. The purpose of the multidirectional model is not only to describe the winning technology; it also looks at the discontinued technology. This helps answer the question of why a particular piece of technology or artefact is successful and another vanishes.

Since problems are not purely technical, solutions are not merely technical - they may also be judicial and moral. “In this way [by focusing on the conflicting solutions], one can expect to bring out more clearly the interpretive flexibility of the technological artefacts” (Pinch & Bijker 1987). According to SCOT, the first stage of a new technology is interpretive flexibility. By this we mean not only that there is flexibility in how people think or interpret artefacts but there is also flexibility in how artefacts are designed. There is not just one possible way or one best way of designing an artefact. In principle, this could be demonstrated by interviews with technologists who are engaged in a contemporary technological controversy (Pinch and Bijker 1987).

Closure and stabilisation of an artefact follows interpretive flexibility. At some point, the interpretive flexibility stops, and the winning technological artefact emerges. There are several ways to reach closure. Pinch and Bijker (1987) mentioned two types of closure: rhetorical and redefinition of the problem. It is not necessary to have actually solved the problem in order to reach rhetorical closure. The key point is whether the relevant social groups consider the problem as having been solved. However, it is sometimes necessary to redefine the problem an artefact tries to solve. An example is the air tyre of the modern bicycle, which originally addressed a vibration problem on paved roads. Sporting cyclists could not recognise this problem; they had a hard time accepting the aesthetically distasteful air tyres. However, when the air tyre was seen as a solution to the sporting cyclists concern about how to go as fast as possible, the artefact could reach closure (Pinch & Bijker 1987).

The third stage of SCOT is the wider context. This relates the content of a technological artefact to the socio-political aspects. Bijker (1995) referred to this description of the history of a technological artefact as the descriptive model. The point of origin is the social deconstruction; the identification and deep description of relevant social groups, such that all social groups are treated equally. Interpretive flexibility is described by looking at the different meaning the relevant social groups give to the artefact. Stabilisation emerges from the process of closure. This also fits well with our need to position the assets we build within the context we set them through the urban planning process and in terms of the future the application of the smart city/nation paradigm from a technological point of view.

To achieve this, we need to identify measurements which represent the way that human based communities react and perceive themselves and their fellow community members in relation to each other. This is a complex matter - the benefit of the physical measures described in Chapter two are bound by the physicality of actual values and the application of criteria (normally driven by cost or regulation) to create a performance envelope for the asset to perform. These rather mechanistic rules do not exist within the community - people are different, they have different jobs, which could be sedentary or active, they are young and old, large and small, male and female, the list goes on. They are all specific individuals with different needs, desires and personalities. This makes the application of a mechanistic measurement system a rather poor fit. Whatever the measurement methodology, the outcome would be a qualitative value. In itself this is not necessarily an issue except that we need to devise or identify a methodology to bring these qualitative feedback values back to the quantitative values needed to compare the actual asset performance and provide objective feedback to the asset owner or operator. To do this a deeper understanding of the potential measured variables pertaining to social wellbeing and outcomes and how they can be measured and presented is needed.

3.3 Definition of “Social Outcomes”

The term “social outcome” appears to be inconsistently applied to a measure of quality of life, well-being and socioecological systems (King et al 2013). This definition is used to evaluate the general well-being of individuals, communities and societies. The term is used in a wide range of contexts, including the fields of international development, healthcare and politics. There seems to be much emphasis placed on the concept of “standard of living”, which is based primarily on income as a proportion to Gross Domestic Product (GDP) but this should not be confused with social outcomes and quality of life. Research published by New Economics Foundation, (NEF 2015) shows that, since 1970, the UK's GDP has doubled, but people’s satisfaction with life has hardly changed. Further, they say that 81% of Britons believe that the UK Government should prioritise creating the greatest happiness not the greatest wealth. There are many methods of measurement but unfortunately many of these focus on GDP ratios and not actual physical measures of wellbeing. We are for the purposes of this work only interested in the indicators of the quality of life relating to the built environment, not solely wealth and employment. Key issues include relationships to the built environment, physical and mental health, education, recreation and leisure time and social belonging.

According to King et al (2013), the concept of a socioecological system emphasizes the interconnectedness of the biological and biophysical processes of ecosystems and the cognitive, socio-cultural and institutional processes of human systems (Adger 2006), (Berkes & Folke 1998). This interconnectedness is still poorly understood (Maltby & Acreman 2011) and often unacknowledged (Hancock 2010). However, what is clear is that loss and degradation of ecosystem function has complex consequences for a socioecological system as a whole, impairing the flow of ecosystem services upon which humans rely for their livelihoods and well-being as variously discussed by Balmford & Bond (2005), Maltby & Acreman (2011) and Folke (2006).

There is a range of competing views in this area but the definition for Social Impact offered by BS EN 16309 is “any change to society or quality of life, whether adverse or beneficial, wholly or partially resulting from social aspects”, where social aspects are defined as “aspects of construction works, assembled system (part of works), processes or services related to their lifecycle that can cause change to society or quality of life”. It offers a useful point of departure for this research.

3.4 Overview of “Social Outcome” Indicators

King et al (2013) discuss the large number of recent studies (Brauman et al 2007), (Chiesura & de Groot 2003), (Engelbrecht 2009), (Hancock 2010), (Glaser 2003), (Knight and Rosa 2011), (NEF (2005), (Pereira et al 2005), (Summers et al 2012), (Vemuri & Costanza 2006) which all indicate a positive relationship between ecosystem (including the built environment) services and human physical, physiological, and psychological well-being. The benefits of ecosystem services to quality of life are diverse, some of which are non-material. Such benefits include food, freshwater, fibres, and building materials Millennium Ecosystem Assessment MA (2005); mental and physical health and medicines (Balmford & Bond 2005), (NEF 2005). They also identify that the concept of measuring well-being and social outcomes has evolved and continues to do so. This is due to the multi-dimensional, dynamic, person-specific and culture-specific nature of the subject. According to King (2013) the concept of ecological embeddedness of well-being has also gained recognition, and this development of the concept demands that we explore and identify new conceptual frameworks and appropriate methodological approaches towards the assessment of quality of life within a socioecological context providing links to finite resources and the built environment. A socio-ecological system is defined by Redman & Grove (2004) in terms of the following criteria:

a. A coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner
b. A system that is defined at several spatial, temporal, and organisational scales, which may be hierarchically linked
c. A set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems and
d. A perpetually dynamic, complex system with continuous adaptation

Redman & Grove (2004) also identifies the concept of socio-ecological systems to emphasise the integrated concept of humans in nature and to stress that the delineation between social systems and ecological systems is artificial and arbitrary, whilst resilience has somewhat different meaning in social and ecological context, the approach holds that social and ecological systems are linked through feedback mechanisms and that both display resilience and complexity.

3.4.1 History of Social Indicators

Social indicators are a statistical time series "used to monitor the social system, helping to identify changes and to guide intervention to alter the course of social change" (Land 1999). The term social indicators was born in the United States in the 1960s when the American Academy of Arts and Science, in a project funded by the National Aeronautics and Space Administration (NASA), attempted to "detect and anticipate the nature and magnitude of the second-order consequences of the space program for U.S. Society" (Land 1999:1). Frustrated by the lack of sufficient data to detect such effects and the absence of a systematic conceptual framework for analysis, an attempt was made to develop a system of social indicators to detect and anticipate social change as well as evaluate the impact of specific programs and policies. This culminated in the publication in 1966 of *Social Indicators*, edited by Raymond Bauer. There are, according to King et al (2013), two influential approaches, the Capabilities Approach and the Basic Needs Approach which can be recognised in all current measures of well-being. The Capabilities Approach appeared a little after the Basic Needs Approach and gives a greater emphasis to functioning of a human within its community and the role of freedom. This is important from the point of view of looking at an asset's performance in the context of other interfacing assets and their Smart City type performance and whilst this is a consideration for this research this research is scoped to a single asset with observations as to the potential for wider application. For this analysis the Basic Human Needs may be more appropriate, The Basic Needs approach includes, inter alia, (Doyal & Gough's 1984, 1991) Theory of Human Needs (THN) and (Max-Neef's 1991) Fundamental Human Needs (FHN) matrix. This approach includes autonomy as one basic need among others of equal importance. Doyal & Gough (1984), THN considers basic needs as ''goals that must be achieved if any individual is to achieve any other goal.''. To achieve these goals Doyal & Gough (1984) further describe twelve universal preconditions for participation in social life which are described below. These build upon the twelve basic needs which define in the view of Gough & Doyal (1984), that every person has an objective interest in avoiding serious harm that prevents his endeavouring to attain his vision of what is good, regardless of what exactly that may be. That endeavour requires a capacity to participate in the societal setting in which the individual lives. More specifically, every person needs to possess both physical health and personal autonomy. The latter involves the capacity to make informed choices about what should be done and how to implement it. This requires mental health, cognitive skills, and opportunities to participate in society's activities and collective decision-making. How are such needs satisfied? Doyal & Gough (1984) point to twelve broad categories of "intermediate needs" that define how the needs for physical health and personal autonomy are fulfilled:

1. Adequate nutritious food and water (delivered as a function of the built environment and social infrastructure, which is in scope for analysis in this research)

2. Adequate protective housing (delivered as a function of the built environment and social infrastructure, which is in scope for analysis in this research)
3. A safe work environment
4. A supply of clothing
5. A safe physical environment (delivered as a function of the built environment and social infrastructure, which is in scope for analysis in this research)
6. Appropriate health care (much of which is delivered as a function of the built environment and social infrastructure, which is in scope for analysis in this research)
7. Security in childhood
8. Meaningful primary relations with others
9. Physical security (delivered as a function of the built environment and social infrastructure, which is in scope for analysis in this research)
10. Economic security
11. Safe birth control and child-bearing
12. Appropriate basic and cross-cultural education. (delivered as a function of the built environment and social infrastructure, which is in scope for analysis in this research)

There were a number of other publications in the 1960s that attempted to establish a "system of social accounts" that would facilitate a cost-benefit analysis of more than the market-related aspects of society already covered by the National Income and Product Accounts. Probably the most influential was the work of the University of Chicago sociologist William Ogburn. He produced for the Hoover administration in 1933 "Recent Social Trends", (Ogburn 1933) which represented a ground-breaking contribution to social reporting. Ogburn's students played a major role in the emergence of social indicator in the 1960s. Developments then moved on to include the establishment of the Social Science Research Council Centre for Coordination of Research on Social Indicators; the publication by the U.S. Federal Government of comprehensive data on social indicators; initiation of survey research on social indicators; the founding of the journal "Social Indicators Research" and the spreading of social indicators to international agencies such as the UN and the OECD. Weisbrot & Ray (2011) observed that "after a sharp slowdown in economic growth and in progress on social indicators during the 1980-2000 period, there has been a recovery on both economic growth and for many countries, a rebound in progress on social indicators (including life expectancy, adult, infant, and child mortality, and education) during the past decade". Interest has now re-emerged due to a wider understanding of the physical and political impact of these issues. A time line documenting the development of social indicators between the 1960's and present is shown in Table 3.1 Social Indicators Development Time line.

Table 3.1 – Social Indicators Development Timeline

Indicator	1960	1970	1980	1990	2000 to Present
Objective indicators	Social Indicators (Bauer 1966)	Social Indicator Programme (OECD 1976)	Physical Quality of Life Index (Morris 1979)	Human Development Index (UNDP 1990)	
Subjective indicators	Affect Balance Scale (Bradburn 1969)		Satisfaction with Life Scale (Diener 1985)	Psychological Well-being (Ryff & Keyes, 1995)	
Ecosystem services and environmental sustainability indicators		United Nations Environmental Programme (1972)	World Conservation Strategy (IUCN 1980) World Resources Institute (1982) Intergovernmental Panel on Climate Change (1988)	Sustainable Livelihoods Approach (Chambers & Conway 1992) Ecological Footprint (Wackernagel & Rees 1996)	Millennium Ecosystem Assessment (2005) Happy Planet Index (Marks et al. 2006)
Quality of Life (QOL) indices		Subjective QOL (Andrews & Withey 1976; Campbell et al.1976) Having, Loving & Being (Allardt 1976)		Comprehensive QOL Scale (Cummins 1996)	Wellbeing in Developing Countries QOL (2006)
Theories on multidimensional wellbeing			Basic Needs (Streeten et al. 1981) Theory of Human Need (Doyal & Gough 1984); Capabilities Approach (Sen 1985)	Prudential Values (Qizilbash 1996) Fundamental Human Needs (Max Neef 1991)	Voices of the Poor (Narayan et al. 2000)

The interesting challenge that all of these measures identifies is the low coincidence of the relationship between relative wealth and well-being or social outcome and the recognition of the part played by the built environment. Further to this is the relatively low level of literature relating to how the subject's environment can be objectively measured to provide insights as to how improvements can be made.

3.4.2 Types of Indicators

According to Land (1999), there are three types of social indicators that have been identified.

3.4.2.1 Normative Welfare

These indicators relate to social policy-making considerations and are sometimes referred to as criterion, normative or policy indicators. Olsen (1962) characterised these as "statistics of normative interest which facilitates concise, comprehensive and balanced judgements about the condition of major aspects of society". These measures are direct measurements of welfare and indicate movements of change. Land suggests that the use of these indicators requires consistency from society as to what needs to be improved and he also suggests that it is possible to aggregate the indicators to a level at which policy can be defined. He does not identify any functional or implied link between the measures and the briefing process, but does imply that there could be a cause and effect. The measures are reflected by King et al (2013) and fall into the three measurement characteristics that are identified, namely objective, subjective and mixed.

3.4.2.2 Life Satisfaction

These indicators are often referred to as subjective well-being or happiness indicators. They attempt to measure psychological satisfaction, happiness and life fulfilment through various methods that measure the subjective reality in which people live. The method is based on the principle that direct monitoring of key social-psychological states is necessary to understand social change and quality of life.

3.4.2.3 Descriptive Social Indicators

The third set of social indicators focuses on social measurement and is designed specifically for measuring our understanding of society. These indicators are often related to public policy objectives and the physical environment being measured. The measures come in many forms and can vary in level of abstraction and aggregation.

3.4.3 Measurable Entities

The Organisation for Economic Co-operation and Development (OECD) has a mission to promote policies that will improve the social well-being of people around the world. The OECD provides a forum in which governments can work together to share experiences and seek solutions to common problems. They work with governments to understand what drives economic, social and environmental change.

They also look at issues that directly affect the lives of ordinary people, like how much they pay in taxes and social security, how much leisure time they can take, where they live and how their communities operate. They compare how different countries' school systems are readying their young people for modern life, and how different countries' pension systems will look after their citizens in old age.

They have produced analysis in a number of areas including housing and education which have made use of the following indicators.

- Physical Environment
  - Housing Conditions
    - Indoor dwelling space
    - Access to outdoor space
    - Basic Amenities
  - Accessibility to Services
    - Proximity to selected services
  - Environment
    - Exposure to air pollutants
    - Exposure to noise

- Personal Safety
  - Exposure to risk
  - Fatal injuries
  - Serious injury
- Perceived risk
  - Fear for personal safety

According to ecological economist Costanza (2001), while Quality of Life (QOL) has long been an explicit or implicit policy goal, adequate definition and measurement have been elusive. Diverse "objective" and "subjective" indicators across a range of disciplines and scales and recent work on subjective well-being (SWB) surveys and the psychology of happiness have spurred renewed interest. Mistra (2005) in his “Social Impact Assessment Methodology” identified that Social Impacts of development or human settlements need to be measured and identified to enable effective management to ensure negative impacts are mitigated and reduced by positive influences and interventions. Mistra (2005) identified the following key data attributes:

- Location
- Land requirements
- Needs for ancillary facilities / infrastructure
  - Roads
  - Power
  - Water (Clean / Dirty)
  - Data
- Programme of Works
- Size of Workforce (By Time)
- Facility size & shape
- Need for local workforce
- Institutional resources

Also frequently related are concepts such as freedom, human rights, and happiness. However, since happiness is subjective and hard to define and measure, other indicators are generally given priority. It has also been shown that happiness, as much as it can be measured, does not necessarily increase correspondingly with the comfort that results from increasing income. This is further supported by the OECD (2015) who confirm that wellbeing and happiness is multi-dimensional, with the latest evidence on their eleven dimensions having diverse patterns of strengths and weakness. They confirm that countries in the top third of the OECD Gross Domestic Product (GDP) ratings per capita tend to do well with respect to wellbeing, but this is not exclusive by any means. They also summarise that "While we have known for a long time that there is more to life than GDP their research shows even the richest countries have a long way to go to achieve widespread happiness".

Through the review of the literature, the impact of relative wealth and the built environment have a large impact upon people wellbeing. As relative wealth is not categorically linked to wellbeing this work focuses on other themes which are more able to be influenced by the provision of better assets. Key to these themes is the ability to measure social outcomes. These will be reviewed and considered in a wider consideration including the following indicator values:

- Social Inclusion; measures to avoid social disadvantage and relegation to the fringe of society where sections of society are systematically blocked from rights and opportunities which are fundamental to social integration. This can include housing, benefits, education etc.
- Equality; these measures are related to social inclusion, but are focused on parts of society and their freedom of speech, rights and other discrimination on the basis of race or religion.
- Safety; the environment the population inhabits should provide protection from harm, hazards and other undesirable outcomes
- Security; the security indicator should consider the degree of resistance to protection from harm of a person or valuable asset. This would normally consider a separation between risk and the asset (or person)
- Health and Comfort; is a measure of relative comfort of assets that provide human accommodation

- Liveability; this is a measure derived from quality of life. It is defined by Mercer (1999) as a combination of subjective life satisfaction and objective measures such as quality of life, divorce rates, safety and ease of access to services and infrastructure.
- Employee Satisfaction; A derived qualitative measure of a person's happiness with his work and/or employer
- Corporate Social Responsibility; is a form of corporate self-regulation approach whereby a business monitors and publishes key sustainability and ethical information
- Quality of Live; is a measure of the general wellbeing of individuals or societies. This is not the same as standard of living, which is based primarily on household or individual income.
- Access to key services, including transport and healthcare
- Adaptability; the ability for the built environment or the population to reuse and repurpose assets and services to make best use of available capacity and capability.
- Loadings and effects on the neighbourhood including relations with stakeholders
- Maintenance; the level to which assets are kept in serviceable condition

Other Key Indicator Categories of Interest (with respect to the Built Environment)

- Indexes which provide a consistent historical estimate of trends; for values such as urbanisation and other key public services
- Cross country/geography; the extents to which the scope of the measurement and the service are provided
- Trends in wellbeing from local communities; for values such as urbanisation and other key public services
- Normative Welfare; is a rating of more or less desirable social welfare outcomes
- Life Satisfaction; A derived qualitative measure of a person's happiness with his life.
- Measure of economic welfare; is a measure of the level of prosperity and the standard of living of an individual or group of persons. Normally this is viewed as the part of social welfare that relates to economic activity.
- Genuine progress indicators; are metrics that are put forward to replace GDP as the main measure of economic growth

- Index of economic wellbeing; an economic indicator intended to replace the Gross Domestic Product, which is the main macroeconomic indicator of System of National Accounts. Rather than simply adding together all expenditures like the gross domestic product, consumer expenditure is indicated by such factors as income distribution and cost associated with pollution and other unsustainable costs. It is similar to the Genuine Progress Indicator in that there are many competing options.
- Human development index; is a mixed measure of life expectancy, education and income
- Index of social health; a measurement of relative health
- Quality of life index; a measure of which a country or city attempts to share information about health, safety and prosperous lives.
- Index of social progress; a measure of the extent that countries provide for the social and environmental needs of their citizens

3.4.4 Social Perception

The high occurrence of subjective measures in an area of research that is directly interfacing the highly objective world of engineering and the built environment provides the key challenge for both academic and industrial application. By way of example (Spalding 2015) asks us to perceive a coffee cup on our desk. Seeing the coffee cup is immediate and direct. We do not have to infer from sense data that there is a coffee cup on the desk, we simply see that there is a coffee cup there. Seeing involves unconscious computational processing (Dehaene et al 2014) light reflects off the object, the visual system detects surfaces and edges and constructs a three dimensional representation of the object. The claim that we directly perceive some objects does not deny that visual perception involves computational processing. Social Perception holds that we can see mental states with the same immediacy and directness that we see ordinary objects, like the coffee cup on the desk. We need not infer from the observation of a target's behaviour the existence of mental states. In some cases, we just see the mental states like we see the coffee cup on the desk. As described, Social Perception is ambiguous with respect to the seeing/seeing-that distinction (Dretske 1969). Simple seeing, also known as non-epistemic seeing, is possible for any creature with a functioning visual system. This type of seeing, also referred (Dretske 1969) as epistemic seeing, additionally requires conceptual capacity and capability. For example, an insect can see a tennis ball insofar as it can visually discriminate the tennis ball from other objects in the environment. However, the insect cannot see that the object is a tennis ball. To see that it is tennis ball requires that you have the concept of a "tennis ball", which the insect would lack. It is unclear whether Social Perception claims that we can see the target's mental state or we can see that the target has a mental state, e.g., whether we see an individual's emotions such as anger, or we see the individual is angry. Some Social Perception observers defend the idea that we epistemically see mental states, e.g., (McNeill 2012b) and (Gallagher 2008a). Others are less explicit but could be interpreted as suggesting that we non-epistemically see mental states, e.g., (Zahavi 2011). There is clearly no agreed view on this. The behavioural expression of anger can be seen, but it is an unanswered question whether we can see (epistemically or not) the anger itself. The view that we can see mental states ought to be interpreted as claiming that we can epistemically see mental states. Social Perception leads to the view that we can understand others' behaviour by attributing mental states to explain and predict their behaviour (De Jaegher 2009) and (Gallagher 2008a). Thus, Social Perception could be interpreted as claiming that we can epistemically see others' mental states through their behaviour.

This metaphysical commitment about what mental states are, distinguishes Social Perception from the more straightforward claim about theory-laden observation. Social perception is opposed to Inferentialism. According to Inferentialism as defined by MacFarlane (2009), recognition of mental states involves observing behaviour and inferring a mental state on the basis of that behaviour. Inferentialism and Social Perception are asymmetrical in their scope. Whereas Social Perception allows that recognition of some mental states in some circumstances this involves an inferential process. Inferentialism recognises mental states and always involves an inferential process. Newen (2015) offers one of the clearest accounts of direct perception of emotions and explicitly contrasts it with inference-based emotion recognition. The framework for distinguishing Social Perception from Inferentialism is very clear. Despite this the description fails to describe Social Perception from Inferentialism because it does not offer an adequate account of inferential processing. Newen (2015) discusses three ways of recognising an emotion. Though their account focuses on emotions, these distinctions apply to the recognition of all sorts of mental states.

- Direct perception without top-down processes
- Direct perception with top-down processes
- Inference-based recognition

A top-down process, according to Newen (2015) is a specific process involving activation of the brain, which necessarily is involved in the activation of a conceptual, complex cognitive process. Note that on this definition of top down process, an inference is a top-down process. In order to evaluate Social Perception, we need to clarify what an inference is (beyond a top-down process) and explain how to tell the difference between inferential and non-inferential processing. The question in need of an answer is how do we understand and identify the differences between the three approaches? According to the Newen (2015) account of how we directly perceive a mental state, the key to direct perception is to recognise a characteristic pattern of behaviour by establishing a stable perception.

- Bottom-up processes use sensory cues such as sight, smell and touch to form a sensory estimate.
- Relevant sensory cues are integrated in a way that binds together non-redundant features from different senses, systematically weighting redundant information to exclude irrelevant features.
- Relying on Bayesian principles to form a Maximum Likelihood Estimate, a stable percept is developed. (In statistical analysis the maximum likelihood estimate is a method for estimating the parameters of a statistical model, (Fisher 1912))
- Establishing the Maximum Likelihood Estimate can be influenced and constrained by top down processes in the following ways
    - Sensory input may trigger relevant conceptual background information that directly influences the process of searching for the most probable perception.
    - The percept can trigger a cognitive evaluation of the object that may influence the percept, modulating the focus of attention in that context.

This creates a framework for Social Perception that is part of perception that allows people to understand the other people or environments in their social world. This sort of perception is defined as a social cognition which is the ability of the brain to store and process information, (Smith & Mackie 2000). Social perception allows individuals to make judgments and impressions about other people or things. It is primarily based on observation, although pre-existing knowledge influences how we perceive an observation. New perceptions are then cumulative to the pre-existing knowledge and help form long term views.

Social perception gives individuals the tools to recognize how others affect their personal lives. They help individuals to form impressions of others by providing the necessary information about how people usually behave across situations. One method of explanation of how social perceptions provide information needed for impression formation is by approaching the behaviour with an implicit personality theory outlook. Delamate et al (2003) indicated that implicit personality theories state that if an individual observes certain traits in another person, s/he tends to assume that his or her other personality traits are concurrent with the initial trait. These assumptions help us to make quick judgments about the character of an individual or space. It also helps us to "categorise" things so that we can infer additional information about them and predict their behaviour.

Social perception refers to the initial stages in which people process information in order to determine another individual's mind-set and intentions, (Allison et al 2000). It is combined with the cognitive ability to pay attention to and interpret a range of different social factors that may include: verbal messages, tone, non-verbal behaviour, and knowledge of social relationships and an understanding of social goals, as well as environment. Social perception is a key component of social interaction and social skills. A key aspect of social interaction is the process of figuring out what others are thinking and feeling which is also referred to as Theory of Mind (ToM) otherwise referred to as empathy (Calarge et al 2003). These principles are complex and have taxed the minds of social scientists and psychologist for many years. The scope of this research does not extend to the theory of these issues but does recognise that a basic understanding must be established to enable useful understanding of the impacts and measurement options to ensure the best decisions are made at briefing and design stages. The review of the literature has shown that there are a very small number of measurement systems which address this space.

Social Perception is effected by cognitive bias, which is a pattern of deviation in judgment introduced by Kahneman & Frederick (2002), whereby inferences about other people and situations may be drawn in an irrational fashion. Individuals create their own "subjective social reality" from their perception of the input based on their existing knowledge and experience. An individual's construction of social reality, not the objective input, may dictate their behaviour in the social world. Thus, cognitive biases may sometimes lead to perceptual distortion, inaccurate judgment, illogical interpretation, or what is broadly called irrationality.

Kahneman & Frederick (2002) go on to identify that some cognitive biases are adaptive. Cognitive biases may lead to more effective actions in a given context. Furthermore, cognitive biases enable faster decisions when timeliness is more valuable than accuracy, as illustrated in heuristics which is a technique used to solve problems which employs practical methods, by way of example this may be drawing a picture to assist a verbal description of a problem to assist explanation. Other cognitive biases are a "by-product" of human processing limitations, resulting from a lack of appropriate mental mechanisms (bounded rationality), or simply from a limited capacity for information processing.

Bias arises from various processes that are sometimes difficult to distinguish. These include

- information-processing shortcuts, as defined practical approaches such as heuristics
- mental noise and other distractions including the chatter of the mind or the inner conversations that go on constantly in the mind
- the mind's limited information processing capacity, such as limitations on capacity and cognisance of other issues and noise that may be occupying capacity
- emotional and moral motivations, which are playing on the mind and promoting a change in cognitive bias
- social influence and peer pressure may impact the point of view and create deviations in bias

The notion of cognitive biases was introduced by Kahneman & Frederick (2002) and grew out of their experience of people's innumeracy, or inability to reason intuitively with the greater orders of magnitude. Kahneman & Frederick (2002) and colleagues demonstrated several replicable ways in which human judgments and decisions differ from rational choice theory. Kahneman & Frederick (2002) explained human differences in judgement and decision making in terms of heuristics. Heuristics involve mental shortcuts which provide swift estimates about the possibility of uncertain occurrences (Baumeister & Bushman 2010). Heuristics are simple for the brain to compute but sometimes introduce "severe and systematic errors" (Tversky & Kahneman 1974), however depending upon circumstances these may or may not be acceptable. For example, the representativeness heuristic is defined as the tendency to "judge the frequency or likelihood" of an occurrence by the extent of which the event "resembles the typical case" (Baumeister & Bushman 2010). Alternatively, critics of Kahneman & Frederick (2002) such as Gigerenzer & Brighton (2009) argue that "heuristics should not lead us to conceive of human thinking as riddled with irrational cognitive biases, but rather to conceive rationality as an adaptive tool that is not identical to the rules of formal logic or the probability calculus."

3.4.5 Creating Physical Actions from Perceptive Influences

The understanding of Social Perceptions is but a first step in using perceived information to identify and create an "actionable" outcome. Argyris (1982) was one of the early researchers of organisational behavior and he observed how Social Perception influenced how executives behaved in large organisations, especially in the management of difficult people of technical issues and how these situations could lead to counterproductive situations. He observed the following phenomena;

- Executives used flawed reasoning to manage people and technical issues which lead to unpredictable outcomes
- The executives are unaware of this issue as they are disconnected from their own reasoning processes whilst making tough decisions
- The reason they are disconnected from these processes is because of the skills such as planning, scheduling, structures and accounting they have learned to solve complex problems also lead them to failure

This may sound counterintuitive until he explains that the nested paradoxes he has identified indicate that we are attempting to understand deeply embedded features of the human mind including Social Perception. It is useful that Argyris (1982) uses the example of the executive (or leadership) mind as he points out these are the individuals who are responsible for dealing with difficult issues, creating premises, making inferences and arriving at conclusions in organisations and society at large. His definition of executive was developed by his observations on how executives make inferences (through perception) and arrive at conclusions. The two reasons he cites are "they have good reasoning skills and when they make errors other people, especially subordinates, tend to play down the error". This phenomenon is often witnessed when decisions are made by boards where low levels of awareness for engagement with the lower levels of the organisations through arrogance or poor perception which leads to poor decisions.

The impact of poor leadership reflects into a business or community and can lead to unexpected outcomes. These outcomes can be identified as self-fulfilling prophesies or unexpected consequences but are more practically observed as organisations that fail to learn or develop with changing and emerging markets. This was discussed by Argyris (2002) where he identified two types of learning. "Learning may be defined as the detection and correction of error. Single-Loop learning occurs when errors are corrected without altering the underlying governing values". For example, a thermostat is programmed to turn on if the temperature in the room is cold, or turn off the heat if the room becomes too hot. Double-loop learning occurs when errors are corrected by changing the governing values and then the actions. A thermostat is double-loop learning if it questions why it is programmed to measure temperature, and then adjusts the temperature itself. This in two key steps provides us with a link between perceived observations and the use of this information to make or create actions to improve the performance of a system (In this case a systems controlling temperature) or more commonly named "feedback".

Argyris (1982) developed these principles and from this review of the literature appears to be the only researcher who has made significant observations in this area. The process in Figure 3.1 summarises his approach of defining a set of governing variables with which to accurately measure, defining appropriate actions strategies from the information being gathered from the variable and then measuring the outcomes through the variables to return to the beginning of the loop again. This is developed further in Chapter Four.

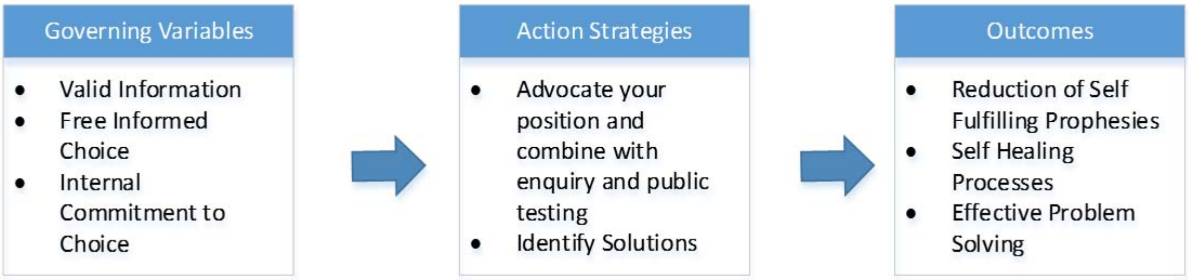


Figure 3.1 - Action Planning Based Feedback, adapted from Argyris (1982)

3.5 Measurement Tools

As we have identified above there are numerous methods of looking at social outcomes, asset performance and the perceptions between the two, so it should be of little surprise with such a complex environment that there are many methods of measurement available to select. Some have been developed for use at the generic human level and some are highly sector specific and have been developed with specific activities in mind. In the paper published by the Social Impact Investment Task group set up under the auspices of the G8 a working group member is quoted as saying "We have come a long way, but there is limited convergence around a common set of impact measurement practices." The literature identifies a number of reviews of tools which have been carried with one carried out by the Building Research Establishment BRE (2006) being the most recent UK based investigation. For the purposes of this review some of these UK approaches have been compared to a number of international tools by way of comparison. During the review it was observed that the tools evaluated fell into the following categories:

- Urban Planning (Overall Regional and Town Planning for Political and Social Benefit)
- Design (The detailed process of documenting design intent and requirements)
- Rating Systems for Buildings (Asset categorisation models)
- Lifecycle Assessment (LCA) (Methods of understanding lifecycle asset performance)
- Social and Perception derived issues (as defined above)
- Environmental (Methods of measuring environmental aspects)

- Fiscal/Economic (Methods of measuring fiscal and economic aspects)

The Lifecycle Assessment (LCA) tools did not address social aspects and none were holistic with regard to the three dimensions of sustainability in their approach:

i. Options and Types (There was a low level of measurement type consistency and as such relative comparisons are difficult and often meaningless)
ii. Selection Process and Rationale (The selection process is poorly documented and lacks consistency)
iii. Issues and Constraints (Unexpected results are poorly explained or categorised)

3.5.1 Current State of the Art for Measurement and Feedback

The current state of the art in the definition of measures, indicators and tools is wide, there is a large range of specialist tools being used in isolation by different users to answer different questions, ranging from environmental measures such as temperature or light through to wider impacts and social measures. The BRE developed BREEAM tool continues to be a leading UK approach with tools and methods closely regulated and controlled offering a very large base of data to analyse. A number of tools and measures have extended the capability of BREEAM including LEED in the US. They have had some penetration into the economic measures but little into social issues, preferring to focus on environmental issues. Most tools have focused on the built environment not infrastructure with the notable exception of CEEQUAL, but this also fails to consider social issues. Infrastructure however does appear to be better approached at the briefing stage than buildings with several large schemes having wide scope environmental and social definitions, such as that evidenced by the TfL (2008) Cross Rail example. There appears to be minimal post-delivery measurement to establish outcome performance and certainly no evidence of systematic use of feedback data to improve the quality of the brief.

Table 3.2 summarises a selection of tools in common use in the UK market covering both buildings and infrastructure assets., The list is not exhaustive but covers the ones with the majority of the UK market and has at least some acknowledgement to the issues of social wellbeing and outcomes. A brief overview and a commentary on the positive and negative aspects of each of the tools is included.

Table 3.2 - UK Measurement Tools and Analysis Summary

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
1	BREEAM	Environmental	BSRIA	Large amount of data now available to provide base for analysis	Only used for buildings and mainly focuses on environmental issues at the expense of social issues	
2	CEEQUAL	Environmental	CEEQUAL	Focused on infrastructure only	Significantly less data and history compared to BREEAM	Products and methodologies have recently (2015) been divested to BRE to be integrated into BREEAM
3	TM22	Environmental	CIBSE	Recent UK and European initiatives mean that the benefits of performance assessment are being backed by legislation. TM22 and its software provides support for these assessment needs.	No social aspects are catered for with this application	A method for assessing the energy performance of an occupied building based on metered energy use includes a software implementation of the method. While primarily directed at assessing energy performance, the procedure has a wide range of uses for building managers, design professionals, and energy management specialists contributing to the 'virtuous circle' of good building management and satisfied occupants

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
4	Leaman	Social & Workplace	Leaman	Very people and outcomes centric	Over focused on environmental factors and trying to fix a broken market. Little publically available data to evaluate outside the Probe project	The BUS methodology has been created from thirty years of continuous development in building use studies for post occupancy evaluation. The method was developed and refined during the 1990's when it was used for the seminal series of government funded PROBE building performance evaluation studies regularly published in the industry press. It has been used on the Carbon Trust's Low Carbon Accelerator and Low Carbon Building Programme and also on the Technology Strategy Board's Building Performance Evaluation programme.
5	Carbon Buzz	Environmental	RIBA	Good amount of data now being collected which is statistically significant enough to identify trends across multiple assets	Focused on CO2 and environmental issues not on social considerations or their impacts. Not required by legislation so data capture is	Carbon Buzz is an RIBA CIBSE platform for benchmarking and tracking energy use in projects from design to operation. It is intended to encourage users to go beyond compliance of

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
					only patchy Buildings only covered	mandatory Building Regulations calculations and refine estimates to account for additional energy loads in-use. The platform allows users to compare design energy use with actual energy use side by side to help users close the design and operational energy performance gap in buildings
6	Usable Buildings (BUS)	Social & Workplace	UBL	See Leaman comments	See Leaman comments	
7	SOFI	Social Perception	SOFI Inc	Very complete measurement view based on entire community perceptions of wellbeing and relationships. Can be configured to any shape community. Based on published research	No relationship to built environment or spaces other than through configuration of palate. SOFI are now developing extensions to the built environment with a new interface Table.	Very configurable toolset enabling extensions and application to many scenarios
8	The Awareness of Social Inference Test (TASIT)	Healthcare Derived	TASIT	Very much focused on the ability to measure and understand human interaction and perception through a structured measurement methodology	Very specific to human measurement with no environment al or spatial consideration s	The Awareness of Social Inference Test (TASIT) is an audio visual tool designed for the clinical assessment of social perception with alternate forms for re-testing. Part 1 assesses emotion recognition, Parts

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
						2 and 3 assess the ability to interpret conversational remarks meant literally (i.e., sincere remarks and lies) or non-literally (i.e., sarcasm) as well as the ability to make judgments about the thoughts, intentions and feelings of speakers.
9	AMA Work ware	Social & Workplace	A Marmot	Focused on the occupancy of built assets mainly on offices and academic institutions.	Little understanding of how the asset is configured just utilized and no understanding of how that asset performs to its brief.	AMA Work Ware is a toolkit of quantitative and qualitative methodologies invented and developed by AMA and now used around the world. It delivers – effectively and economically – evidence on how buildings are really used, combining building measurement and the best social science techniques. An extensive database drawn from 60,000 people in over 250 office buildings provides benchmarks for individual projects and reports on sector trends.
10	Whole Building Functionality &	All	ASTMS		No UK based coverage or datasets	ASTM Standards for Whole Building Functionality and

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
	Serviceability				Generic cross industry tools	Serviceability is an American resource for building occupants; facility managers; corporate real estate executives; business unit senior managers; federal, state and local government agencies; professional and trade associations; design professionals and consulting firms; and universities.
11	Design Quality Method (DQM)	All	BRE	Broad multi-disciplinary scope	Focuses on an undefined design quality index rather than attempts to create objective actions based on outcomes	The DQM assesses design quality, building performance feedback and operational efficiency in a quick and economical fashion - using expert opinion; professional judgement; user opinion; and scientific measurement. The DQM database includes over a hundred buildings, evaluated over the past decade, to form industry benchmarks for all building types and portfolios.
12	Design Quality Indicators (DQI)	All	CIC		Low number of users over last decade may indicate poor or unreliable results.	DQI is a facilitated process. It takes the form of structured workshops and is supported by a bespoke

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
					Not based on scientific research or principles Design input rather than user outcomes lead	evaluation model and an expert from the Industry.
13	DQI for Schools	All	CIC		See DQI	See DQI
14	Healthcare Design Quality Assessment	All	EHPN	Primary experience is in the evaluation of healthcare buildings, but more recently is under adaptation for use in all sectors including urban design and public space. Entered a second phase of development in 2006 for use in a study of radiotherapy environments for the UK Department of Health. Added a feed forward dimension in a study to support the design development of a new Neonatal Intensive Care Unit in 2009 for Feilden Clegg Bradley Studios, UK	There are no results in the public domain to evaluate There is no accreditation system There are no sTable benchmarks	A European Health Property Network funded project to develop a triangulated study technique initially designed for the analysis of design quality in healthcare buildings but now being developed for use in all areas of the built environment. Emphasis is on creating a better understanding of healthcare provision as related to socio-cultural context. The approach comprises an on-site case study with walk-through, questionnaires, structured interviews, diaries, overnight stay in the building are some potential modules of the study, but characteristics of the study are project specific. Each study

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
						undertaken responds to the needs of the brief to define the appropriate methodology and determine which techniques to use. This approach is necessary in order to uncover and explain the relationship between care model, context and built response, and how this impacts on design quality.
15	Higher Education Design Forum	All	RIBA	Raises awareness of interesting and innovative practice	A subjective judging panel type approach with low repeatability	The RIBA's Higher Education Design Quality Forum (HEDQF) is a unique partnership between higher education clients and design professionals. Its aim is to improve the performance of higher education buildings and estates.
16	Learning from Experience	Social & Workplace	DBA		Information dissemination only	This was a research project involving 10 design led organisations. Useful observations re information dissemination but otherwise not suitable for actually evaluating an assets performance or understanding social outcomes
17	NHS	Environmental	BRE	See BREEAM	See BREEAM	NEAT was the

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
	Environment Assessment					NHS Environmental Assessment Tool, developed in 2002 by BRE on behalf of the NHS Estate (for use in England and Wales). It was a self-assessment tool to establish the environmental performance of healthcare buildings, both new build and existing buildings in operation. Since the 1st of July 2008, NEAT was superseded by BREEAM Healthcare 2008 and more recently BREEAM New Construction 2011 which incorporates Healthcare building types, and is no longer available to download.
18	Overall Liking Score	Social & Workplace	Manchester University	Good for evaluating the performance of an occupied building to better understand occupant needs. It can be helpful when considering refurbishment or relocation options as well as providing before and after benchmarks to measure improvements	Based on a simpler "likeness" measure which doesn't understand which part of the asset is being used or the impact of the wider community The main user (ABS) of the process doesn't publish the results for analysis	An occupant survey method that measures how people feel about their work environment. It consists of the Overall Liking Score occupant survey, the Overall Liking Score fingerprint and a report with analysis of results and recommendation.

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
				Approach is reasonably mature with over 100 assets reviewed since 1992		
19	POE in Year 1	All	BRE	Does cater for key environmental considerations	No formal methodology for gathering occupancy outcomes or linking to spaces or the wider community No link between occupancy and brief to enable root cause analysis	Post-Occupancy Evaluation (POE) is the process of obtaining feedback on a building's performance in use. The value of POE is being increasingly recognised, and it is becoming mandatory on many public projects. POE is valuable in all construction sectors, especially healthcare, education, offices, commercial and housing, where poor building performance will impact on running costs, occupant well-being and business efficiency.
20	Dundee University POE	All	Dundee	See above	See above	Now using BRE approach
21	Post Occupancy review of Buildings and their Engineering (PROBE)	All	CIBSE	Sound focus on engineering and environmental aspects of the asset, the project used TM22 (see above)	Makes use of BUS tools for social aspects The approach doesn't seem to have moved	PROBE was a research project which ran from 1995-2002 under the Partners in Innovation scheme (jointly funded by the UK Government. It was carried out by Energy for Sustainable Development,

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
						William Bordass Associates, Building Use Studies and Target Energy Services.
22	(HMG) Soft Landings	All	HMG/BSi	Now embedded in a British Standard to enable contractual referencing	Little in the way of formal understanding or management of social outcomes and issues, no measurement system, for the same	1. The Government identified the following key points of the GSL Policy 2. GSL will be used to reduce cost and improve performance of asset delivery and operation. 3. All departments will appoint a GSL Lead to manage the GSL Golden Thread on all projects. 4. All departments will actively manage aftercare during early operations, supported by the design and construction team. 5. Post Operational Evaluation will be used as a collaborative tool to measure and optimise asset performance and embed lessons learnt. 6. BIM will be

Ref	Title	Domain	Owner	Pros	Cons	Observations / Notes
						progressively used as a data management tool to assist the briefing process
23	Wellbeing Index	Social	UN	Compares 180 nations levels of well being	Doesn't relate to community or space	Country scale developed from an approach by the World Conservancy Union, considers human wellbeing, eco systems, wellbeing and stress indices
24	LEED	Environmental	LEED	Very widespread use Independent third party validation	Lack of social outcome measures relating to community and space	Leadership in Energy and Environmental Design (LEED) is one of the most popular green building certification programs used worldwide. Devel oped by the non-profit U.S. Green Building Council (USGBC) it includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighbourhoods that aims to help building owners and operators be environmentally responsible and use resources efficiently.

3.5.2 Selecting Appropriate Social Perception Methods

From the observations in Table 3.2 it can be seen how diverse the approach to measurement of social wellbeing, outcomes and social perception is. It is by far the least well developed and used of all the tools considered in this research. According to Argyris (2002) the combination of physical and neuro-scientific “perception” simulation has also been used in other industries where the combination of many variables and the perception of human behaviour serves to present a complex scenario. During the review of these characteristics only two approaches were identified as being of sufficient rigor with respect to social measurement. Neither approach has been specifically developed for use in the built environment but both have good references with respect to use in the assessment and measurement of social condition, with the multi community aspects of the SOFI approach described by Cousins (1986) and Cousins & Downs (2009) being particularly relevant to the often complex mix of community structure commonly found in the built environment. The approach described by TACIT (2015) and McDonald (2006) is a commercial tool set which is very much focused on the ability to measure and understand human interaction and perception through a structured measurement methodology. The Awareness of Social Inference Test (TASIT) is an audio-visual tool designed for the clinical assessment of social perception with alternate forms for re-testing. Part 1 assesses emotion recognition, Parts 2 and 3 assess the ability to interpret conversational remarks meant literally (i.e., sincere remarks and lies) or non-literally (i.e., sarcasm) as well as the ability to make judgments about the thoughts, intentions and feelings of speakers.

Both of these approaches are characterised by coming from the neural physics and social perception and interaction domain, rather than from the physical built asset or operations activities. This indicates that all the other models reviewed in the literature appeared to have addressed the issue from the point of view of the constructional and built environment markets and have failed to address the fundamental issues of providing adequate solutions to the challenges of understanding society and personal perceptions.

3.5.2.1 The Spheres of Influence Model

The work discussed above of Argyris (2002) has led to further research into how the principles of double loop and social perception can be applied to the operation of organisations and their communities. Cousins (1986) and Cousins & Downs (2002) through post graduate research have developed the Spheres of Influence Models (SOFI) system. This approach starts with a configurable template organisation bound by eleven necessary and sufficient elements arranged as spheres. They have identified that the interconnectedness of these spheres can show the quality or health of a community or organisation. The detailed function of these spheres is described below and is supported by many long and detailed conversations with Phillip Cousins and Diane Downs (P Cousins, D Downs, personal communications, 9/13 – 5/16)

According to Brown (2010, 2015) "the eleven necessary and sufficient Spheres are held together at the centre of the model by Culture and the Development of people and processes. 'Culture' expresses what in the brain is called implicit memory - the central reference points that determine actions and to which the basic emotions are profoundly attached. 'Development' of people addresses the individual's relationship with their self - crucial in the process of 'me becoming who I am" and how I fit in my community. The SOFI Logic System derived from this work is an organisational model that is underpinned by some experimental rigour - exemplified by a reductionist semantic analysis of the following criteria;

- It is an exemplary model for the way that the issue of 'What is an organisation?' as described by Osgood (1957) and as his colleagues demonstrated in The Measurement of Meaning. The specific focus of the work cited by Brown (2010, 2015) is that SOFI was implemented as digital feedback process for in service assets covering the measures of social outcomes.
- Might be tackled so that this aspect of organisational theory might rest upon well-tried experimental rigour rather than, as is usually the case, untried sociological analysis.
- The method is subjected to rigorous experimental enquiry.

Thus the existence of a whole-system organisational model that might itself be systematically subjected to scientific verification plus a developing science about the person-of-the-brain, begins to create the possibility of a unified theory of the individual and the organisation. Both come together around a theory of mind that proposes information, energy and relationship as the key components of mind; which is itself a special product of the way the human brain organises itself. The model of mind as shown in Figure 3.2 below, developed by the interpersonal neurobiologist Siegel (1999), describes a basic working model of both the individual and the organisation, where energy is defined by the quality or quantum of the relationships between the spheres.

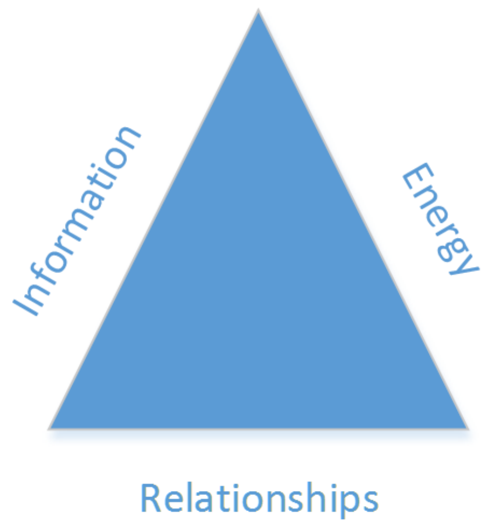


Figure 3.2 - Key Functions of the Mind (Adapted from Siegel 1999)

Figure 3.3 shows the outline definition of the SOFI model and its eleven elements. In practical application this is operated through a 66-item questionnaire in which the statements are specific to whatever organisational or community is under consideration (the 'focal point' question). The model is configurable and allows any community or question to be modelled. This allows SOFI to be used across domains for the real time analysis of relationships dynamics and interaction effects (influences) by simultaneous analysis of qualitative and quantitative data sources.

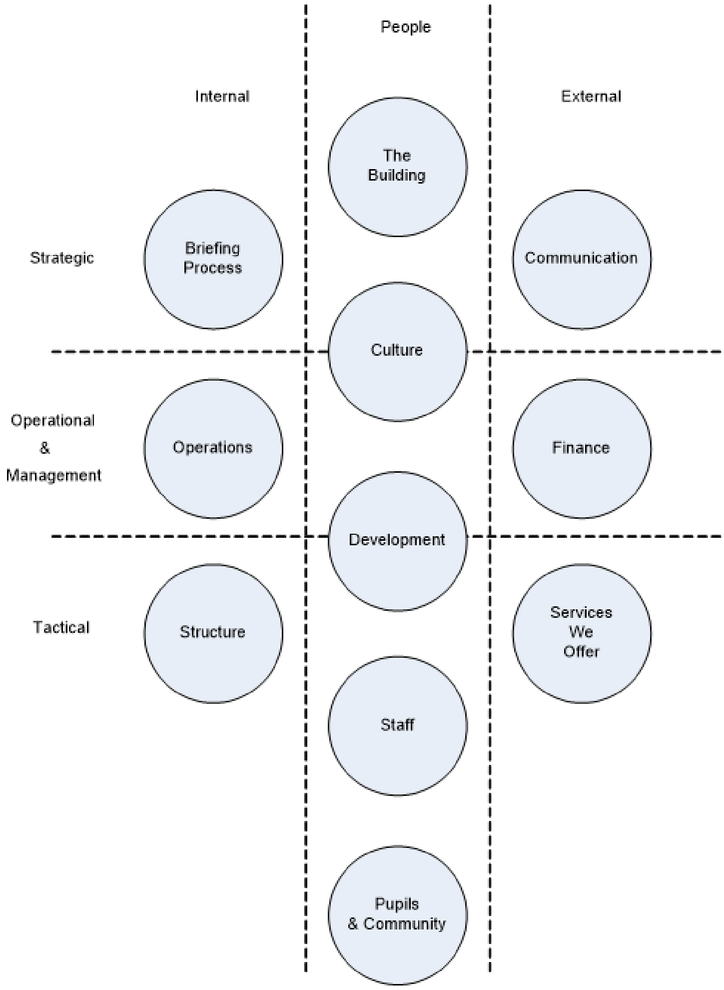


Figure 3.3 - Elemental structure of an Organisation or Community as modelled by SOFI

The interconnectedness between the Spheres is determined heuristically by the agreement of respondents with the survey statements. This agreement can be mapped by links between the Spheres that show where energy (functional interconnectedness of the parts) is flowing and, through the absence of links, where the system is blocked. An overall 'Diagnostic' facility is established by each individual allocating traffic light colours - red, amber and green, defining the quantum of the relationship. The system displays the results via the traffic light dashboard providing a very insightful map of the communities' condition and relationships. The system allows for a series of "worlds" to be defined enabling the comparison of communities either with other datasets or to enable a time element to be mapped, giving visibility as to how communities develop over time. This multi-world view has the potential to enable an analytical relationship to be created between the community world and the building physics through careful development of questions and relationships and forming a double loop in the terms of the Argyris (2002) work between the community and the building physics enabling both to learn from each other and ultimately providing the analytical data to create an "actionable" item or an adjustment to the project brief or the way the users occupy and use the asset.

The results of this approach indicate that perception could be measured and there was a reliable perceptible difference depending upon the scenarios. However, the system is highly configurable which is both a strength and a necessary condition when it comes to providing a reliable and repeatable set of data to analyse, not only through the cross section of an asset or community, but across many assets or services and over a long period of time. The approach does differ from the TASIT approach in that it can be linked to different parts of the community and this may be an essential capability as a deeper understanding emerges of how the community perceives each part of the buildings or assets they occupy. It further defines eleven core activities to measure social impacts in a double loop learning system that facilitates testing of single loop systems such as building physics data. The adaptive design allows us to configure the system to interface with apply data set, enabling a double loop learning function in the Test Bench.

3.5.2.2 The Awareness of Social Inference Test (TASIT)

The second model reviewed was TASIT (The Awareness of Social Inference Test) (McDonald 2006) and (TACIT 2015). TACIT is an audio-visual test that was created for the clinical assessment of social perception. The test is based upon several critical components of social perception that are critical to social competence using complex, dynamic, visual, and auditory cues to assess these critical components. The test assesses the ability to identify emotions, a skill that is impaired in many clinical conditions. It also assesses the ability to judge what an individual maybe thinking or what their intentions are for the other person in the conversation, also referred to as Theory of Mind. Lastly, the test was developed to assess the ability to differentiate between literal and non-literal conversational remarks. The test is divided into three parts to measure; human personal emotion, social inference – minimal, and social inference enriched. The test is composed of scenes, or scenarios, and those being assessed are asked to identify the emotions, feelings, beliefs, intentions, and meanings of the interactions. The results of this testing assess the level of social perception of an individual. The TACIT (2015) and McDonald (2006) literature cites that TASIT has adequate psychometric properties as a clinical test of social perception. It is not overly susceptible to outside effects and is reliable on a repeat basis. The approach comprises of three parts;

Part 1: The Emotion Evaluation Test (EET) comprised 28 scenarios in which an actor portrays one of seven basic emotional states (happy, sad, fearful, disgusted, surprised, angry, neutral). In each scenario the actor is either engaged in an interaction without dialogue (e.g., listening on the phone with the occasional ‘comment) or with dialogue using a script that is ambiguous and can therefore be interpreted in a number of ways. The ability to correctly recognise emotional expression was assessed by asking subjects to decide which of the basic seven categories each emotional expression represented.

Part 2: Social Inference – Minimal (SI-M) comprised 15 scenarios that represented dialogues between two actors, e.g. a woman complimenting a co-worker on all the hard work he has done. In five scenarios, the exchange was sincerely meant. In another five scenarios, similar scripts were enacted sarcastically, e.g. in a sarcastic version of the above example the woman is clearly angry with her co-worker and while on the surface she is complimenting him, she is, in fact, implying that he has done very little. In the remaining five scenarios, the scripts were literally paradoxical, i.e. they could only make sense if it was understood that one person was being sarcastic. After viewing each vignette participants were required to answer questions regarding the speaker’s (i) feelings, (ii) beliefs, (iii) intentions and (iv) meaning. The questions in each scenario were carefully worded to be simple to understand and to avoid recursive, doubly embedded phrases.

Part 3: Social Inference – Enriched (SI-E) comprised 16 scenarios that provided additional information before or after the dialogue of interest to ‘‘set the scene’’. For example, two co-workers confide to each other that a party at the weekend was truly dreadful. This was followed by a scene with the host of the party in which they claim the party was a great success. In half of the scenarios, the scripts were enacted as a diplomatic lie, trying to make the best of a bad situation. In the remainder, they were enacted sarcastically.

The results of this work indicated that perception could be measured and there was a reliable perceptible difference depending upon the scenarios. However, the tests are not standard clinical measures and there is no normative data with which to compare performances. The team indicate that TASIT is a new test and they consider that neuropsychology is an emerging domain in its own right. They agree that Social perception is a critical area to understand rehabilitation and other environmental influencers. They conclude that "TASIT appears to have adequate psychometric properties that make it satisfactory as a clinical test for assessing social perception. It is not overly prone to practice effects and produces reliable and valid data for the Awareness of Social Inference Test scores on repeat administrations. The test is sensitive to social perception deficits after brain injury. Although the construct validity results suggest that performance on TASIT will be affected by deficits in information processing speed, working memory, new learning and executive functioning, the uniquely social material that comprises the stimuli for TASIT will provide useful insights into the particular difficulties people with clinical conditions experience when interpreting complex social phenomena."

The results cited by McDonald (2006) are of interest as they provide a framework of individual and group involvement through the process of providing scenarios to provide context. It would be interesting to understand how these synthesised scenarios could be exchanged by the established "Soft Landings" processes used in construction and what the relative differential in outcomes would become.

3.5.2.2 Critical Contrast

There are many assessment methodologies and only those with a significant physical, environmental or combination of physical and neuro-scientific "perception" simulation criteria have been reviewed in detail. All of the other approaches failed to adequately understand the human perceptive elements and, further to this, fail to allow adequate relationships to be built with specific spaces that people inhabit and interact. The methods listed in Table 3.2 are a full cross section of the available tools and based on the work of Argyris (2002) only two attempt to fully understand the reasons for the social perceptions, where the perceptions are physically derived and the types of potential interventions that can be made to make dramatic improvement.

3.6 Summary

Having conducted a detailed review of methods, constraints and implementation of the measurement of social perception and outcomes it is clear that this is a complex and dynamic domain. The measures which are commonly used are distorted and misused by many for political ends, providing unclear information and confusion. It is clearly tempting to follow the common approach and relate wellbeing to relative wealth but the evidence cited here clearly breaks the myth that happiness is entirely driven through relative wealth.

The literature has shown that the construction industry has attempted to measure the social performance of their products and services and have failed to address the issue of understanding how the users of their products and services actually operate on a day to day basis and what makes built environments actually function effectively in terms of delivering good social outcomes for users. This is due to two factors, firstly, the lack of any such objective measurement approach which is categorically supported by evidence and underwritten through third party accreditation. Secondly there is a lack of a body of evidence demonstrating relative performance.

Having identified the quantitative criteria of the physical built asset and the qualitative definition of the world as socially perceived the next Chapter identifies opportunities for integrating and comparing the two data types and providing value enhancing composite viewing methods to provide new insights into asset performance.

Chapter 4

Building a Relationship Between Humans, Society & the Built Environment

4.1 Introduction

The purpose of this Chapter is to provide a synthesis of the research presented in Chapters two and three describing the areas of asset delivery and measurement of social perception, outcomes and impacts. From this synthesis then to identify how these synergies could be exploited through combining the two data sources to provide new insights into the provision of assets that more effectively deliver desirable outcomes.

4.2 Background

The scope of this research is wide and complex especially in the case of forming synergies between a measured dataset in the physical environment which is objective and quantitative, being compared and analysed alongside a subjective, qualitative dataset derived from users and human interaction.

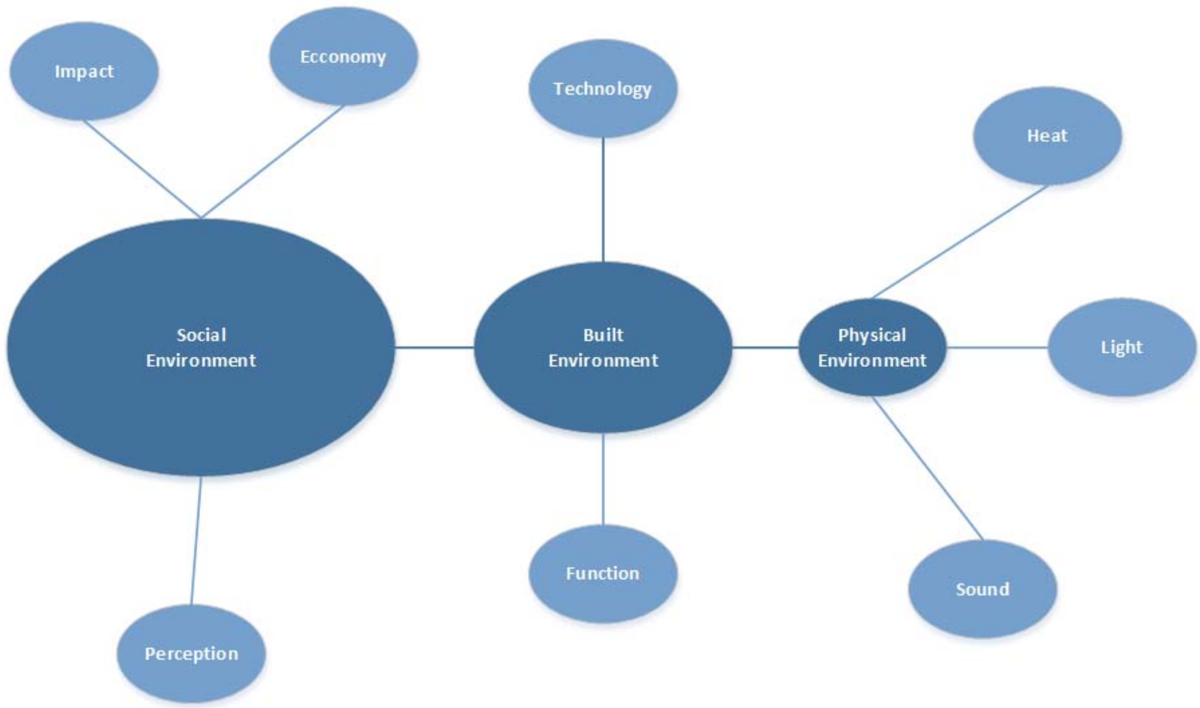


Figure 4.1 - Hierarchy of Parameters that can be influenced. Adapted from Oral et al (2003)

There is much literature covering both these domains, but virtually none which specifically brings the two together other than rather rudimentary tools such as BREEAM and LEED which are described below.

To articulate this relationship Figure 4.1 indicates how Oral et al (2003) defined the building envelope as the elements which separate the indoor environment of the building from the outdoor environment., This is a useful view on how each in scope measureable can be seen to relate. This is further supported by the BCES Report (BCES 2012) which uses the concept of “enabling factors” such as “light, temperature, comfort, build quality, acoustics and air quality”. This approach is described more fully in Chapter 2. They also go on to say the building envelope is designed with respect to various determinants such as environmental, technological, social-cultural etc. and offer an approach to how an emergent design can take account of all of the physical factors to deliver an effective product. However, after identifying social-cultural as an influencing factor they fail to describe its relationship of effect. Barrett et al (2012) took this approach further looking at the micro view of the impact of classroom design on pupil’s learning. However, this took little account of influences outside of the class room - the impact of staff and resources and the relationship of these on each other and how they need to be considered in the process of delivering a well ordered and functioning asset. Abbas et al (2009) further developed the relationship between the physical environment (in schools), with a study of pupil behaviours in well and poorly defined teaching environments. This involved the analysis of the relationship between internal physical environments of the classroom located in both urban and non-urban areas and the types of behaviours students engaged in interactive, non-interactive, appropriate, inappropriate and neutral. Abbas et al (2009) concluded that "prosocial interaction (cooperative play and social conversation) improved in well defend and specified teaching spaces with respect to those which were defined as not so well defined". They further discovered that this held true in a number of geographical and social settings.

4.3 The Problem

To ensure clarity for the point of departure for this research the main problems identified during the literature review are synthesised as: there are no functional links between social outcomes or the asset provision process. Kiviniemi (2005) spoke of the difficulties of the basic design process and the issue of poor connection with requirements and design documentation, the impact of personnel and contractual changes during the lifecycle and the divergence of direct and indirect requirements on the project. The methods of measurement are very elementary and only just starting to emerge. The work of the British and European CEN standards which were introduced in Chapter three is far less detailed than similar environmental documentation provided in the same series of documents. They fail to address retrofitting, linear structures, civil engineering and the interdependencies between each (Collins 2010). This is not helped by the current planning process which has limited ability to manage the dependencies and interdependencies of assets and infrastructure on each other and fails to quantitatively measure the impact of social outcomes as described in the (IUK Report 2011) and (Planning Portal 2011).

There is an ongoing theme of poor and inadequate briefing of the design team by the client. This is not new as supported by NEDO (1974), Latham (1994), Kelley et al (1992), Murray (1996) and Bowen et al (1999). All support the view that the brief is one of the most critical factors in determining a client's satisfaction with a building project. Briefing is operated as a linear process which stops too early in the delivery process. It does not gather data in a structured way to enable automated reuse and is often executed by resources poorly placed to make key decisions. Kiviniemi (2005) and Hibberd et al (1995) reiterate the iterative process and the critical balance of client need, technical characteristics, performance, quality, cost and programme. They also point to the fact that briefing data is often unstructured and is unable to be reused in the way that building geometry data can be reused for example. Designers make substantial assumptions. The impact of these decisions are documented by Brown (2001) and Nutt (1988, p130) where the impact is explained in terms of irreversibility – reversibility and again in terms of effort against effect by Patrick McLeamy in the “McLeamy Curve” during the design process, where he suggests that the design process should be pulled forward in the delivery process to improve certainty of outcome. These assumptions are founded in a lack of adequate briefing information and understanding as to how the facility will be used and the poor methods employed by design teams as described by Kiviniemi (2005). There is however some evidence of some high level social issues being considered in large public sector programmes. For example, in the Crossrail Business Case, (TFL 2008) a definition of a number of modelling techniques appears, including those relating to social outcomes such as social inclusion, environmental issues, noise and impact of differing transport modes on different social economic classes. Yet there remains no single measure which adequately defines all aspects.

There are many tools for social wellbeing analysis and measurement but no one toolset has emerged as the de facto approach. Therivel et al (2004) concluded that there are plenty of existing metrics models and toolkits, but they did not seem to be converging. She further suggests that there is little consensus on what “social issues” are and that there was some contention surrounding what significant social impacts may comprise, especially with respect to environmental and economic. Another issue raised was the concept of intergenerational equity, which she argued, was poorly understood and could be distorted with environmental matters, which can impact on social issues over time through unforeseen circumstances. This included the impact of unemployment and poor accommodation and the phenomena of second and third generation unemployment on families and societies. From a social outcomes point of view there is no agreed method of measurement that is clear in the literature or assessment toolkit that has been adopted as a clear or de facto standard. This is further complicated by the lack of a clear understanding as to the impact of perceptions on the overall measurement process.

In the area of environmental and economic sustainability, where sophisticated asset control systems are provided, they can cause 'information overload' for facility managers. Surveys abstracted by Bacon (2011) have shown that alarms on controls are not understood and so they are often deactivated. This leads to a degradation of building performance and its impact on its users. However, Crosbie et al (2009) suggest that integrating ICT systems used to assess the design and operation of buildings could significantly improve the way in which the performance of buildings is assessed. They additionally point to the barriers to achieving such a scenario due in the main to slow uptake of such technologies. The literature does not as yet give any indication of digital feedback process for in service assets covering any measures relating to Social Outcomes. However, there are many referencing the emergence of economic and environmental, such as Crosbie et al (2009) and Ahmed et al (2010). The concept of continuous commissioning is discussed by Ahmed et al (2010) and this work is of interest in that it gathers data regarding performance, but draws few conclusions as to what use this data should be put.

The literature has shown that there is a poor history of post-occupancy review. There is little quality data in the public domain. Guidance has to be drawn from what is often highly aggregated data and while there are some financial and environmental data, social outcomes are not well documented. Feinstein et al (2008) references the need for this approach to be longer term, with many impacts, especially in housing, running through a number of generations. There is no evidence of major projects publishing them in service social performance and little evidence according to Whyte et al (2010) of any data being passed from delivery to operational stages with any notable success. All operational data seems to be collected post occupancy within separate processes. However, Whyte et al (2010) and the public sector BIM Strategy, HMG BIM Task Group (2010) Building Information Modelling and Management (BIM (M)) indicate a wider belief that significant benefits are likely if this relationship was wider adopted.

Araya et al (2006) concluded that there is little empirical evidence regarding the association of social and built environments and health. They go on to state that social and built environments are best seen as contextual concepts that are developed from an aggregation of other inputs such as perception, trust or the desirability to occupy a certain area. The results showed significant (up to a third) and it is suggested that the impact of perception played a large part.

This variability in results due to perception bias indicates a need to include perception measures in any dataset. Both the SOFI and TACIT toolsets are derivations of tools designed for other domains and as such require additional functionality of configuration to capture the essence of the perceived social impact and building physics. Rossi & Berglund (2011) have further investigated the process of the measurement of human perception and interpretation, they identified that physicists and engineers should perhaps be more open to accept that measurement may also be performed with a person as a measuring instrument although, obviously, in properly designed and conducted experiments. They reflect that this is somewhat foreign to the traditional view which often considers ‘‘objectivity’’ to be a prerequisite in parity with the absence of human intervention. There is clearly some ambiguity in this area and they call for a number of areas of research to be pursued.

4.3 Practical Impacts

Hitchcock et al (1998) describes how buildings consistently fail to meet client’s aspirations. They are led to believe that they will be delivered a high performing building, which will have a positive desired impact on the users. This is often through over-engineering which is expensive and diverts finance away from energy reduction measures and awareness of social implications. Kiviniemi (2005) says that there are two major areas in the whole-life cycle process where decisions are made that fundamentally affect social outcomes; early stage design and facility operations. All of the identified problems discussed above lead to either poor process or information management in these two key areas. Further to this according to Collins (2014) the interrelationship of the asset and its surroundings, both in terms of adjacency and dependency are poorly understood and executed and the methods of understanding the user's perceptions and needs are rarely collected or effectively analysed and used.

Architects who are frequently responsible for managing the briefing process are often not domain experts or are unaware of the social implications of the asset on the population, especially its interactions on the surrounding assets and infrastructure. There is repeated evidence of ineffective consultation during the briefing process indicating an approach which continues to accept business as usual and be content with the old "norms" rather than making use of technologies to challenge the problems we face as discussed in RAE (2011) and Bacon (2011). The results of the development can often take much longer to manifest than the single activity of delivering the asset in isolation, this is further exacerbated by ownership and accountability become cloudy and ambiguous over the delivery and operational periods.

There is poor understanding of how buildings perform "In-Use" as described by Hitchcock et al (1998). This significantly undermines design team's ability to optimise designs for future projects. There is a very poor relationship between how assets are designed and how they perform "In-Use". Where building automation systems are continuously optimised (what has been referred to as 'Continuous Commissioning') they perform significantly better than those in their peer group which have not. There has also been, according to the Smith Institute and Feinstein L et al (2008) a change in the way society perceives social wellbeing since the Second World War. There was a significant divergence of view between 1965 and 2003 with significant declines in the population with children using social housing, but there was no change in the lowest 20% of the population. The use of social housing has identified links between tenure, life chances and disadvantage in adulthood. The link between social housing and the actual asset is not discussed and there appears to be little literature available to discuss this relationship and more review will be needed to explore this area. The housing charity Shelter (2004) has identified that good-quality, affordable, safe housing is essential to our wellbeing. They list poor housing or homelessness as contributors to mental ill health or can make an episode of mental distress more difficult to manage. This may also be compounded by the fact that poor housing and homelessness are often linked to other forms of social exclusion, such as poverty. They also discuss the links between overcrowded family housing and depression, anxiety, sleep problems and strained relationships. In terms of formal measurement this is a relatively new area of interest in terms of understanding impacts, causes and effects and as such there is no single agreed measurement method for social outcomes, but many subjective views and solutions. This offers little help to those briefing, delivering or operating assets, or the end user.

'Decent Homes' are described by Shelter (2004) as homes that support the health and wellbeing of those who live in them. Decent Homes should be; warm, weatherproof, equipped with modern facilities, in a good state of repair. Additionally, the immediate environment of a Decent Home should provide; access to clean, safe, green spaces, access to public services and opportunities for social contact. Unfortunately, good housing is not available to everyone in the UK. The following main problems have been identified:

- The Shelter literature indicates there is a lack of affordable housing. This started with the 'right to buy' policy of the 1980s, which allowed council tenants to buy their homes, and greatly diminished the local authority housing stock. Rising house prices in the private sector have compounded the problem.
- There is a lack of good-quality housing. Social housing is often associated with poor-quality buildings, high levels of unemployment and crime and poor access to local services. Levels of housing support for people with particular health and social care needs are declining.
- Poor housing is often associated with urban areas, where the issues of overcrowding, poorly designed large-scale estates and associated social problems are well known. However, the lack of affordable housing has also been identified as one of the biggest social problems in rural areas.
- Problems of isolation and poor access to public services are also more common in rural areas. These housing problems have a disproportionate impact on particular groups, such as older people, children and young people, those on low incomes and those with health problems, including mental ill health.

According to the US National Research Council, (NRC 1981), "Human beings spend more than 90% of their lives indoors, yet we know much more about ambient environmental conditions and health than we do about the built environment and health. The built environment affects mental health in two major ways. Characteristics of the built environment can directly influence mental health. Shelter (2004) identify environmental characteristics with direct effects on mental health include housing, crowding, noise, indoor air quality and light. In addition to direct effects, the built environment can indirectly impact mental health by altering psychosocial processes with known mental health consequences. For example, according to Shelter (2004) higher residential density interferes with the development of socially supportive relationships within the household. Diminished social support increases psychological distress." The relationship between the built environment, especially residential housing and mental health is complex. Poor housing can contribute to mental ill health, while mental ill health can make it more difficult for people to find and maintain good-quality accommodation, thus creating downward spiral effects. Synthesis of the literature reviewed from Shelter (2004), Feinstein et al (2008) and Hitchcock et al (1998) identify the following issues:

- People with mental health problems are under-represented in owner-occupied accommodation, which is generally seen as the most socially valued and secure housing in the UK today.
- Compared with the general population, people with mental health problems are twice as likely to be unhappy with their housing and four times as likely to say that it makes their health worse.
- Mental ill health is frequently cited as a reason for tenancy breakdown.
- Housing problems are frequently cited as a reason for a person being admitted or re-admitted to inpatient mental health care.
- Housing sector staff (for example, Local Authority Homeless Persons Units) often lack awareness of mental health issues. Equally, some mental health support staff would benefit from greater awareness of housing issues.

The challenges for other assets such as schools are just as acute as residential accommodation. According to the Delta Report (2008) schools begin to become obsolete as soon as they are occupied. The school curriculum is changing so fast and radically that any school over ten years old is arguably out of date. Also new teaching technology in the form of computers, Tablets, smart boards etc. is putting pressure on power supplies and comfort conditions. Schools are becoming saturated with technology but are not designed for it. The impact of poor accommodation on education is frequently cited and much research has been taken out on this especially following the Building Schools for the Future programme which placed a significant financial burden on the population. Much has been made of the implications of the physical asset as well as the individuals responsible for managing the teaching in such institutions. Barrett et al (2012) reviewed a hypothesis as to the positive impacts on learning against ten design parameters within neuroscience frameworks of three design principles. The model was used to predict the impact of design parameters on pupils learning progression. A comparison of the worst and best class room in the sample was found to have a significant impact on a typical pupil in the year.

The Design Council (2003) studied the impact of learning environments on students' achievement, engagement, affective state, attendance and well-being. It looked at a body of literature which is mainly based in the USA and the UK. The analysis of the range of evidence led them to make the following principal points.

"It is extremely difficult to come to firm conclusions about the impact of learning environments because of the multi-faceted nature of environments and the subsequent diverse and disconnected nature of the research literature. The empirical research that exists on the impacts of environment on teaching and learning tends to focus much more upon some elements (for example, noise) and to fail to synthesise understandings (for example the implications of noise and temperature research tend to conflict). Cultural and geographical differences also highlight the importance of sensitivity to context. For these reasons it is very difficult to make judgements about which areas are 'worth' focusing on. There is clear evidence that extremes of environmental elements (for example, poor ventilation or excessive noise) have negative effects on students and teachers and that improving these elements has significant benefits. However, once school environments come up to minimum standards, the evidence of effect is less clear-cut. Our evaluation suggests that the nature of the improvements made in schools may have less to do with the specific element chosen for change than with how the process of change is managed. There appears to be a strong link between effective engagement with staff, students and other users of school buildings and the success of environmental change in having an impact on behaviour, well-being or attainment. The ownership of innovation, in contrast to the externally imposed solution, appears to tap directly into motivational aspects which are key factors in maximising the impact of change. Changing the environment according to the Delta Report (2008) is 'worth doing' if it is done as a design process. The causal chain between environmental change and changes in students' attitudes, behaviours and achievements is a fairly complex one taking in issues of:

- Choice and autonomy in consultation processes
- Increased self-worth and morale for staff and students based on the investment of time and money in their ideas and their working space
- The 'fitness for purpose' of innovations for particular contexts
- The process of trialling, testing and embedding new practices shaped by environmental change.

These organic, locally governed processes of change and engagement are also necessarily dependent on a process of renewal. As staff and students move on, it is necessary to engage new cohorts in improving the environment in order to continue to reap the benefits. It is important, therefore to beware of 'architectural determinism' of plans for renewal and development which do not allow for both local variation and ownership, and of programmes which do not budget for an ongoing investment in and iteration of, school environments.

The British Council for School Environments, (BCSE 2012) describes a "Decent School Standard", in the context of regulation being reduced, lower costs being imposed but identifying the need to remain collaborative and consistent as to how knowledge and best practice are shared and used. The Government is exploring the concept of baseline designs, which are standardised design exemplars to provide a common minimum standard to ensure learning is shared amongst the supply chain and to try and accelerate the delivery process with the backdrop of the need to provide 450,000 new educational places by 2015. This is supported by the James (2011) Review which had improving client skills as one of its key findings. The Education funding Agency (EFA) according to (BCSE 2012), has over 5500 pages of evidence as to how schools perform. However, the evidence is not complete or easily accessible and there is very little available information about the learning environment and its impact on pupils and their social outcomes.

Figure 4.2 - Engagement Model (© 2012 BCSE)

Figure 4.2 is a model developed by the BCSE which supports the view shown in Figure 4.1 derived from Oral et al (2003). It creates a strategic link between the elements of the built and social environments identifying the physical elements as "enabling factors", the community or functional processes or links as "Facilitating Factors" and the community itself as the "Core Stakeholders". There is evidence from the Design Council (2003) and BCSE (2012) that there are a range of significant findings including the following;

- There is strong, consistent evidence for the effect of basic physical variables (air quality, temperature, noise) on learning
- Once minimal standards are attained, evidence of the effect of changing basic physical variables is less significant
- There is conflicting evidence, but forceful opinions, on the effects of lighting and colour
- Other physical characteristics affect student perceptions and behaviour, but it is difficult to draw definite, general conclusions
- The interactions of different elements are as important as the consideration of single elements

Table 4.1 summarises all of the findings with respect to the educational environment through identifying environmental impacts on key criteria.

Table 4.1 - Summary of Literature conclusions from Design Council (2003)

Impact	Temperature/Air Quality	Noise	Light	Colour	Other School Build Features
Attainment	Poor internal air quality – low attainment	Reading scores, pre-reading skills, general attainment	Link claimed		Outdoor spaces, pathways; What is 'good enough'?
Engagement	Air conditioning noise may distract	Attention and distraction; Time lost through noise interruption; Internal noise			
Affect		Annoyance; Learned helplessness		Children want colour; High hopes but no coherence	Conflicting evidence on ceiling height
Attendance	Conflicting evidence				
Well-Being	Asthma; allergens; poor ventilation – build-up of pollutants, CO_2, etc.	Some suggestion of other physical effects (e.g. raised blood pressure	Eyestrain, headaches, fatigue; Perhaps weight gain, dental cavities		

4.4 Enabling Learning

To resolve these impacts and the effects the physical and social environments have on each other it is necessary to understand how these phenomena can be observed, measured, analysed and represented in a way that can provide objective feedback to the asset owners and users to enable practical actions to be taken to improve performance. This activity known as feedback is well established in other sectors but has no formal or contractual evidence base in the built environment with the exception of a small minority of contract scenarios such as The Private Finance Initiative (PFI) and Design, Build, Finance and Operate (DBFO)., However, for the purposes of this research these models have been excluded as they use commercial mechanisms rather than data to provide system and service based business and asset improvement. They also fail to address the challenges of providing better social outcomes.

4.4.1 Feedback

Feedback occurs when the outputs of a system is routed back to become an input as part of a chain of cause and effect that forms a loop. The system is seen to "feedback" on itself. The danger of circular arguments or feedback noise have to be avoided if a continuous loop continues to loop over and over again so mechanisms need to be enabled to control and validate the feedback. Hoagland & Dodson (1995) identified that “Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and regulate factors such as body temperature, blood pressure and cholesterol levels. The mechanisms operate at every level from the interaction of proteins in cells to the interaction of organisms in complex ecologies”. The typical building may have many systems within it which employ feedback such as heating and cooling systems but when it comes to the overall system of systems i.e. the building itself, there is little evidence at all, with most assets being delivered and demolished 40 - 80 years later even though they were unfit for productive use many years before. The Level 2 BIM data interchange and data management models shown in Figure 2.10 and Figure 2.13**Figure 2.** illustrate this linear concept.

4.4.2 Physical Feedback

As part of the UK Government Level 3 programme “Digital Built Britain”, (DBB 2015) the concept of measurement has been extended to include sensors such as SCADA, IoT and BMS (Defined in Chapter two section six). The data management model defined in Figure 2. has been extended to include a logical data store for data labelled "Performance Management". The DBB (2015) project identifies this as enabling a feedback loop to be created to check physical performance against that which was briefed providing for the first time structured data to establish actual performance. Figure 4.3 taken from and fully detailed in DBB (2015) vision document illustrates this concept along with the relationships formed with other asset types grouped by geography or portfolio. The figure shows the three key types of data proposed for Level 3 BIM, the CAPEX (project delivery), OPEX (asset operations) and performance management (or sensor) information measuring in some cases real time the way that the asset is performing. The ability to make use of this actual performance data and relate it back to both briefing and design information creates a data and knowledge feedback loop for the first time on a routine basis in the built environment.

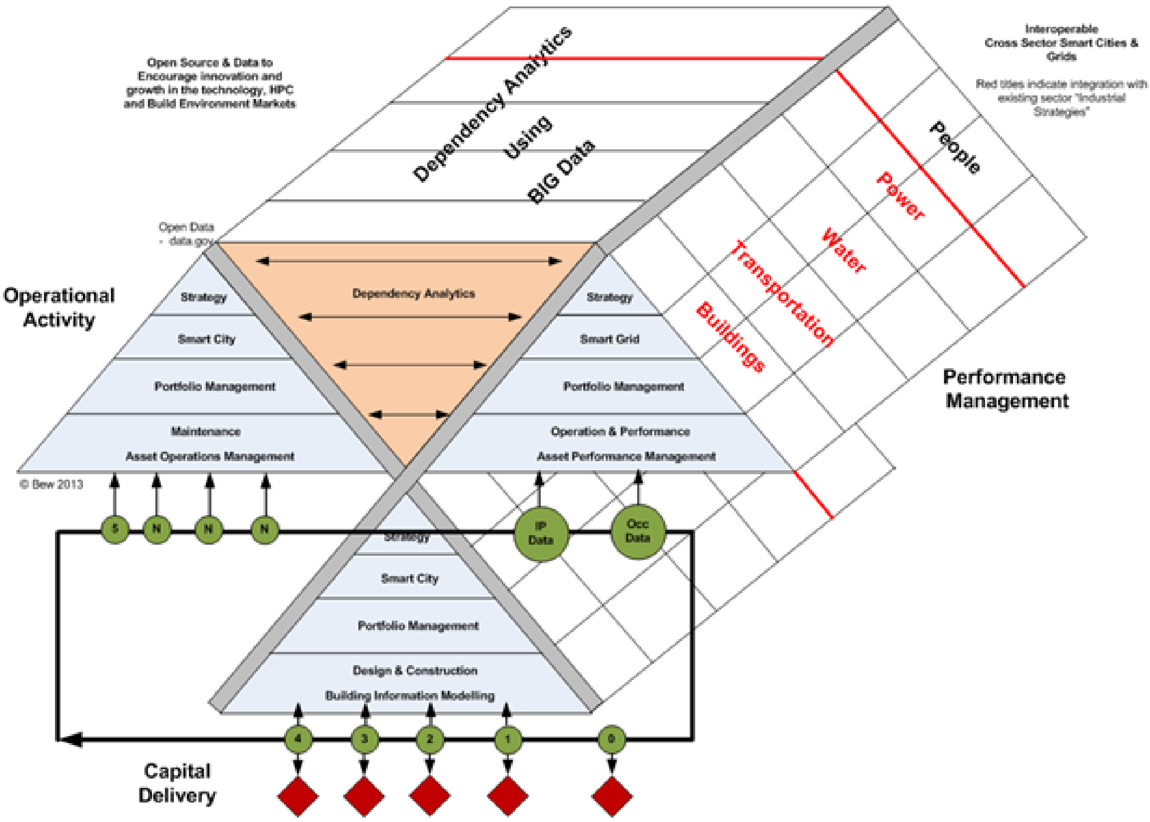


Figure 4.3 - Multi Asset Information Management (BIM & Smart Cities) as defined by DBB (2015)

The Enabling Factors identified by the BCSE (2012) literature were defined as

1. Temperature
2. Light
3. Acoustics
4. Air Quality
5. Build Quality
6. Comfort

These factors generally have a direct impact upon learners and other stakeholders. For example, light has a direct impact upon learning when it is too dark for people to see clearly or, as is more often the case, the light is too bright and glare prevents people from seeing clearly. Enabling factors are also for the most part quantitative. That is, they can be defined objectively on a scale such as decibel levels when talking about acoustics. A Decent School Environment is defined as one in which the level of each enabling factor is in the specifications definition 'adequate'. BCSE (2013) suggest that enabling factors tend to have a negative impact when they are out of specification rather than having an actively positive impact. For example, it is possible to have an out of specified temperature in the learning environment i.e. too hot or too cold but not a "really great" temperature. A positive enabling factor is one that is not having a negative impact and is not a barrier to learning. These categories have been reflected by the following observations from the literature review carried out by the Design Council (2003).

4.4.2.1 Temperature and Air Quality

Earthman (2004) identifies temperature, heating and air quality as the most important individual elements for student achievement. Two studies (Young et al, 2003; Buckley et al, 2004) mention the importance of these issues in reports which address the needs of particular US states' schools, while Fisher (2001) and Schneider (2002) similarly rate these factors as likely to affect student behaviour and outcomes.

Within the studies there are some reasonably clear findings but also significant ambiguity. Much of the USA derived research emphasised comfortable temperatures and therefore, given the climates of some of the regions studied, identified an increased use of air conditioning. There has been questioning of some of the assumptions made about maximum comfortable temperatures (Wong & Khoo 2003) and about the necessity of using air conditioning to achieve ventilation (Khedari et al 2000) and (Grams et al 2003). Furthermore, it is notable that air conditioning, ventilation and heating systems are found to contribute quite distinctly to the level of classroom noise (Shield & Dockrell 2004). This is considered too noisy by many researchers in that area and suggests the potential for conflict between demands for certain physical elements to be prioritised over others. However, the importance of ventilation in educational establishments continues to be emphasised (Kimmel et al 2000) and (Khattar et al 2003), while the inadequacies of indoor air in schools continue to be reported (Lee & Chang 2000), (Kimmel et al 2000), (Khattar et al 2003) and linked to ill-health (Ahman et al 2000). Smedje & Norback (2001) argue that since irritants and allergens collect in dust, it might be advisable to avoid particular sorts of 'fleecy' furnishings and open shelving and to increase the frequency of cleaning. It is evident that the demands of clean air might come in to conflict with the teacher's desire to provide a comfortable, cosy and welcoming classroom. Most of these studies work on the basis that air-related health problems are self-evidently problematic, but the study of (Rosen and Richardson 1999) went further by linking poor air quality to absenteeism. They found that reducing the number of particles in the air and so improving air quality, in a nursery school resulted in reduced child absence. Clearly this has implications for learning and academic achievement. In contrast, the Heschong Mahone Group report (Heschong 2003) argues that operable windows and air conditioning have no effect on absenteeism which could indicate poor air quality being processed (ie blocked or missing filters) or could identify the limitations of uncontrolled data collection or processing mythologies.

4.4.2.2 Noise

There is more literature considering the effect of noise on human functioning, quite a lot of it relating to children learning in noisy environments. This can be seen as developing from laboratory based cognitive psychology experiments such as (Salame & Wittershiem 1978), which attempted to understand the effect of noise on cognitive functioning through examining performance of narrow tasks, often involving memory. However, even these experiments, in situations which are considerably more restricted than in a classroom, allow for some argument about the precise cognitive mechanisms for the results they obtained (Poulton 1978). However, they do advocate explanatory elements that recur in the ‘real world’ literature, such as noise annoyance, distraction and direct masking of cognitive processes, as well as revealing a general tendency for noise to be disruptive, therefore impairing performance. Cohen et al (1980) argue for combining field and laboratory methodologies when considering the effect of raised levels of ambient noise on children and they conclude that there are consistencies in the findings of the two approaches. The research into the effect of living or learning in noisy surroundings was initially driven by concerns about exposure to chronic external noise, such as that due to aircraft or road traffic. In a review of the area, Stansfeld & Matheson (2003) discuss the possibility of health and psychological problems and conclude that: ‘The evidence for effects of environmental noise on health is strongest for annoyance, sleep and cognitive performance in adults and children”. Cohen et al (1980) found evidence of raised blood pressure and signs of learned helplessness due to noise, although these problems have not been found by other studies such as Haines et al (2001). A more reliable finding is that chronic noise exposure impairs cognitive functioning and a number of studies have discovered noise-related reading problems (Haines et al 2001), (Evans & Maxwell 1997), deficiencies in pre-reading skills (Maxwell & Evans 2000) and more general cognitive deficits (Lercher et al 2003). As a result, reviews of the consequences of aspects of the physical environment tend to conclude that acoustics and noise are important factors in a school environment (Fisher 2001), (Schneider 2002), (Earthman 2004). Schneider (2002) comments that in general the research is 'consistent and convincing: good acoustics are fundamental to good academic performance'. There has been some discussion about the mechanism for the widely reported reading deficits. It has been observed that teachers pausing during bursts of external noise leads to an effective reduction in teaching time (Weinstein 1979), which has been put as high as an 11% loss in teaching time (Rivlin & Weinstein 1984). Although there is interest in noise annoyance (Boman & Enmarker 2004), (Kjellberg et al 1996) and links to mood (Lundquist et al 2002, 2003), it seems there is also a more direct cognitive mechanism (Haines et al 2001a). Hygge (2003) reports that various noises (recordings of aeroplanes, road traffic and trains) appear to interfere with the encoding stage of memory and that this is not mediated by distraction or mood. Evans and Maxwell (1997) argue that the reading deficits result from problems with language acquisition and, specifically, with speech perception. A related suggestion is that, in general, impairment in performance is partly explained by the interference of any noise with inner speech (Poulton 1978), while Knez & Hygge (2002) found that irrelevant speech is a particularly distracting noise. All this evidence fuels concern that many have about internal or ambient noise levels in classrooms, even where there is not particularly loud external noise. Shield & Dockrell (2004) found that external noise levels did not generally affect levels of classroom noise, which were mainly dependent on internal factors such as the nature of the classroom activity, number of children etc. It must be noted, though, that they measured the noise levels with the classroom windows closed, and that when the children were engaged in silent reading the external noises became more significant and possibly distracting. However, they found that background noise in unoccupied classrooms was above guideline levels.

Other researchers have drawn attention to these problems of inadequate acoustics (Addison et al 1999), (Lundquist et al 2002) and proposed various solutions such as increased carpeting (Tanner & Langford 2002), sound amplification systems (McSporran et al 1997) and ceiling hangings to dampen reverberation (Maxwell & Evans 2000). As Seaborne (1971) describes, this last solution was in use in the 1830s. Another line of research interest relates subjective perceptions of noise and noise annoyance to objective measures of noise. Dockrell & Shield (2004) conclude that the judgements of both adults and children correlate well with background noise, while noise annoyance is more related to peaks of noise and some noises are perceived as more annoying than others. Other researchers (Stansfeld & Matheson 2003) and (Kjellberg et al 1996) have noted that factors such as predictability, control and judged necessity influence how annoying people find particular noises. However, there are limits to the judgements about the effect of noise with several studies finding that participants can be apparently mistaken about the effect of the noise situation on their performance (Salame & Wittersheim 1978) and (Knez & Hygge 2002). In addition, there are some limited suggestions that some individuals might be more sensitive to noise than others (Belojevic et al 2001) and (Zimmer & Ellermeier 1999).

4.4.2.3 Light

There is also a lot of literature relating to lighting in the classroom. There is research relating to different kinds of lighting, from daylight to artificial and there is a disagreement among researchers on which form of lighting is the most suitable for the classroom. In relation to student achievement it is argued that day lighting offers the most positive effect (Earthman 2004) and (Heschong Mahone 2003) as daylight produces biological effects on the human body (Wurtman 1975). However, having solely a daylight source in the classroom is not practical or possible. Benya (2004) suggested that for 'lighting to be effective, daylight must be supplemented by automatically controlled electric lighting that dims in response to daylight levels'. Barnitt (2003) suggests that good lighting can only be achieved by a combination of direct and indirect lighting. There are different kinds of indoor lighting and differences in the intensity depending on colour temperatures. Jago & Tanner (1999) argue that 'the visual environment affects a learner's ability to perceive visual stimuli and affects their mental attitude and thus, performance'. Knez (1995) found evidence that lighting conditions that induced negative affect reduced performance, and therefore, lighting conditions that induced positive affect improved performance. Veitch (1997), however, argued that lighting has no effect on mood or performance. In another study, (Knez 2001) studied the effect of lighting and gender and found that females were more perceptive to light than males. Furthermore, he also suggested that males and females performed differently in different kinds of lighting. Differences in performance and mood under different kinds of lighting in relation to gender and age were studied by (Knez 2001) and (Kers 2000). Another line of research discussed by Knez (2001) relates to how lighting is concerned with health issues. The most common complaints of inappropriate lighting are headaches, eyestrain and fatigue. To overcome these complaints, Karpen (1993) suggests the use of full spectrum polarised lighting as it is glare-free and flicker-free. As there is an increased use of computers in schools the idea of creating glare free lighting is important (Barnitt 2003). However, concerns about glare and suggestions for overcoming it are not new: Donovan (1921) includes advice about the alignment of desks and the use of blinds. One way of determining the health of students is to examine absenteeism. In Heschong & Mahone (2003) they argue that physical classroom characteristics, including lighting, do not affect student attendance, while other researchers, for example, Hathaway (1990) argues that there is a correlation between absenteeism and lighting. Hathaway (1990) goes further on the aspects of lighting than other researchers, linking lighting to incidence of dental cavities and gains in height and weight.

4.4.2.4 Comfort

Frontczak & Wargocki (2010) tell us that in developed countries people spend more than 90% of their time indoors. In their literature survey they identify how the indoor environment in buildings affects human comfort and how the inside environment can be influenced using the variables indicated above. They also identify the external factors - such as personal character, season, thermal and visual appeal - as key influencing factors.

4.4.3 Perceptive & Social Feedback

Argyris (2002) suggests that each member of an organisation or community constructs their own representation of the whole community, as any community is virtual and they are always perceived by each individual as being different, the picture is always incomplete and people are continually working to add pieces and to get a view of the whole. They need to know their place in the hierarchy it is argued. An organisation or a community is like an organism each of whose cells contains a particular, partial, changing image of itself in relation to the whole. And like such an organism, the organisation’s practice stems from those very images. Organisation is an artefact of individual ways of representing organisation. Hence, our inquiry into organisational learning must concern itself not with static entities called organisations, but with an active process of organising which is, at root, a cognitive enterprise or community. Individual members are continually engaged in attempting to know the organisation and to know themselves in the context of the organisation. At the same time their continuing efforts to know and to test their knowledge represent the object of their inquiry.

Members of the community require external references and there must be public representations of organisational theory to which individuals can refer. This is the function of organisational maps or structure charts. These are the shared descriptions of the organisation which individuals jointly construct and use to guide their own understanding of the community. Organisational theory, continually constructed through individual enquiry, is encoded in private images and in public maps. These are the media of organisational learning as defined by Argyris & Schön (1978). With this set of moves we can see how Argyris (2002) connected up the individual world of the worker and practitioner with the world of organisation and community. Their focus is much more strongly on individual and group interactions and defences than upon systems and structures. By looking at the way that people jointly construct maps it is then possible to talk about organisational learning (involving the detection and correction of error) and organisational theory-in-use. For organisational learning to occur, ‘teaching agents’, discoveries, inventions, and evaluations must be embedded in organisational memory (Argyris & Schön 1978). If it is not encoded in the images that individuals have and the maps they construct with others, then ‘the individual will have learned but the organisation will not have done so.

For Argyris & Schön (1978), learning involves the detection and correction of error through feedback (or loops). Where something goes wrong, it is suggested an initial port of call for many people is to look for another strategy that will address and work within the governing variables. In other words, given or chosen goals, values, plans and rules are operationalised rather than questioned. According to Argyris & Schön (1974), this is single-loop learning. An alternative response is to question the governing variables themselves, to subject them to critical scrutiny. This they describe as double-loop learning. Such learning may then lead to an alteration in the governing variables and a shift in the way in which strategies and consequences are framed. This is how Argyris & Schön (1978) described the process in the context of organisational learning.

When the error is detected and is corrected this permits the organisation to carry on its present policies or achieve its present objectives, then that error-and-correction process is single-loop learning. Single-loop learning is like a thermostat that learns when it is too hot or too cold and turns the heat on or off. The thermostat can perform this task because it can receive information (the temperature of the room) and take corrective action. Double-loop learning occurs when error is detected and corrected in ways that involve the modification of an organisation's underlying norms, policies and objectives such as the room doesn't need heating as it is a Bank Holiday.

Single-loop learning seems to be present when goals, values, frameworks and, to a significant extent, strategies are taken for granted. The emphasis is on "techniques and making techniques more efficient" (Usher & Bryant 1989). Any reflection is directed toward making the strategy more effective. Double-loop learning, in contrast, "involves questioning the role of the framing and learning systems which underlie actual goals and strategies in many respects the distinction at work here is the one used by Aristotle, when exploring technical and practical thought. The former involves following routines and some sort of pre-set plan and is both less risky for the individual and the organisation, and affords greater control".

In an organisational or community approach this is synthesised by Argyris & Schön (1978) as "Single-loop learning is characterised when, members of the organisation respond to changes in the internal and external environment of the organisation by detecting errors which they then correct so as to maintain the central features of theory-in-use". Further Double-loop learning is characterised by "Those sorts of community enquiries which resolve incompatible organisational norms by setting new priorities and weightings of norms, or by restructuring the norms themselves together with associated strategies and assumptions (Argyris & Schön 1978). They further describe the concept of double-loop learning (DLL) in which an individual, organisation or entity is able, having attempted to achieve a goal on different occasions, to modify the goal in the light of experience or possibly even reject the goal. Single-loop learning (SLL) is the repeated attempt at the same problem, with no variation of method and without ever questioning the goal. These concepts are shown in Figure 4.4 in the derived process models showing how the physical and social feedback loops create the double loop.

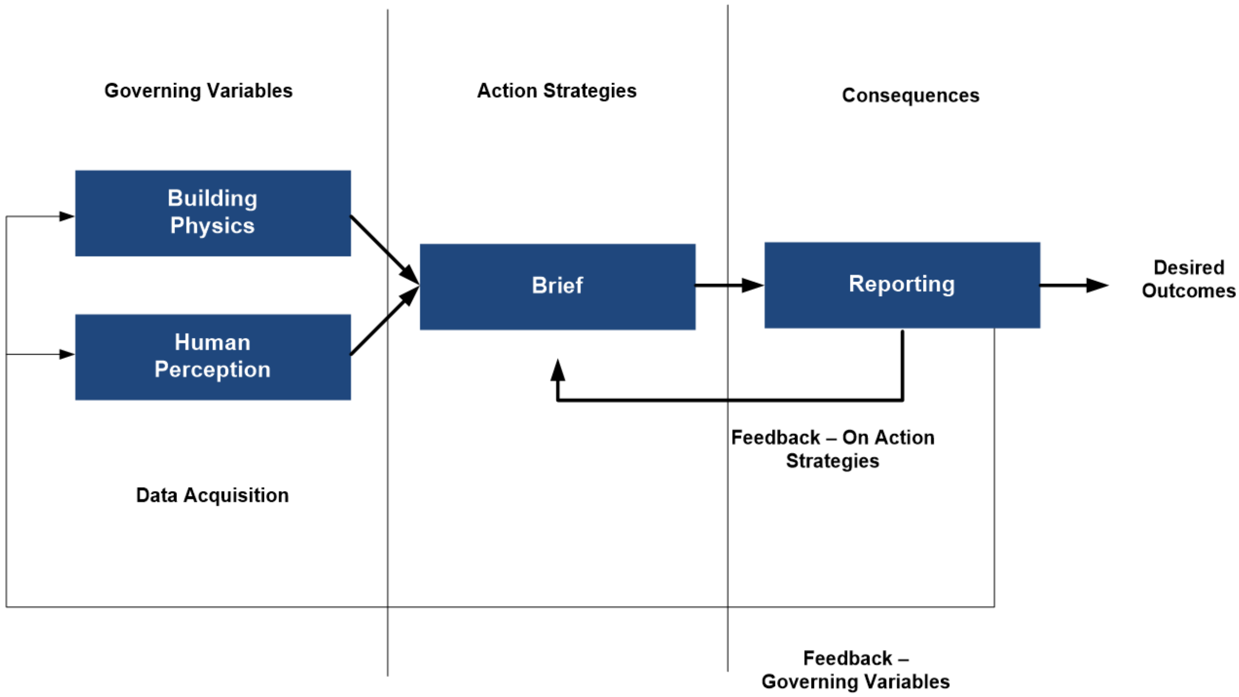


Figure 4.4 - Double Loop Principles Applied to Physical and Social Measures. Adapted from Argyris (2015)

To fully appreciate the theory, we require a model of the processes involved, to this end Argyris and Schön (1974) initially looked to three elements which are illustrated in Figure 4.4

> **Governing variables** those dimensions that people are trying to keep within acceptable limits. Any action is likely to impact upon a number of such variables – thus any situation can trigger a trade-off among governing variables, in our case the brief and as-built data defining the asset

> **Action strategies** the moves and plans used by people to keep their governing values within the acceptable range, such as updates to the brief, approved changes and modifications to the asset during its lifetime.

Consequences are the result of an action. These can be both intended, those which the actor believe will result in an outcome and unintended which the actor did not anticipate

Where the consequences of the strategy used are what the person wanted, then the theory is confirmed. This is because there is a match between intention and outcome. There may be a mismatch between intention and outcome. In other words, the consequences may be unintended. They may also not match, or work against, the person's governing values. Argyris and Schön suggest two responses to this mismatch and these can be seen in the notion of single and double-loop learning. In terms of deploying and applying this technique it should be considered as to how the formulation and implementation of an intervention strategy is approached and structured. Argyris and Schön (1978) identify that this involves the delivery of six phases of work to provide such a structured methodology. The approach incorporates the essence of the double loop approach and is described in in Table 4.2.

Table 4.2 – Six Phases of Work (Argyris and Schön (1978))

Phase	Activity
1	**Mapping the problem as customer sees it.** This includes the factors and relationships that define the problem, and the relationship with the living systems of the organisation.
2	**The internalisation of the map by clients.** Through enquiry and collaboration with clients to develop a map for which clients can accept responsibility. However, it also needs to be comprehensive.
3	**Test the model**. This involves looking at what "testable predictions" can be derived from the map and looking to practice and history to see if the predictions stand up. If they do not the map has to be modified.
4	**Invent solutions** to the problem and simulate them to explore their possible impact.
5	**Produce the intervention**.
6	**Study the impact**. This allows for the correction of errors as well as generating knowledge for future designs. If things work well under the conditions specified by the model, then the map is not disconfirmed.

4.5 Integration of Physical & Social Data

Based on this research, the principles and theories supporting the concept of measuring a physical and social data set describing an asset and its user community have been described. Further described are the different objective and subjective data types that can be collected and brought together to be analysed in a way that key performance criteria can be evaluated and actionable strategies developed to effect improvements. As has been discovered there are no tools or literature detailing the integration of these principles and so it is proposed that a set of working assumptions will be made on the basis of a conceptual Test Bench. This Test Bench will indicate how the data sets and processes can be integrated to form a double loop integrated feedback process to analyse and identify actions informed through feedback to improve the operation of the asset. Figure 4.5 shows in conceptual form how these elements come together based on the feedback loops (and double loops). The physical information is managed through the black pathways, with data loops being generated from

- The briefing process (As Requested)
- The delivered asset (As Built)
- The operational asset (As Operated)

These data sets are gathered from the brief, the design and construction BIM delivery process and the data collected from the sensors and other devices. This is held in a database to enable query activities between the two data sets. This data can be used for longitudinal analysis to see how the design develops and cross sectional to perform analysis and comparisons with other external data sets such as the social data. This outer loop can be considered a single loop with the feedback data only able to be considered in terms of the actual sensor measured values, the as built expected values and the as required brief.

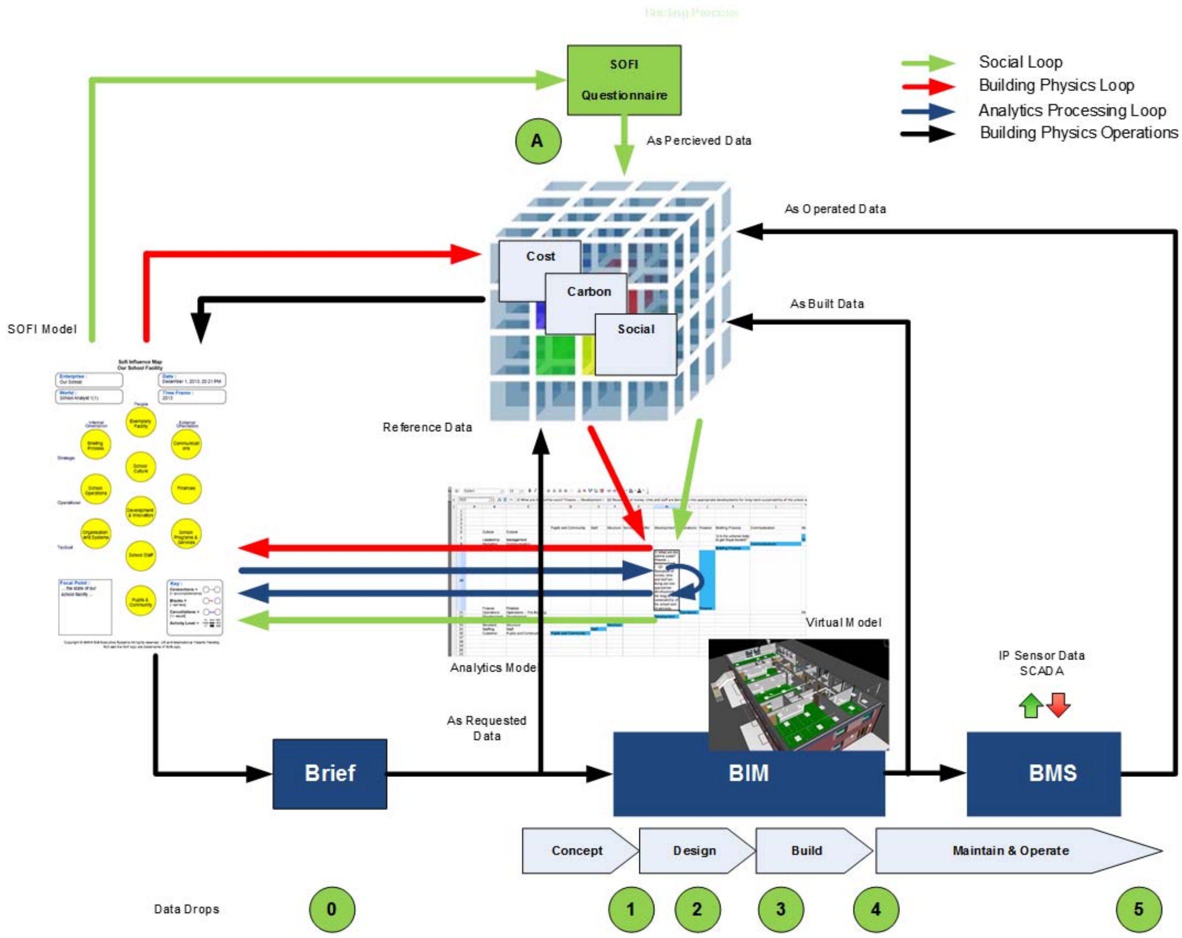


Figure 4.5 - Test Bench Context Model

The social data is gathered through the green loop, this is subjective, qualitative data gathered about the perceptions of the asset's users. For this data to be of use it must be pre-processed to sectors with relative values. The SOFI and TASIT tools both have some capability in this area, enabling calculated values to be used to visualise the perceptions of the users with respect to themselves, their co-community members and the space they generally inhabit, this taken in isolation can be considered a single loop. The social data collected is presented in an analytic form but it can only be interpreted with respect to its control which, in this case, would be set by the research focus question or in practice the brief and regulation. It is only when these two loops are brought into sequence that we can create a double loop just as Argyris (2002) envisaged. The proposed model depicts this by the red and blue lines. The red is a reference set of building physics meta values designed to ensure that physical data of the correct state is presented for analysis. However, this is all derived from the data collected from the black processes. The blue loop then traces the interface with SOFI and the analytics of the two data sets, physical and social linked through space and community to provide a composite analytic with physical loop outputs providing reference and reasons for social performance and vice versa, thus providing a double loop learning process. SOFI makes use of an internal function known as worlds which enables double loop testing of the convergence with and across data sets. This is then passed back to the briefing process as an "action" and thus around the loop again. The application of the double loop principle is discussed in detail as part of the application process in Chapter seven.

4.6 Summary

To fully understand the operational outcomes of an asset in service is a complex and time consuming activity. There are many dimensions to consider and the analysis is dependent upon perceptive and time critical transactions. However, taken in sections an approach can be suggested that has certain levels of scientific evidence to support the integration of these sections into a synthesised model to provide social and physical information to an analysis regime that can provide proactive feedback to identify "actions" to improve the performance of assets over time.

These principles have been found to provide useful insights in their own right but through the application of a feedback framework and methodology for integrating the processes and information a far richer insight will be possible from the point of view of the building or service user. This framework or Test Bench will be the focus of further research defined in the next Chapter to establish the validity of the approach.

Chapter 5

Research Methodology

5.1 Introduction

At the end of Chapter four the concepts of managing social and physical data in a structured methodology and the incorporation of a feedback loop had led to the development of a Test Bench. This Test Bench is the theoretical position where an approach is required to test its validity. The purpose of this Chapter is to introduce the relevant research methodologies which may be suitable for such a test and to select an appropriate approach.

5.2 Background to Research Methods

The selection of a research methodology requires the understanding of what research is and how the various methods of research can be applied to a research subject to the best effect. Leedy & Ormrod (2001) said "research is at times mistaken for gathering information, documenting facts and rummaging for information. Research is the process of collecting, analysing and interpreting data in order to understand a phenomenon." They went further to say "The research process is systematic in that defining the objective, managing the data and communicating the findings occur within established frameworks and in accordance with existing guidelines. The frameworks and guidelines provide researchers with an indication of what to include in the research, how to perform the research and what types of inferences are probable based on the data collected".

Research starts with a research question according to Williams (2007), to help the researcher focus on the phenomenon of interest. It is from this point that the researcher can chose an appropriate approach or perspective from which to make sense of each phenomenon of interest. This perspective is further developed by the review of the literature as presented in Chapters two, three and four.

The research philosophy of this work is informed and structured by the research process "onion" shown in Figure 5.1 presented by Saunders et al (2008). There are a number of approaches that can be taken to research but the lack of ambiguity of the onion approach allows a clear focus on the key issues of interest whilst ensuring a clear framework within which to work. This is supported by Guba & Lincoln (1994) who suggest that the question of research methods is of secondary importance to questions of which paradigm is applicable.

The philosophical domains that this research covers are diverse. This indicates an approach to the research as a whole that excludes an extreme view, the subjectivity of the human measurement element, including potential emotional or unpredictable responses combined with the more prescriptive engineering inputs presents a need to be clear but flexible. The following sections describe the research process which has been considered.

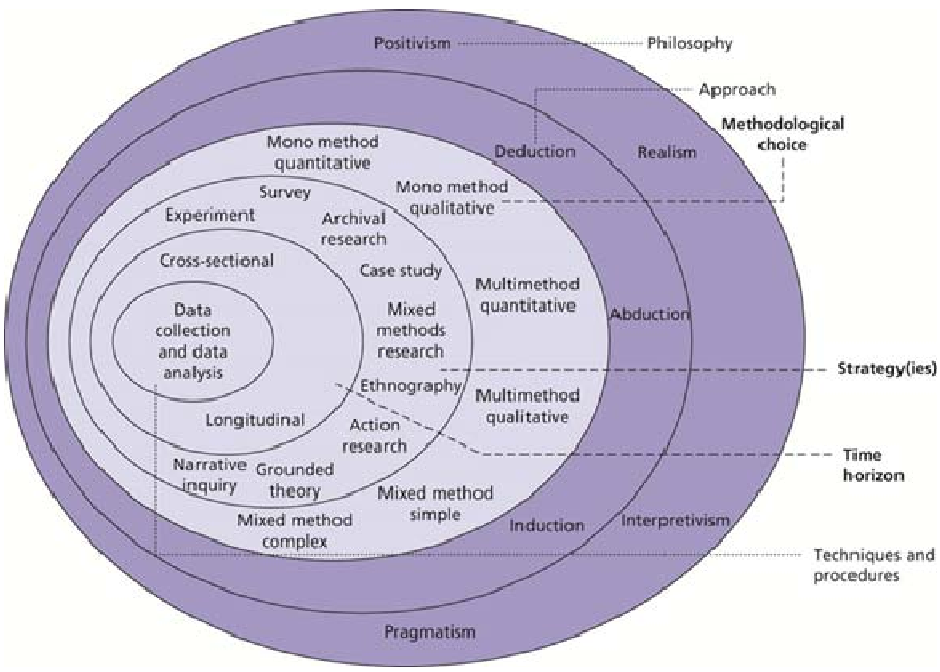


Figure 5.1 - Saunders Research Onion - © Saunders, Lewis & Thornhill 2012

The literature outlines two distinctive research approaches; deductive and inductive. A deductive approach is suggested to be applicable to scientific research, where the researcher develops a hypothesis which is tested and examined to establish a theory (Hussey & Hussey 1997). The inductive approach follows research data to construct theory. Therefore, it can be suggested that both of these approaches are relevant to the scope. Saunders et al indicates that this combined approach is perfectly possible and may indeed be advantageous. The deductive elements will lend themselves well to the BIM and engineering elements, but as we move from data to theory in the world of social measurement a more inductive approach may be better suited. There are six layers to the research onion as presented by Saunders et al and they are considered below in the context of this research.

5.3 Critical Understanding of Research

5.3.1 Research Philosophy

Research paradigms are the philosophical perspectives (or world views) about what constitutes valid research (Myers 1997a). Research paradigms are based on epistemological, ontological or metaphysical assumptions covering the nature of knowledge and how it can be obtained (Myers 1997b) and (Meredith et al 1989). This study has adopted a paradigm closer to interpretive and critical assumptions than to positivist ones. As is evident in the published papers, the research conducted does not strive to confirm an existing phenomenon or to measure it against another but seeks to bring meaning and structure to a series of phenomena (BIM concepts and their relationships) through a human perceptive perspective. The study also includes epistemological elements pertaining to critical thought – not only to study BIM as a set of interrelated phenomena within a historical context but also to inform how BIM is implemented within organisations and the wider industry.

The development of knowledge is complex and the research domain broad. The organisation of this complexity to ensure the delivery of new knowledge is embodied in the research philosophy. The philosophies recognised in the literature are positivism, interpretation, realism and pragmatism. Each of these approaches offers a distinct view on the way that the knowledge is developed. Pragmatism and positivism represent the extremes of philosophical approach with positivism implying scientific reasoning and law like generalities in the process of knowledge construction (Remenyi et al 1998). The research methodology is influenced by the philosophy and is characterised by a transparent structure to enable replication (Gill & Johnson 1997). This approach may be applied to some of the engineering calculation elements of our BIM methodologies. The Pragmatist view has emerged (Saunders et al 2008) in recognition of the view that it is possible to work with variation in epistemology, ontology and axiology in a mixed methods mode. Realism is relatively close to the philosophy of positivism but at the same time possesses clear characteristics in that the approach highlights the inappropriateness of exploring people's interactions in the style of natural science described by Saunders et al (2008). Interpretivism is the last approach offered by Saunders; here he advocates that it is necessary to understand the differences between humans in the role of actors and influencers. It also requires a full understanding of how humans interpret the social fabric of the world around them.

As described earlier, the complexity of the scope of research indicates the composite approach of realism should be selected as the philosophical approach for this research. It maintains the scientific enquiry relationships but when we explore realism more carefully we see it possesses two forms. Direct realism indicates a view of what you see is what you get and this could be applied with a mono view of an asset management system recording the performance of an asset. However, the second type of realism is critical realism and this applies to how we experience effects. It is the impact of these effects that are the cornerstone of our research interest developing the understanding of the impact of the built environment on people. Bhaskar (1989) further identifies that it is only possible to understand the social structures that have given rise to the phenomenon that we are trying to understand. This is especially true when applied to the interdependencies of infrastructure upon each other and the built environment as well as the social fabric, as we only normally see part of the picture.

The process of research is complex and the model shown in Figure 5.2 is derived from conversations with Arto Kiviniemi and Martin Fischer. The flows indicate the entry point to the process, where the motivation to research a specific subject is brought together with the research literature to identify gaps in knowledge and useful opportunity. This is focused through a suitable research methodology and the results support the scientific contribution.

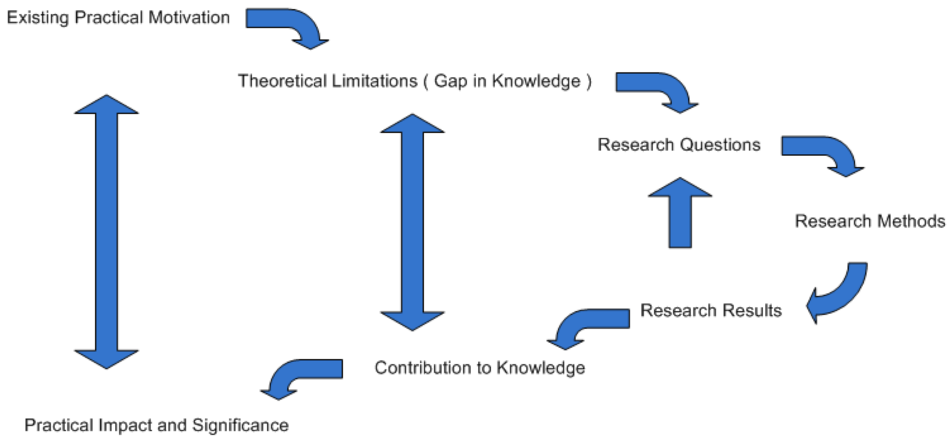


Figure 5.2 - Research Process

Adapted from discussions with Martin Fischer and Arto Kiviniemi

Below is a summary of the specific research paradigms with respect to this research and how they are applied.

5.3.1.1 Positivism

Saunders et al (2005) indicate that if you prefer "working with observable social reality and that the end product of such research can be law like generalisations similar to those produced by physical scientists” Remenyi et al (1998) your research reflects the philosophy of positivism. The positive paradigm has its roots in the natural sciences and is based on the existence of a "priori", real, unidirectional and fixed cause/effect relationship that can be tested (Orlikowski & Baroudi 1991). Positivists generally attempt to test theory and increase the predictability of a measurable phenomenon (Myers 1997), further they assume normally that reality is objectively given and can be measured independently of the observer.

This approach is aligned with the desire the researcher has in the establishment of a controlled understanding of the performance of the physical asset during the experiment using the Test Bench. The relationship with the specification and standards to the data collected by the sensors is classic positivism.

5.3.1.2 Interpretivist

Interpretivist as explained by Saunders et al advocates that it is necessary for the researcher to understand the differences between humans in our role as social actors. This shows a focus on the difference between social analysis and specific factual data analysis. The approach assumes that people create and associate their own subjective meanings as they interact with the world around them. Interpretive research does not predefine dependant and independent variables, but focuses on the full complexity of human sense making as the situation emerges" (Myers 1997). One of the challenges of this approach according to Orloikowski & Baroudi (1991) is the view that researchers "can never assume a value neutral stance and are always implicated in the phenomena being studied, researcher’s prior assumptions, beliefs, values and interests always intervene to shape their investigations". Saunders et al point to the two philosophical traditions of phenomenology and symbolic interactionism which is where views on Interpretivism commenced. Phenomenology refers to the way that humans make sense of the world around them and in symbolic interactionism we are in a continual process of interpreting the world around us, interpreting our environment and social company to establish how to interact.

This is very much in the theme of the social measurement process identified and the methodology proposed to measure the perceptive views of the Test Bench experiment. This leaves the research with a challenge as the downstream analysis and interpretation of the data derived from apposing ends of the philosophical axis.

5.3.1.3 Realism

As can be seen from the Saunders Onion, the Realism view is in the middle of the philosophical axis and introduces the concepts of Direct Realism and Critical Realism. The philosophy of realism is that there is a reality quite independent of the human mind. In this sense realism is opposed to positivism as discussed above as the reality of the sensor data being either within specification or not is a very clear binary value. However, Saunders goes on, if you consider the two types of realism where direct realism says "what you see is what you get" and critical realism where often data received by humans can deceive the researcher, this can sometimes be due to complexity or to the fact that there is insufficient information to form an accurate view of the situation. Bhaskar (1989) said "that the possibility and necessity of experiment show that reality is structured and stratified and Sayer (1992) set out what he called his eight key assumptions of critical realism:

1. The world exists independently of our knowledge of it.
2. Our knowledge of the world is fallible and theory-laden. Concepts of truth and falsity fail to provide a coherent view of the relationship between knowledge and its object. Nevertheless, knowledge is not immune to empirical check and its effectiveness in informing and explaining successful material practice is not mere accident.
3. Knowledge develops neither wholly continuously, as the steady accumulation of facts within a stable conceptual framework, nor discontinuously, through simultaneous and universal changes in concepts.
4. There is necessity in the world; objects—whether natural or social— necessarily have particular powers or ways of acting and particular susceptibilities.
5. The world is differentiated and stratified, consisting not only of events, but objects, including structures, which have powers and liabilities capable of generating events. These structures may be present even where, as in the social world and much of the natural world, they do not generate regular patterns of events.
6. Social phenomena such as actions, texts and institutions are concept dependent. We not only have to explain their production and material effects but to understand, read or interpret what they mean. Although they have to be interpreted by starting from the researcher's own frames of meaning, by and large they exist regardless of researchers' interpretation of them. A qualified version of 1 therefore applies to the social world. In view of 4–6, the methods of social science and natural science have both differences and similarities.
7. Science, or the production of any kind of knowledge, is a social practice. For better or worse (not just worse) the conditions and social relations of the production of knowledge influence its content. Knowledge is also largely—though not exclusively—linguistic, and the nature of language and the way we communicate are not incidental to what is known and communicated. Awareness of these relationships is vital in evaluating knowledge.
8. Social science must be critical of its object. In order to be able to explain and understand social phenomena we have to evaluate them critically" (Sayer 1992).

Bhaskar (1989) also says that researchers will only be able to understand what is going on in the social world if we understand the social structures that have given rise to the phenomena we are trying to understand. In other words, what we can see is only part of a bigger picture, which is true if we apply these thoughts to the built environment, where each asset and each community are a part of wider and overlapping communities and assets serving those communities. Saunders et al recognise this and describe the importance of multi-level study (eg at the level of the individual, the group and the organisation). Each of these levels has the possibility of changing the researchers view of what is being studied as we find with communities and their perceptions of their surroundings.

So from this understanding the researcher will take the philosophical stance of the Critical Realist, with the understanding of the impact of the longitudinal effect of identifying, gathering and processing the data to reach these conclusions comes from opposing ends of the philosophical axis. Ontology is a record of the researcher's view of the nature of reality and being. Gruber (1993) describes Ontology as a "specification of a conceptualisation". The perspective of this is influenced through the chosen research philosophy. The Critical Realism ontology is objective, it builds on views which are independent of human thoughts and beliefs, but are interpreted through social conditioning.

As discussed the pragmatist view has been selected and this leads to an external, multiple view chosen to best enable the answering of the research questions. Epistemology is the measure of the researcher's view on what constitutes acceptable knowledge (Creswell 1994). It is sometimes referred to as the "theory of knowledge" and describes "how" a researcher knows about reality and assumptions about how knowledge should be acquired and accepted. With our predominantly pragmatist view either observable or subjective phenomena can provide acceptable knowledge, within the context of the preceding comments as long as the supporting narrative can make clear the potential to misinterpret the data presented in raw interpreted form. Axiology is the researchers view on the role of values on the research, in the case of realism this is based on the value of the data but in the knowledge that the researcher is likely to be influenced by world views and cultural experience.

5.4 Research Approach

The next element is the reasoning of the research (Sutrisna 2009) which refers to the logic of the research, the role of an existing body of knowledge gathered in the literature study, the way researchers utilise the data collection and subsequent data analysis or Saunders (2009) who said "A research method represents the transition of how the researcher moves from a set of philosophical assumptions and views to the development of a research method which will design and collect data to prove or otherwise the research questions." There are two fundamental approaches to research, the inductive or the deductive. The deductive approach sees the researcher developing a theory and a hypothesis and then designing a research strategy to test the hypothesis (Saunders et al 2009) and the inductive approach describes the process of collecting data and developing a theory as a result of observations on that data.

Saunders et al (2009) also provided a summary Table to indicate the key differences between the approaches. This is detailed in Table 5.1. When testing this research approach to the methodology, there is clearly a deductive process with a hypothesis regarding the performance of assets and user’s perceptions being measured to establish if the hypothesis which indicates there is a relationship is proved or not, but some of the contents of the Table challenge this approach especially with respect to the collection and use of qualitative data. Saunders et al (2009) does discuss combining approaches and cautions to the selection, but if taken as a whole the overall project this research will be viewed as a deductive approach.

Table 5.1 - Major differences of emphasis between deductive and inductive approaches to research (Saunders et al. 2009. p127)

Deduction places an emphasis on	Induction emphasis places an on
Scientific principles	Gaining an understanding of the meanings humans attach to events
Moving theory to data	A close understanding of the research context
The need to explain causal relationships between variables	The collection of qualitative data
The collection of quantitative data	A more flexible structure to permit changes of research emphasis as the research progresses
The application of controls to ensure validity of data	A realisation that the research is part of the research process
The operationalisation of concepts to ensure clarity of definition	Less concern with the need to generalise
A highly structured approach	A flexible learning approach
researcher independence of what is being researched	Understanding the perceptions of a related community
The necessity to select samples of sufficient size in order to generalise conclusions	Understanding the impact of perception

5.5 Research Methodology

The research methodology element relates to strategies of enquiry (Creswell 2009), which refers to the types of qualitative, quantitative and mixed method designs or models that provide specific direction for procedures in a research design.

Saunders et al (2009) argues that in selecting the appropriate strategy of enquiry, one research approach may be better than another. Each strategy is specifically designed for undertaking different challenges and the selection of the most appropriate one depends on the research questions that need to be answered. Jankowicz (2000) however, suggested that choosing one type of strategy over another ultimately hinges on the objectives of the study. In addition to research questions, the arguments for and against the use of each research approach suggest that theories can also be used to determine which methodology will be most appropriate for a particular research. Saunders et al (2009) suggested that if the researcher understands the phenomena underlining the study well enough and aims to develop a theory about factors influencing particular phenomena and to explore the setting further, a qualitative approach is more suitable. Both the quantitative and qualitative methods are concerned with exploring phenomena (Mack et al 2005). However, qualitative analysis is primarily concerned with understanding an individual's or community's perception of a phenomena based on an investigation such as the experiments participants, while the quantitative approach is concerned with issues such as "how much" and "how many" such as the sensor data and seeks to document occurrences passively (Bell 2005). Because qualitative research is an inherently exploratory undertaking, the potential for generating new theories and ideas is significant. Amaratunga et al (2002) further strengthens this stance. Quantitative data, on the other hand, is most valuable when hypotheses and theories have already been established and are being evaluated (Saunders et al 2009) and (Fellows & Liu 2007). So from this we can deduce that this research will be delivered on a mixed methods basis.

5.6 Research Strategy

The Research Strategy element is the research method that involves the forms of data collection, analysis, and interpretation that the researcher proposes in the study (Creswell 2009). Each strategic approach can be used for exploratory, descriptive and explanatory research (Yin 2003). Various methods can be often associated with deductive or inductive approaches but it is possible to use almost any approach in specific scenarios.

There are a whole range of research strategies available including; Survey, Case Study, Action Research, Grounded Theory, Ethnography and Archival Research, but having researched each of these options the Experimental strategy provides the best option for a scenario where the researcher has two data groups or worlds, with a quantitative value set which can effectively be used as a control. An experiment is done in a controlled environment conducted by researchers in a scientific laboratory to establish the validity of a hypotheses. A field experiment is an experiment carried out in the participant's natural everyday environment. In both cases, the researcher is still manipulating the independent variables (changing the thing that affects the dependent variables). The main differences are that in the lab experiment, the researcher is able to control most of the conditions in the setting. For example, the researcher can control who is present, what the staff says, how long the experiment takes, and so on. In the field experiment, the researcher may not have control over any of those conditions, as for example, people not related to the experiment may come and go randomly, those people can say whatever they want, and so on. The lab experiment has more control and so can better isolate factors thought to be important in the outcomes, but may not be very much like the natural everyday environment, and so the results may not generalise to those natural everyday environments. The field experiment is the natural everyday environment, and so the results of the study are more likely to generalise. However, the field experiment has less control and so it may be very difficult to determine what factors were important in explaining the outcome. One of the challenges of the measurement of human perceptions in their environment is this is the only place this data can be realistically recorded, ie: in the field. In the case of this research the experiment will take place in a "live" environment, with real asset users, but they are part of a controlled well scoped environment, so will have some of the "control" elements of a laboratory setting.

The process model in Figure 5.3 shows the field experiment process will be applied to this research, including the final feedback process which returns the research process back to the beginning again, ready for either final conclusions or back through another iteration.

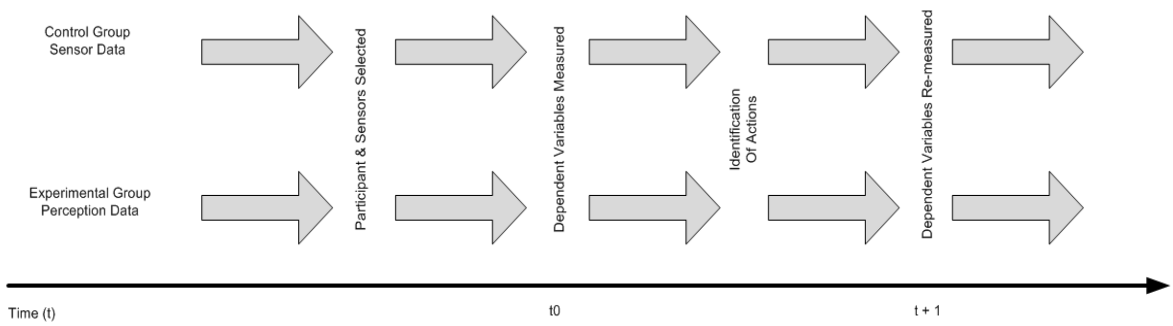


Figure 5.3 - Adapted from "A Classic Experiment Strategy" (Saunders et al. 2009. p127)

5.7 Time Horizon

The selection of a time horizon for research is a critical scoping consideration and provides an understanding of why the research (experiment) produces the answers that is does. There are two strategies, Cross Sectional and Longitudinal. Cross-sectional research is most often used because of the ability to get results rapidly. Longitudinal research studies look at one phenomenon or one group over a period of time. An example of longitudinal research would be review of the entire lifecycle of a building over its entire life, potentially up to 100 years. An example of a cross sectional study would be a single design review or tender process analysis, which only occur once in the life of the project.

The selection of a time horizon for this experiment is a challenge as there is a need to control scope to complete the research, but also the knowledge that the area of research this work covers is positioned in a continuum as communities come and go in buildings as organisations develop and form. With this longitudinal strategy Adams & Schvaneveldt (1991) point out that in observing people or events over time the researcher is able to exercise a measure of control over the variables being measured and this is true of the physical qualities of the asset but the human perception is based on may influences. To demonstrate this the Test Bench experiment will be using a cross sectional strategy as the purpose is to demonstrate a principle relationship between data sets. However, as part of the further research section there are observations and recommendations for future longitudinal work to establish long term trends.

5.8 Techniques & Procedures

The data collection and analysis process for this task is complex in that it requires two data collection processes and a convergence process to present suitable data to analyse. The data collection processes are further complicated by the fact that the data formats are both quantitative and qualitative, requiring pre-processing before the convergence process. The following are key strategic approaches:

1. Documenting the current and emerging practice for the exchange of BIM data during the capital design and delivery stages of the asset. There is considerable progress in the use of data standards such as IFC and COBie. This will be managed in the continuation of the literature review. There is much development in the areas of "Levels of Detail" (dPoW) and work developed by the HMG BIM Task Group will be used as a basis for the development of ensuring valid data is available as required.

2. Further research the Social Indicators and measurement issues which are currently in use will be developed through interviews and case studies. The identification of SOFI and TASIT has been useful research to base the selection of an approach to measure social perception of spaces and community behaviours.
3. Through this research a design database entity relationship design for data attributes and relationships will be developed, which will, through inspection, offer the key data attributes to address the research questions.
4. Through a review of the available literature identify key process failures in the delivery of effective briefing, specification, design and asset delivery, in the current methods of project delivery. The research will also identify alternative methods of information delivery which could improve performance, particularly through the extension of the use of the digital plan of work. This research will also include a review of the current linear delivery process as well as the conceptual "Continuous Briefing or Commissioning" processes described in this document and how it may be applied.
5. Develop a "Test Bench" (database system) to enable an experiment to be undertaken to test the effectiveness of the Test Bench's ability to provide a new methodology for creating assets that meet the needs of the community which use them.
6. Analyse Test Bench data and case study data and draw conclusions.

As discussed above the selection of an experiment is one of the most effective but as Hakin (2000) points out the sample sizes required to have a statistically useful response can prove a challenge. The Eisenhardt approach (Eisenhardt 1989) was developed to be more flexible in its adoption and requires a sample size of 4-10 avoiding concerns about being too narrow (Denscombe 2007). This flexibility is seen as the major benefit and undertaking a case study in the right way can deliver highly valuable insights. Hakin (2000) however sees bias a significant drawback in terms of interpretation and analysis on behalf of the researcher.

5.9 Reflection on Literature

As the literature has been reviewed and synthesised observations have been made of the approach researchers have taken and how it varies to the points of view of each observer or stakeholder. The physical measures described in Chapter two are grounded in realism, their values are finite and until contextualised with the social perceptive information creates an interpretive view. The literature has no examples of a fully structured social perceptive measurement model in the built environment based on scientific measurement techniques. There are however a number of single dimension studies to identify impacts in specific areas, such as the impact of poor residential accommodation on mental health. This lack of information is the rationale as to why an experimental route has been selected for this research.

5.10 Summary

This Chapter has looked at the various approaches to research and what they mean. A research scope that has such a wide ranging brief as this, is by its very nature going to have to be applied differently across the various topics of analysis. The ability to observe both longitudinal and cross sectional views of an assets performance or its user's social outcomes are by necessity long term observations. The positivism approach is rooted in all that is real and that helps provide a control in the research, which is especially important as the selection of an experiment has with it an expectation that a formal control data set is available. However, with a complex and expensive scenario such as a building, the control has to be the building itself or in certain circumstances the brief.

The result of the combination of perceptive and physical data sources leads to a composite view such as realism. The realism view is very pragmatic and supports well our need to balance the opposing views of physical and social views. The data collection process will use mixed methods due to the diverse nature of the data sources and the research strategy will be based on a real world experiment.

In the Introduction to this section we introduced the Fischer Kiviniemi research development process and the generic version discussed at the beginning of this research is shown in Figure 5.2**.** The process of delivering this research has allowed the model to be developed and tested and as can be seen in Figure 5.4 the model can be populated with the specific application of this research. The figure provides a useful summary to the approach taken to deliver this research.

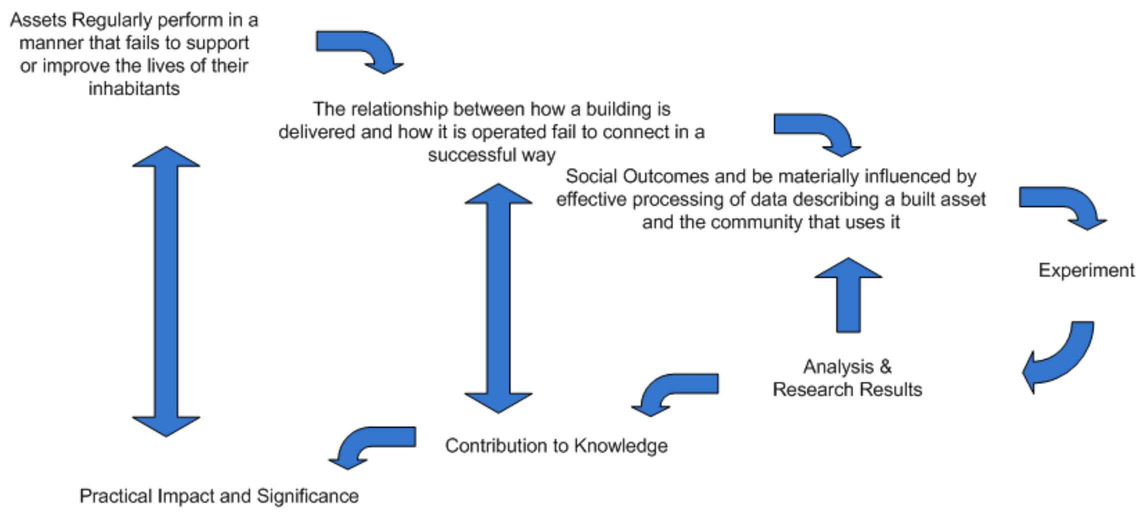


Figure 5.4 - Applied Research Process

Adapted from discussions with Martin Fischer and Arto Kiviniemi

The chart shown in Figure 5.4 shows the process of establishing the need for research, in that assets often fail to perform as expected or provide adequate functional capability to satisfy user's needs. This is tracked through the delivery process, the measurement process and the validation through an experiment. The results of the experiment are analysed before providing observations and conclusions which contribute to overall knowledge.

Chapter six shows how the tools and methods described earlier can be arranged using these research methods to realise an experiment which provides useful knowledge in the relationship between the built environment and the social fabric of society.

Chapter 6

Development of Methods and Tools

6.1 Introduction

The review of both physical and social datasets identified a series of discrete methods for managing information. The opportunities to bring these data sets together to provide deeper insights into the impact of the built environment on people is an opportunity to elicit much deeper understanding as to the social outcomes of asset users. The methodology as to how to pursue this has been discussed in the Research Methodology description in Chapter five.

The purpose of Chapter six is to explain how the principles and theories presented in Chapters two, three and four are brought together to develop and experiment which can be used to demonstrate the principles we have defined. The Test Bench is a working manifestation of this approach but is not designed to be a production system, it is however a working research prototype developed to practically demonstrate the operational principles of the approach.

6.2 Designing the Research

The design of the research must incorporate all of the constraints described already both from a physical and social point of view. It must also incorporate the new functionality identified to enable the concept to double loop to be executed. Assuming the available data will allow useful analysis, the final challenge is to establish a method of measurement of personal satisfaction from the asset's owners, operators and users. There are many stakeholders and all assessments of personal view is based on perception. If this data was gathered, then the assessment of perception could be referenced to the quantitative building physics data and presented in a visual organisational model and graphically in the 3D BIM model in a way that could aid interpretation to lay users a really significant step could be taken in enabling the understanding and opportunities to intervene and take action to improve user's social outcomes and wellbeing during all phases of the project. The choice of the word intervene and action are significant as they are words used by Argyris (1982) in his definition of Double Loop Learning. The use of quantitative and qualitative data in a double feedback loop system brings together the physical built world and the softer human perception with a methodology that supports the research questions.

6.2.1 Feedback Techniques

Feedback is a process whereby information gathered about past performance is used to influence the same phenomenon in the present or future. The process creates a circuit or loop and the detection in the gap between required and actual performance is used to enact a feedback mechanism to close the gap. There are many examples of such systems, such as speed governors on engines and Lambda sensors on exhaust systems to control emitted CO^2.

As described in Chapter four there are many examples in buildings too, with temperature thermostats controlling heating and cooling systems, but each of these controlled systems has an impact on adjacent systems and is often dramatically impacted by the individuals using the asset and the use they make of it. Data from these communities of users are impacted by the organisational hierarchy and individual activities, prejudices and perceptions, making useful analysis challenging.

Making use of feedback data from both quantitative and qualitative data sources will require the qualitative data to be pre-processed to be suitable for analysis and processing with the quantitative asset reference data.

6.2.2 Linear & Continuous Briefing

To enable the principles of feedback described above to operate effectively it is necessary to identify the opportunities to influence both the asset's performance and any potential change or Action. Typically, the briefing process is the normal opportunity. The brief holds the definition of the asset's designed performance and specifies the future changes. If there were an electronic rendition of the brief, a feedback loop could be created from the "as designed", "as delivered" and "as operated" using the BIM and other project or performance data. This feedback loop would replace the traditional text based brief and simple linear design, procure and deliver process found traditionally.

6.2.3 Action & Double Loop Learning

From the work of Argyris (1982) where he described the theories of action, double loop learning and organisational learning and having discovered the ability to analyse data from the briefing, delivery and operational stages of an asset's life as described above, it is now possible for us to begin to understand how we can bring together data from both quantitative and qualitative sources to inform actions for improving the performance and social outcomes relating to the asset.

Figure 6.1 shows the elements of each of the systems as described. At point 0 is the electronic brief which is specific in its description of the functional outputs of the asset. This enables the asset to be digitally "checked" during service to evaluate performance. BIM is used to develop data requirements for design, procurement, delivery and handover into operations as identified by data exchange points 1, 2, 3 and 4. These points represent the formal data exchange processes defined by the Level 2 methods; they coincide with the APM/RIBA Plan of Works and can be digitally defined by the digital Plan of Works (dPoW). In service performance data is collected at point 5 and social perception data at point A. Feedback is identified by the thick arrows, namely at as built stage, as operated and as perceived. All of these data values are stored in a database depicted by the data cube. This service securely holds the data and provides it to enable presentation and analysis activities to be performed.

6.3 The Test Bench

6.3.1 Introduction

These elements in the current delivery process rarely come together., There are instances where many elements are present, but the combined scenario on a continual basis doesn't appear to manifest on a common basis. To evaluate and model the potential for this way of working in real time would clearly be of limited use as it could take between 10-50 years before useful results we emerge. To accelerate this approach and to provide a platform for inspecting delivery and lifecycle data a "Test Bench" approach has been proposed, where an ideal data collection scenario can be used to collect and analyse data at any point in the project lifecycle. This approach allows the inspection to be time sliced at appropriate periods of life stage to understand the performance of the asset and its impact upon its users. Consideration regarding time slicing strategies would include seasonal changes, asset usage and the effect of wear and aging.

The Test Bench system is specifically designed to enable this continuous data collection process enabling the asset's performance to be tested at any stage of its lifecycle. This approach will also enable the implementation of a time slicing strategy to enable learning from many projects to be analysed and reviewed at any stage of the project lifecycle.

The purpose of the Test Bench is "to demonstrate the research aims are achieved through a practical experiment". The design of any successful complex system can often be traced to the amalgamation of a number of smaller simpler systems. The ecosystems used to deliver built assets are complex entities which are brought together in exactly this manner. The advantages of this are teams can be configured for specific tasks of activities and can be selected on a best value or best of breed approach. However, the disadvantage is that the ability to invest in long term commitments and equipment continues to challenge innovation and significant improvements in productivity. The emerging digital tool kits in common use are capable of producing data sets which can be used to manage the project lifecycle. The Test Bench takes these datasets and holds them in a database to enable modelling of briefing, design, as built and as operated datasets. The as operated datasets consist of data from the building physics and engineering data, geometry and perceptive data from the communities using the data.

6.3.2 Data Generation Instruments

Figure 6.1 presents the five key elements of functionality delivered by the Test Bench. The methods of data acquisition the researcher has adopted for this research are based on the UK Government's "Level 2" definition. These are defined in BS1192:2007 Ad2 (2007) and rely on the astute understanding of all supply chain (including clients) information and data needs. These requirements are mapped to procurement documents through the employer's information requirements (EIR) to enable clear procurement rules to be defined.

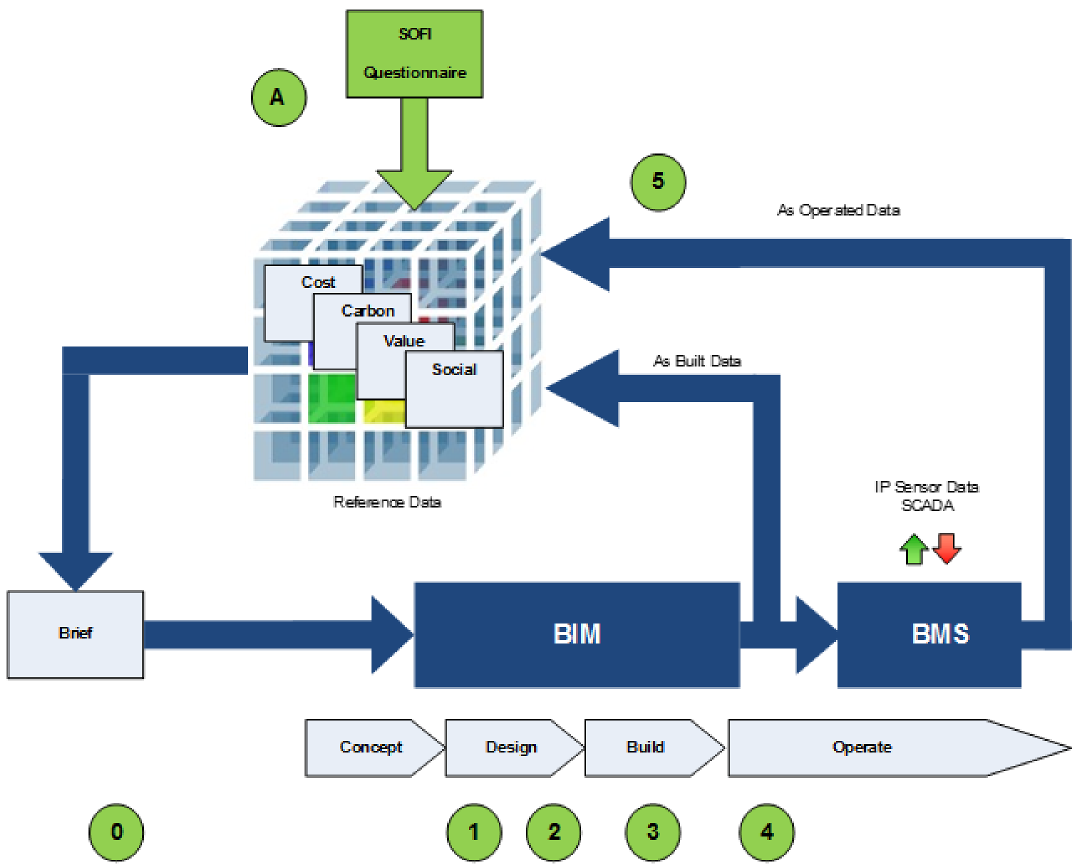


Figure 6.1 - Test Bench High Level Context

There are five key data generation instruments incorporated in the design of the Test Bench.

6.3.2.1 The Briefing

The use of an electronic brief allows the brief, emergent design, as built design and operational design to be compared and reference data obtained over time and from comparable assets. The brief will be needed to be held in a digital format such as IFC or COBie, which should be derived from the traditional briefing process. A digital format will be required to enable electronic checking of the design and operated data.

6.3.2.2 The Delivery

Design, analysis, procurement, construction and commissioning using Building Information Modelling (BIM) tools to create geometric tools and COBie data sets.

6.3.2.3 The Operation

Operational data is derived by Building or Asset Management Systems B(A)MS. As described in the scope of this research the data structures and process being employed here are based on the UK Government Level 2 definitions. All the delivery stages described above have British Standard documents describing their generic operation. Table 6.1 describes the eight documents which lay out the methods for managing digital information throughout the built asset lifecycle.

Table 6.1 - UK Level 2 BIM Standards & Tools

Document	Description
PAS1192:2:2013	This document describes the production of co-ordinated design and construction (CAPEX) information, it is designed to be independent of any procurement route or form of contract is used. Each task needs to be carried out in a particular order for the mutual benefit of all those involved, otherwise known as ”collaborative working”. In a collaborative working environment, teams are asked to produce information using standardised processes and agreed standards and methods, to ensure the same form and quality, enabling information to be used and reused without change or interpretation. If an individual, office or team changes the process without agreement, it will hinder collaboration – a participant insisting on “my standard” is not acceptable in a collaborative working environment. Wherever possible, the principles of lean are also described to reduce the expenditure of resources for any goal other than the creation of value for the employer. The document references BS 1192:2007 which promotes the avoidance of wasteful activities such as: • waiting and searching for information • over-production of information with no defined use

Document	Description
	• over-processing information, simply because the technology can • Defects, caused by poor co-ordination across the graphical and non-graphical data set which require rework. The document clearly describes the data descriptions and processes to enable this lean delivery process. The document also deals with the decommissioning processes at the beginning of the cycle. It may be that this area will require further development to suit the demanding markets of Nuclear and Offshore.
PAS1192:3:2014	This document describes the same data and process delivery and use definitions as described above, but for the operational phase of the asset (OPEX). Of key focus is the development of PAS 55 compliance operational strategies and the effective transfer of data across into operations to aid soft and effective landings
BS1192:4:2014	This document is the final development of COBie-UK-2012, which is the interim data definition for information deliveries. This has been further enhanced and developed through work carried out in the infrastructure market to develop "COBie for all"
PAS1192:5:2015	A document aimed at raising awareness and processes for protecting access of data from those who should not have access
BIM Protocol	A suite of BIM commercial and contractual advice documents and standard forms
Government Soft Landings (GSL)	A suite of documents describing Soft Landing policy and processes to ensure effective involvement of users and operators in the development of scope, design and delivery. Also ensuring effective training and handover into operations and finally the structured gathering of Post Occupation (Operational) Effectiveness data, to enhance both the current and future assets.
Classification System	A structured and standardised information classification system. (Uniclass for the purposes of this research)
The Digital Plan of Works (dPoW)	An industry standard method of describing geometric, requirements and data deliveries at key stages of the project cycle to enable clear definition for contractual deliveries of information

6.3.2.4 Performance Measurement - Telemetry, SCADA, Sensors, BMS and IoT

There are many potential data capture sources available within an operating asset and these have developed over the past two decades. These include telemetry, Building Management Syste4ms (BMS), Supervisory Control and Data Acquisition (SCADA) systems and more recently the emergence of the Internet of Things (IoT). Key focus for this research is those quantitative data that are in common use currently giving key operational information regarding the critical building physics measures such as usage, air quality, temperature and light and this research will focus on the measured values from the selected measurement technology rather than the underlying technology itself.

6.3.2.5 Social Perception Feedback

The collection of social data is at an early stage but social media techniques and mapping are giving new insights to the ways that data is used and people communicate within their communities. The research showed relatively few organisational tools with robust literature to underpin the level of rigour needed to analyse such a complex scenario as an operational asset. There were also very few tools that allowed the integration of multiple assets to analyse the impact of assets on each other. From research described in Chapter three, the SOFI system was selected as an approach and toolkit to undertake this part of the research.

6.4 Detailed Definition & Application of Data Instruments

6.4.1 Briefing Process

The process of briefing is to achieve a clear articulation of the client's needs; this is normally interpreted by a design professional (commonly the architect) into a specification or "brief" as described in Chapter two. This is a complex process and there is as Kiviniemi (2005) discerns a difference between briefing and requirements management. Requirements Management is the process defined by Kiviniemi (2005) which is designed to improve the management, definition and control of the design and delivery process. He observed that in current AEC practice client requirements are typically recorded in a building program, which, depending on the building type, covers various aspects from the overall goals, activities and spatial needs to very detailed material and condition requirements. This documentation is used as the starting point of the design process, but as the design progresses, it is usually left aside and design changes are made incrementally based on the previous design solution. As a consequence of several small changes and without any conscious decisions to change the scope, this can lead to a solution that may no longer meet the original requirements. In addition, design is by nature an iterative process and the proposed solutions often also cause evolution in the client requirements. However, the requirements documentation is usually not updated accordingly. In the worst case the changes are recorded just in the memory of the participants, and in the best case in meeting or personal notes. Finding the latest updates and evolution of the requirements from the documentation is very difficult, if not impossible. This process can lead to an end result which is significantly different from the documented client requirements. Some important client requirements may not be satisfied, and even if the design process was based on agreed-upon changes in the scope and requirements, differences in the requirements documents and in the completed building can lead to well-justified doubts about the quality of the design and construction process.

The main reasons Kiviniemi (2005) states for this are:

- The amount and complexity of project information
- The duration of projects
- The need for designers to work simultaneously on projects
- Changing stakeholders in different project stages
- Shifting design focus, e.g. moving from overall problem solving to detailed technical solutions

To avoid this phenomenon, the emergent design, delivered asset and operational asset must be performance managed with respect to the original requirements. To enable this Kiviniemi (2005) reviewed potential solutions for the tracking and management of design information with respect to emergent design. He analysed the market and academia for potential methods and having rejected approaches such as dRufus, BLIS, IFC, CIFE's VDC Framework and the Berkeley National Laboratory's Design Intent Tool for technical systems, he elected to develop the PREMMIS system. In this system he created the necessary entities and functions to manage the full briefing process for architectural spaces. As these functions also satisfied the needs of the researchers scope a modified version of PREMMIS has been used with this research to form the point of reference for briefing information. Briefing processes are held in the Tables prefaced by a "P_" notation and have been incorporated into the design of the Test Bench. They are displayed in the entity-relationship model shown in Figure 6.2 below.

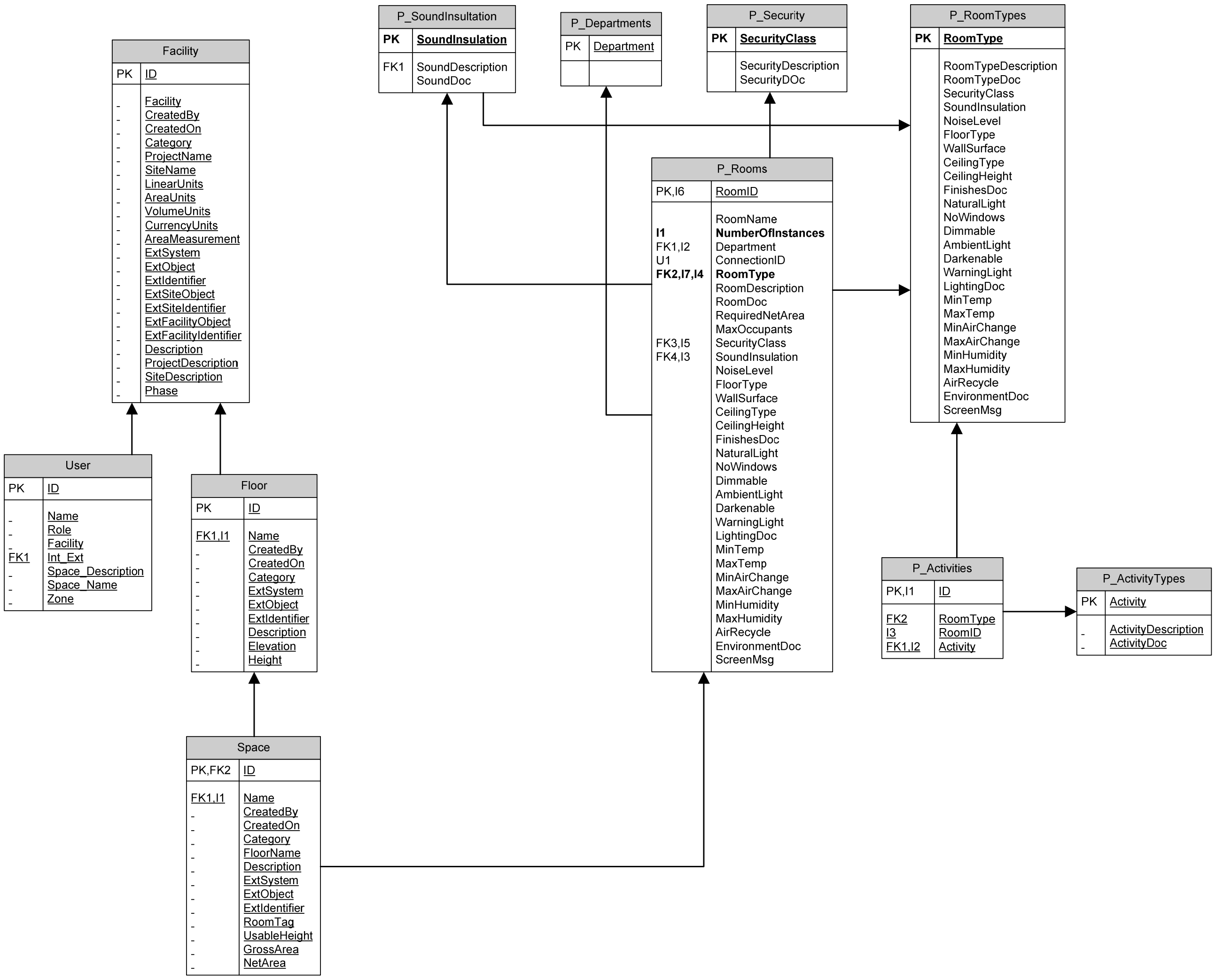


Figure 6.2 – Test Bench ERD, showing P_xx Briefing Entities

These tables will hold the reference briefing information which will be used to analyse the data captured by the sensors once the asset is in use. They will form the fundamental benchmark point to create the point feedback is created. This feedback will be combined with the social perception data to provide further analysis to understand the relationship between the building's performance and its users. The use of different time horizons will enable the analysis of both macro and micro impacts of the asset in terms of the short term instant asset performance through to the longer term impacts.

The results of this analysis will enable the design team to optimise the performance of the asset through its life through interventions and retrofits to address both user requirement changes and the gradual derogation of the asset's condition. These iterations are reflected by the process which occurs during the design phase as discussed by Kiviniemi (2005) indicated in the model shown in Figure 6.3.

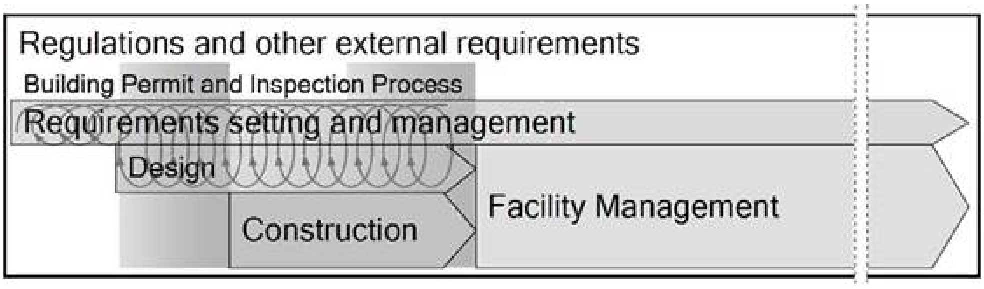


Figure 6.3 Iterating design and parallel process view. Kiviniemi (2005)

6.4.3 The Delivery

The delivery phase of a project is where the client’s requirements (brief) are converted from a textual or electronic brief into a design, is procured, constructed and commissioned before being handed over to a user. This phase is very information intensive and is often the focus of the "cost", however the capital delivery of and asset often only represents 20-30% of the total whole life cost. This is of specific concern to this research as it is in this phase that many often sound ideas are lost through the poor application of "value engineering" activities, with the associated loss of value envisaged by the original design. This is due in the main to commercial pressures to contain capital expenditure at the expense of longer term operational benefits.

The process of managing a design and its associated information is governed by contracts, standards, best practice and guidance notes. These, as discussed in the literature review, have long histories and only in part lend themselves to the management of digital information. For the basis of this research we have used the processes and controls as defined by the UK Government "Level 2" as described in Table 6.1. These define the processes and data required to be delivered at each stage of the asset delivery lifecycle. There is a working assumption that BIM tools or products will be used to develop the geometry and data to describe the physical asset. For this research the various scopes and forms of contract details have been assumed to provide the generic capability to enable specific data to be specified at any stage it may reasonably require by the client.

Building Information Modelling is now considered to be a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception through to demolition. Various tools are used to create data of both the tabular and geometric types. These are in the main stored in proprietary data structures. Most tools in the market allow these datasets to be exported to open standards such as IFC and COBie. As this process insulates this research from the tools the researcher has assumed that all data required will be available in these formats.

It is an expectation of implementing Level 2 BIM project that the client and supply chain will spend some time defining processes to identify how data will be identified, acquired, processed and exchanged to enable a smooth, effective functioning business. The construction delivery process is shown in generic high level form in figure 6.4 in the form of an IDEF0 process model. This indicates a full end to end IDEF0 process definition of an entire project delivery and operational lifecycle. The key data exchange point discussed in common plan of works documents such as the RIBA Plan of Works, (RIBA 2013) are indicated as green spheres. These are the key points when data specified by the client is collected and verified by the client to service key business decisions.

The exact definition of the data exchange points (green spheres) are specific to the particular procurement strategy. For the examples shown here they are shown at a summary level depicting:

0 Briefing
1 Capital Approval
2 Supplier Selection
3 Target Cost
4 Handover
6 Post Occupancy Evaluation

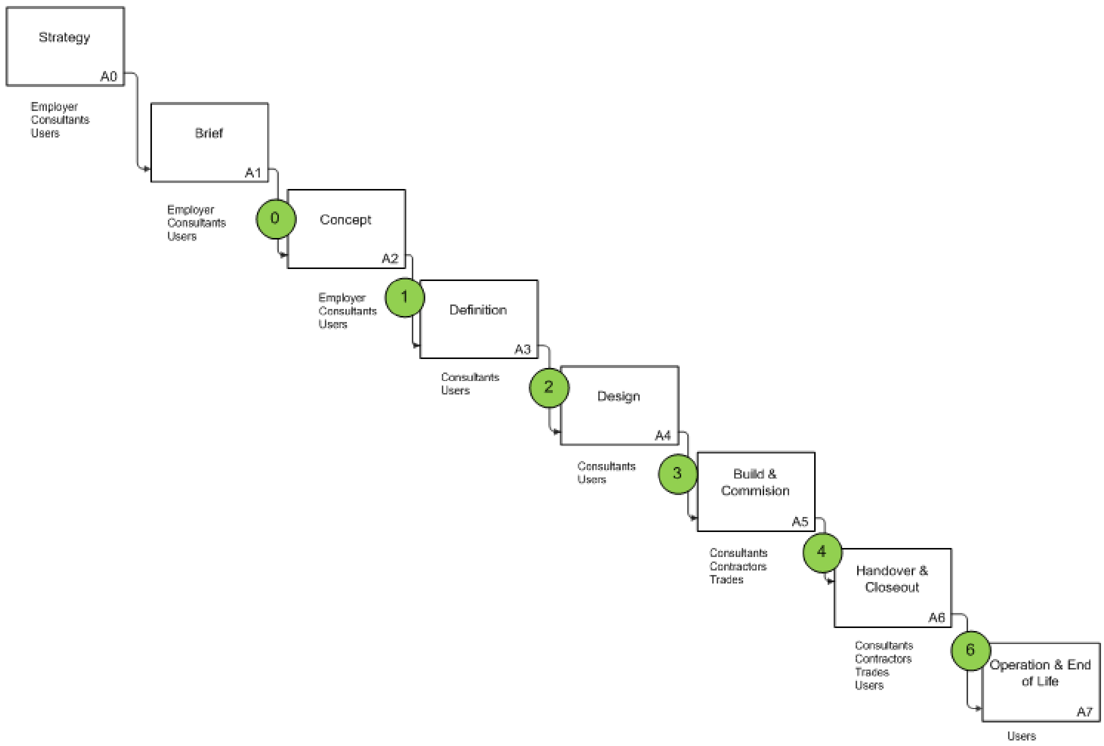


Figure 6.4 - IDEF0 - Building Lifecycle Process Model (For Physical Elements)

This generic process model at its very high level is designed for the explanation of the overall context, data flows and exchange points described by the green spheres. However, more detail is needed to define the detailed needs and activities for each participant in the project. Figure 6.5 shows a standardised implementation of a full lifecycle produced by the UK BIM Task Group and published in by the BSI. The process demonstrates the same fundamental process as that seen in figure 6.4, but introduces the fundamental relationship between the client and supply chain with the data exchange points between each community around the controlling rules embodied in the contract (depicted by the thick black vertical line)

On the left hand side of the diagram are the various tiers of the supply chain and to the right the clients key decision points shown as red diamonds. The green diamonds are the interim decision pints made by the supply chain. The sliding blue box in the centre demonstrates the impact of the various procurement strategies. It is normally up to the prime or tier one supplier to determine the nature of the relationship through the lower tiers, but it would normally be expected to place some requirement on the sub-suppliers to provide detailed information and data deliverables.

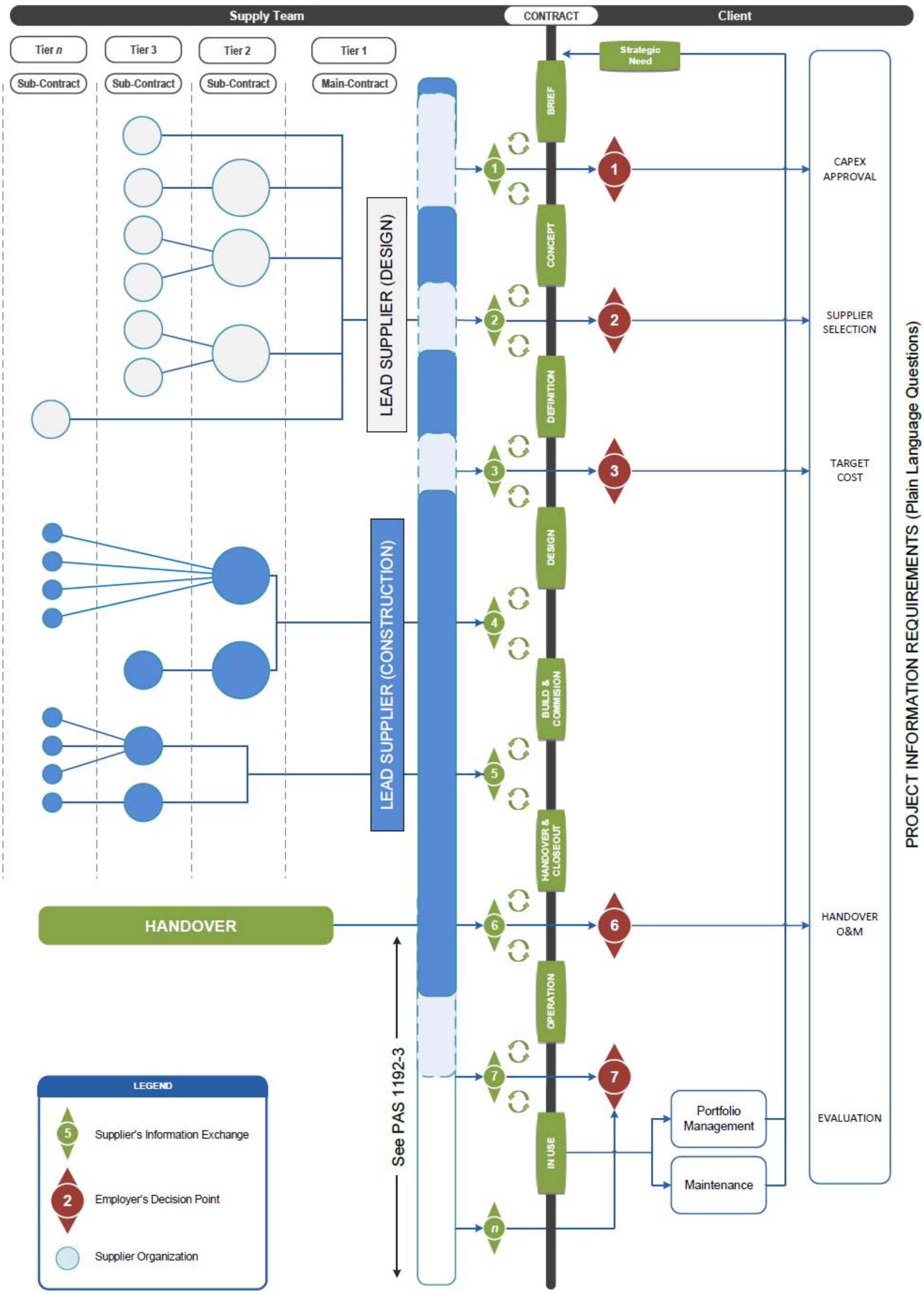


Figure 6.5 – © BSI 2014 – PAS 1192-2-2014 Data Exchange Points between Client (demand) and Supply Chain

The detailed activities which take place between each of the data drops differs as the project progresses. The process flows shown in figures 6.6a – f detail these activities. The activities shown are generic but are consistent in indicating the key features of data needs (red diamonds), data delivery (green spheres), business activities (processes) (White and grey boxes) and the functioning of the common data environment (CDE) designed to ensure that users always provide and consume the correct up to date information.

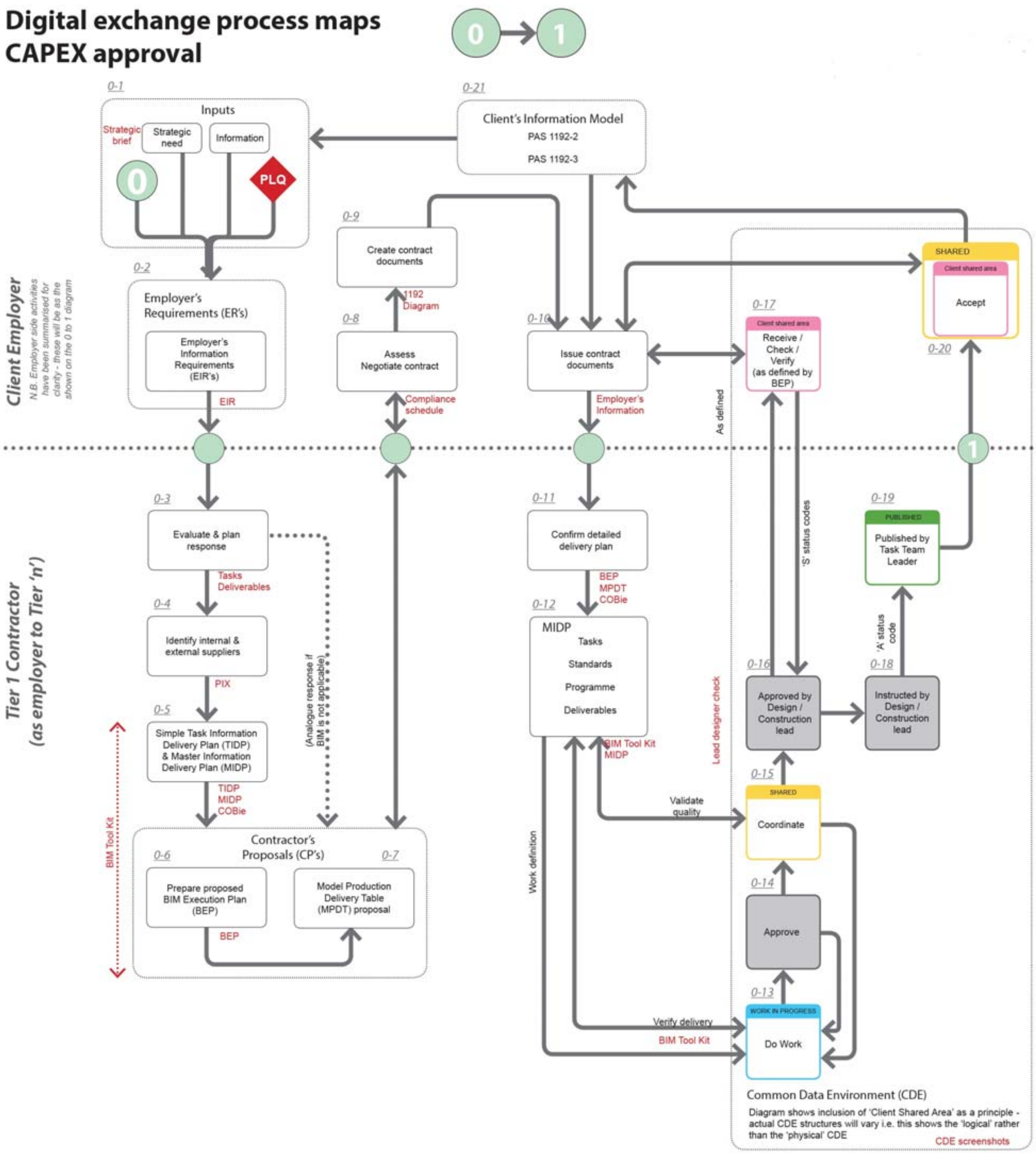


Figure 6.6a - Detailed view of data exchange 0 – 1 Briefing Stage

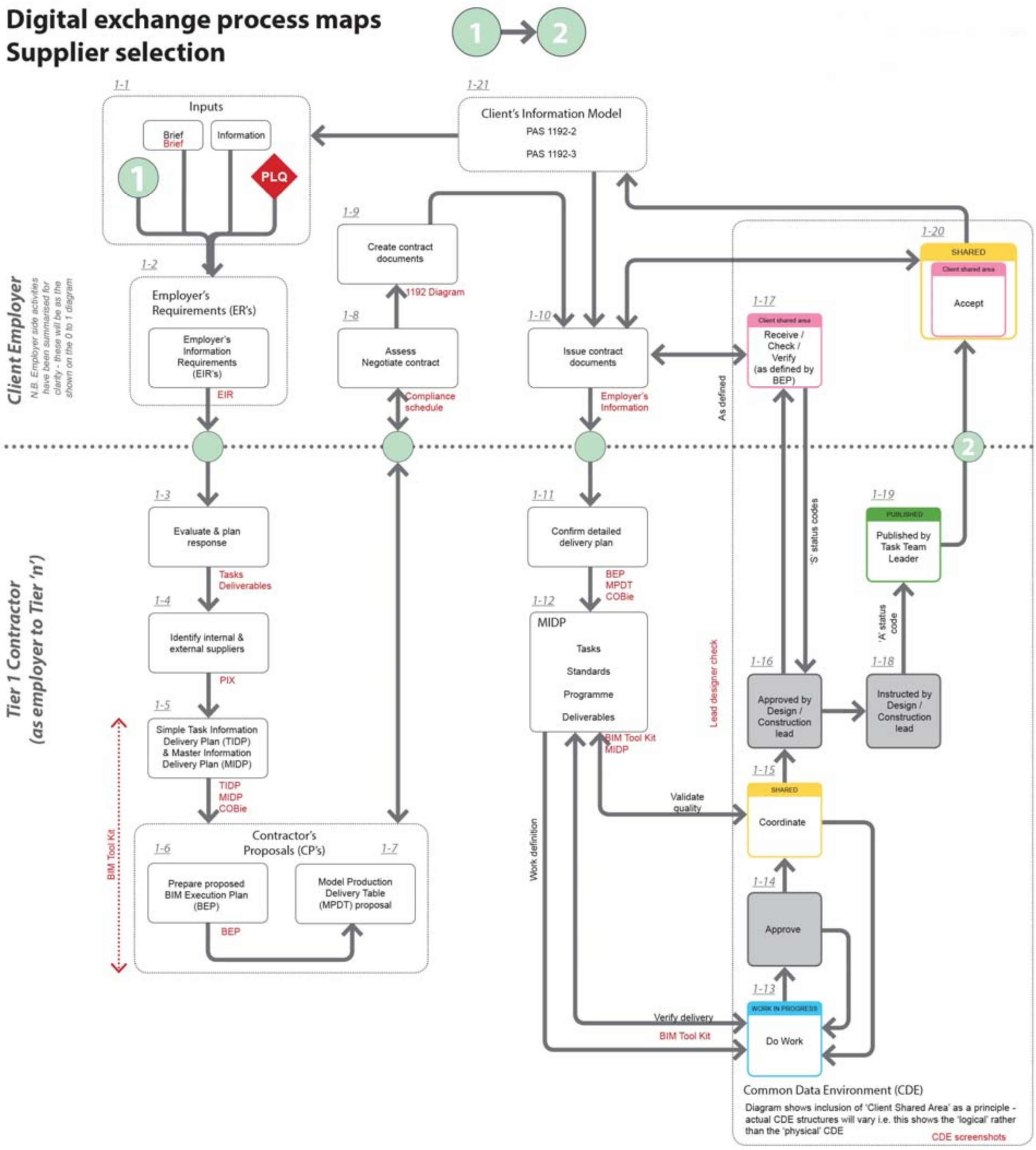


Figure 6.6b - Detailed view of data exchange 1 – 2 Concept Stage

Digital exchange process maps
Target cost

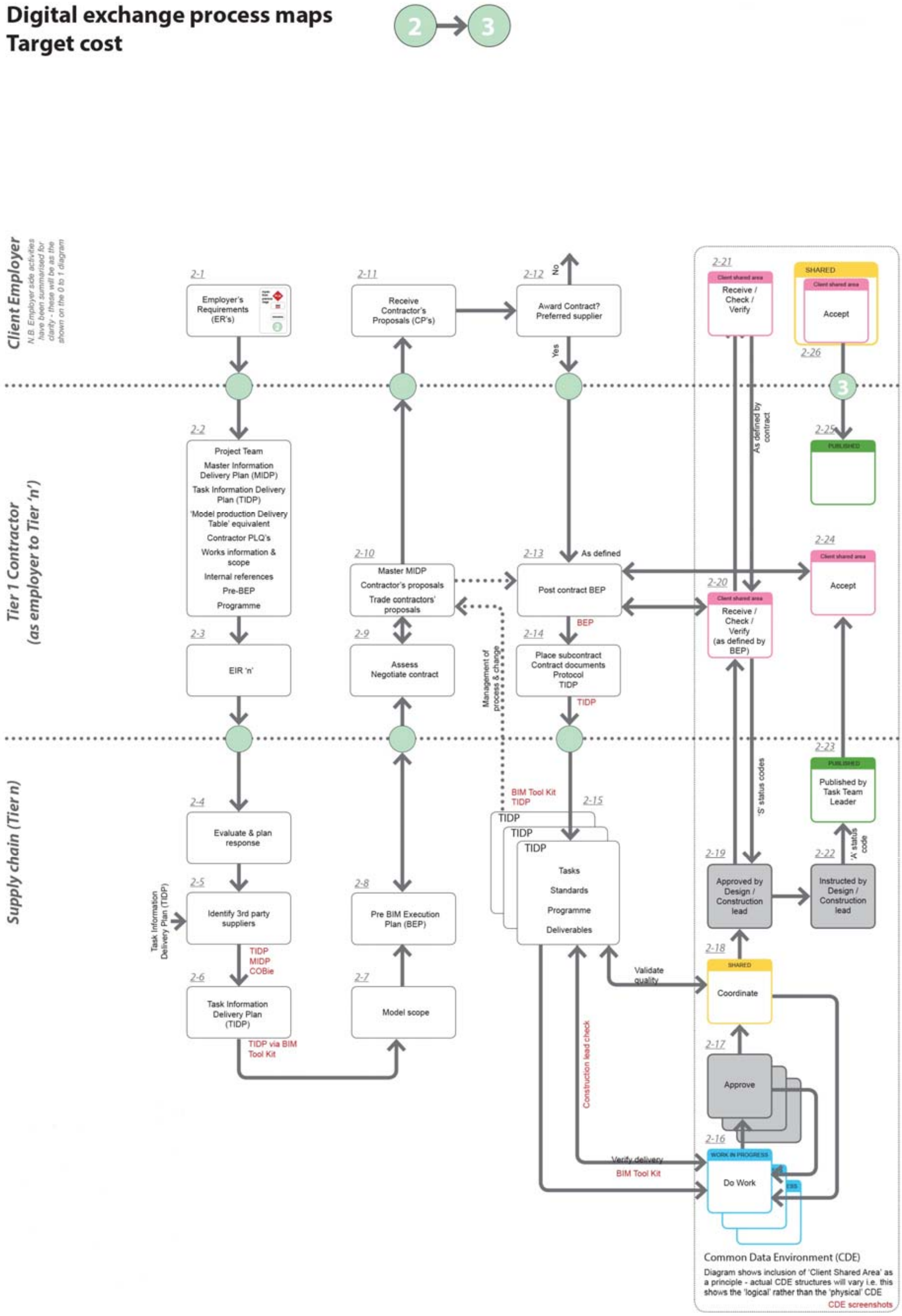


Figure 6.6c - Detailed view of data exchange 2 – 3 Design Definition Stage

Digital exchange process maps
Build & commission

3 → 4
4 → 5

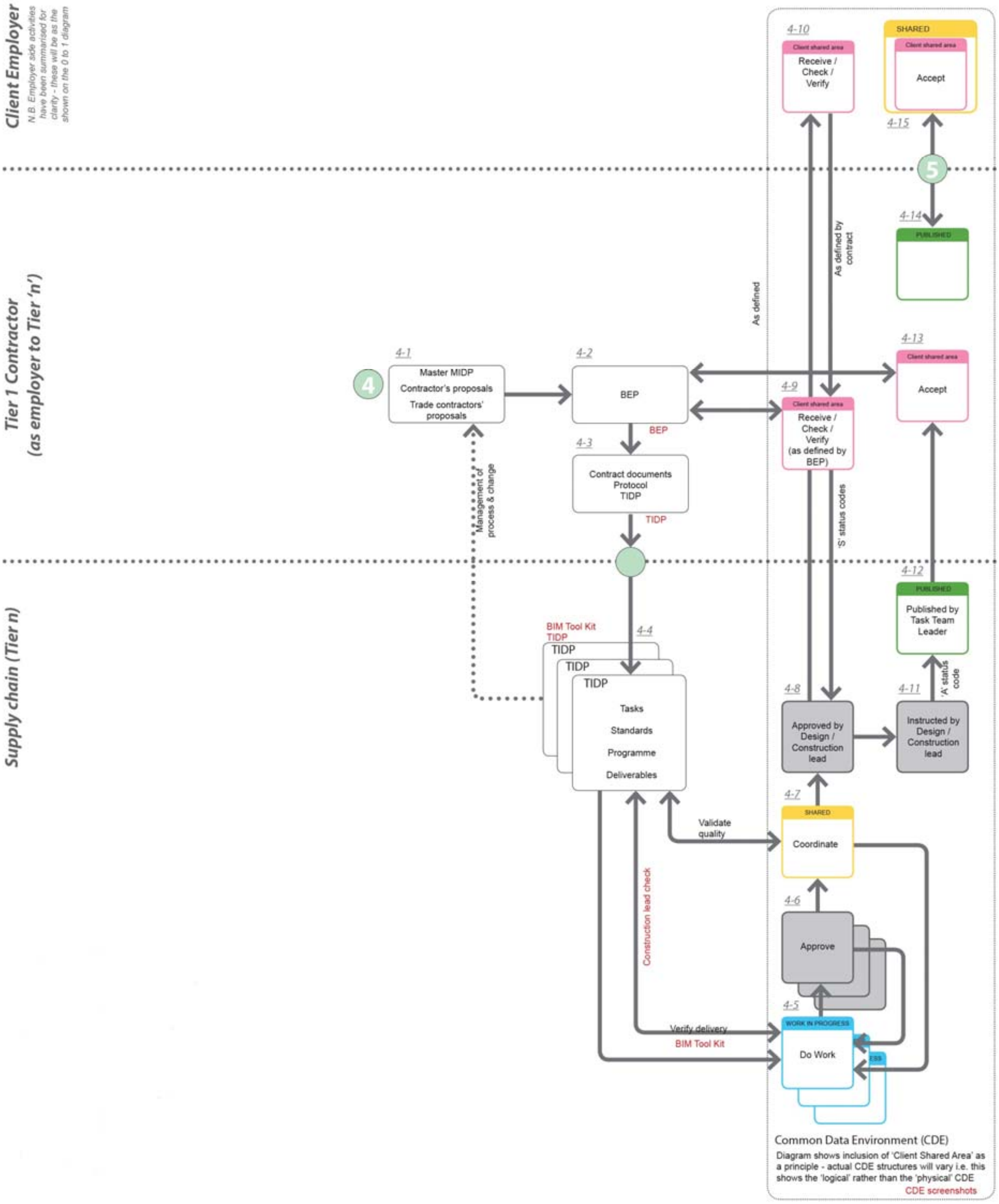


Figure 6.6d - Detailed view of data exchange 3 – 4 Design Stage and 4 – 5 Build & Commission

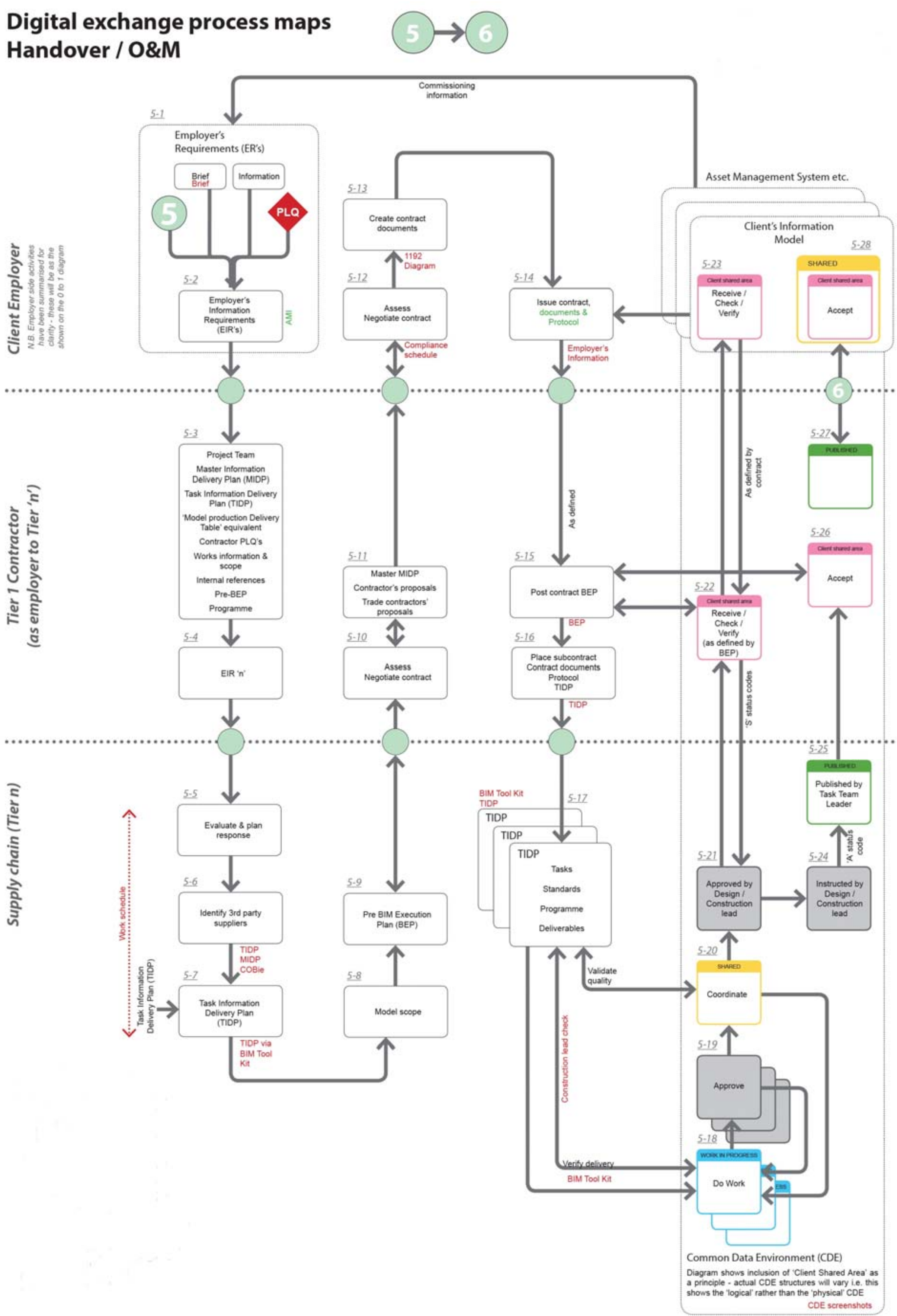


Figure 6.6e - Detailed view of data exchange 5 – 6 Handover and Operational Stage

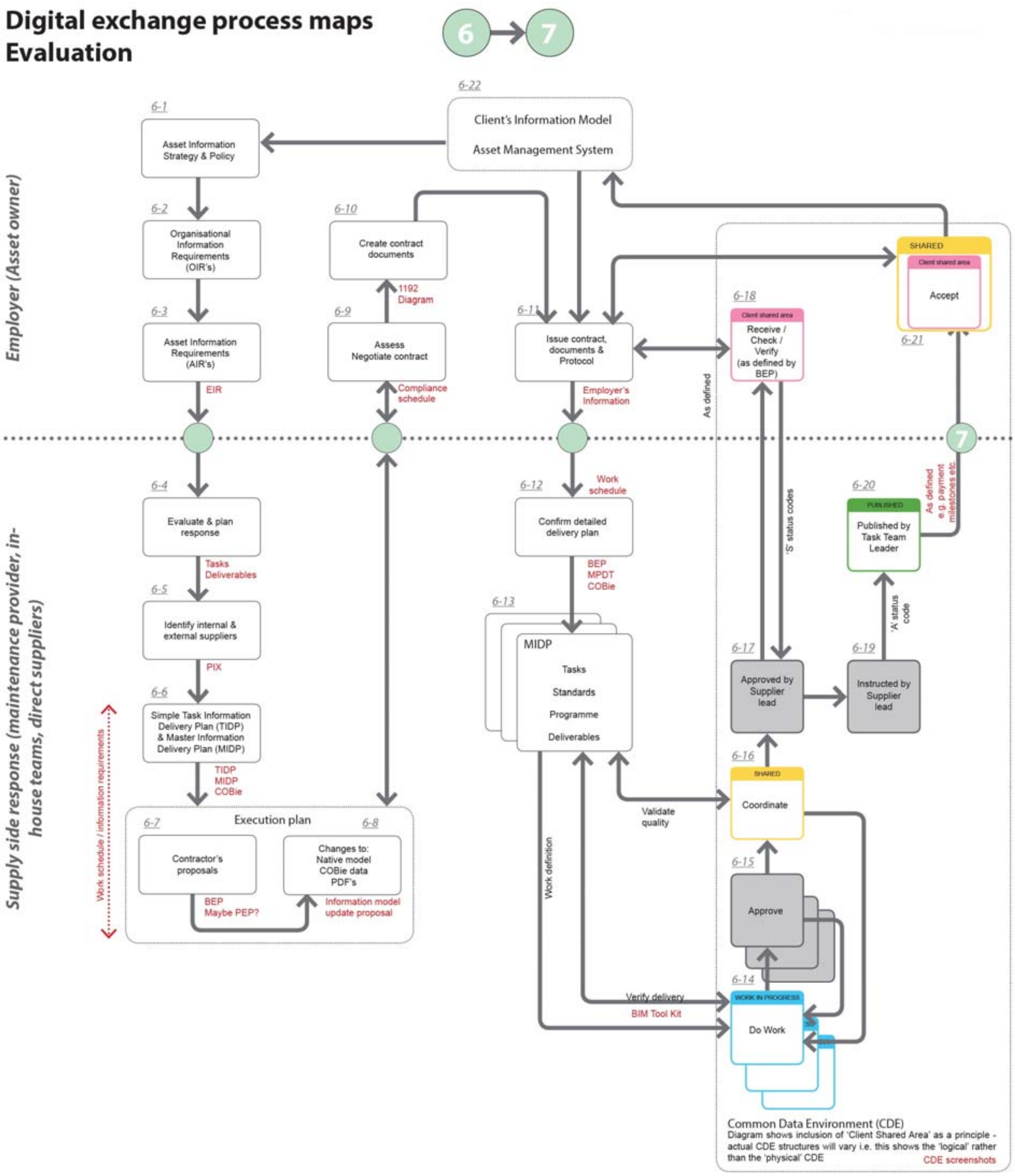


Figure 6.6f - Detailed view of data exchange 6 – 7 Evaluation Stage

The purpose of demonstrating this detailed analysis is to identify the data demands that are required to be acquired at each project stage. This data is acquired as discussed above in a standard format or schema. Level 2 specifies the use of COBie and it is this format that will be used for this research. Each stage of a project is defined by a process, in figure 6.5 and figure 6.6 a-f these processes are defined through the process boxes. At key stages of the project there are decisions to be made. These can be governance points or other key decisions such as tender selection, payments or handover of an asset into operations. To analyse the data needs for these decisions a methodology of identifying key business questions has been adopted whereby the information and questions are documented and used to create a mapping to the data entities held in the COBie schema. Table 6.2 documents the Plain Language Questions (PLQ) for a generic school asset. The stages align with the APM/RIBA Plan of Works. The Table further identifies where data is likely to be located to enable the appropriate commercial measures to be implemented to acquire the data.

Table 6.2 - Plain Language Questions (Generic Asset)

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
0 – Output Definition	1) Is the scheme likely to get Planning Permission?		x		
	2) What are the outline costs?				x
	5) Has Market research been carried to determine demand?		x		
	3) What is the likely revenue income?				x
	4) Have we got the resources to deliver the project?		x		
	5 What are the social imperatives the project seeks to achieve?		x		x
1 – Output Definition	1) What are the site extents?			x	x
	2) What is the Project type? –commercial, residential, mixed, transportation, maintenance operational		x		x
	3) What are the Site layout options? – Routes, adjacencies, servicing, building position and massing model			x	x
	4) What is the resettlement and decant plan?		x		
	5) Target cost?				x

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	6) What is the design and construction programme?				x
2 - Feasibility	1) Is there accurate survey data of the site?	x			x
	2) What are the estimated development costs?				x
	3) What are the forecast revenues?				x
	4) What is the available site?				x
	5) What physical constraints are there on and around the site?	x			x
	6) What services constraints (water / drainage / electricity) exist?	x			x
	7) What site-specific safety and security considerations need to be made?		x		
3 – Option Selection	1) Do the concepts being considered meet clients brief?		x		
	2) Has the market research been carried out suitably on the proposed suppliers?		x		
	3) Do the proposed suppliers meet pre-qualification criteria?				x
	4) Do the proposed suppliers have adequate BIM and data management capability		x		x
	5) What are the costs?				x
4 – Single Option Development	1) What is the pre-design solution? In particular what are the layouts and adjacencies?				x
	2) Does the architecture meet the vision?			x	x
	3) Does the design's performance meet the design brief?		x		x
	4) What is the outline proposal for structural design?			x	
	5) What are the output requirements from services systems?			x	x
	7) What targets are to be used for Post Occupancy/Operational Evaluation?		x		x
	8) What is the commissioning strategy and how can it be tested?		x		
	9) Can the designers show the project can		x		

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	be delivered safely?				
	10) Has the concept been designed for efficient manufacture and assembly?		x		x
	11) How easy is it to build?		x		
	12) What is the preliminary cost estimate?				x
	13) Does the design optimise the use of standard library?		x		x
	13) Is the Architectural, MEP and Structural design coordinated?				x
	14) Can the MEP services and structure be combined within the Architectural Design within the proposed 3D volume strategy?			x	x
	15) Has the market research been carried out suitably on the proposed suppliers?				X
	16) Do the proposed suppliers meet pre-qualification criteria?				X
	17) Do the proposed suppliers have adequate BIM capability				X
5 – Detailed Design	1) Have all the deliverables of the design brief been met?		x	x	x
	2) Is the Architectural, Structural and MEP design coordinated?			x	
	3) Is the design developed to demonstrate detailed proposals for site layout?			x	x
	4) Is the design developed to demonstrate detailed proposals for planning and spatial arrangements?		x	x	x
	5) Is the design developed to demonstrate detailed proposals for external design?			x	
	6) Is the design developed to demonstrate detailed proposals for environmental systems?			x	
	7) Is the design developed to demonstrate detailed proposals for buildability?			x	
	8) Does the design meet other aspects of statutory standards, specs and brief?		x	x	x
	9) Has value management/ engineering taken place?		x		

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	10) Is the design safe to construct?		x	x	
	11) Is the design safe to use?		x	x	
	12) Does the design optimize the use of library components versus bespoke components?		x		x
	13) How are the facilities/asset built?		x		
	14) What are the task durations?				x
	15) How will the client be consulted with respect to detailed changes to designs during construction?		x		
	16) Is the information complete enough to procure the package contractor?		x		x
	17) How are defects controlled and managed?		x		
	18) Do the systems being commissioned meet clients brief?		x		
	19) What are the actual costs?				X
	20) What is the actual carbon?				X
6 Test & Commission	4) Do the systems integrate as the brief?		X		
	5) Is the data ready to hand back to the client/operator		x		x
	1 What are the Asset Management Datasets?				x
7 – Scheme Hand Back	2 Third party interfaces		x	x	
	1) Does the Project meet the brief?		x	x	
	1) Does the Project meet the brief?		x	x	x
	2) What changes have been incorporated?				
	3) What has been actually built?				x
8 – Project Closeout & Operate	4) Does the asset perform to its sustainability and output specifications		x		
	5) Are the operational data feeds working?		x		x
	6) How does a specific product / element				x

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	perform?				
	7) How is the facility/asset being operated?		x		
	8) How is the facility/asset being maintained?		x		x
	9) How has the GSL and POE performance worked?				

As the project progresses the data maturity increases. This phenomenon is necessary to enable the data to be of adequate fidelity to answer the questions. The concept of data fidelity is vital as it enables us to establish whether the data we are transacting is of a suitable quality and maturity to give an answer within the limits of tolerance to be valid and safe or not. Figure 6.7 depicts this progressive maturity graphically for a single element of an asset. Clearly when defining data, the maturity requirements will be different for each type of asset element. For example, a bespoke element such as a feature or elevation will need earlier data maturity than say a commodity item such as a pump or concrete plank to establish key information such as cost certainty.

A limitation of the COBie data schema is the lack of an entity which indicates "state". State is the functionality used to identify the stage that a data set is applicable (ie APM 0-7). To create a "work around" for Level 2 the Common Data Environment (CDE) defined in PAS1192-2/3 is used to identify the delivered schema as a file. Once this file is received it is then transformed in the Test Bed database where the necessary attributes are applied. It can also be noticed that a number of questions are repeated in Table 6.2, this is for the same reason, i.e. to establish key metrics as the project progresses such as programme or cost. As the data increases in maturity the greater the quality of the derived answer. This concept will be especially important to consider in the design as any tolerance of error at any key stage will need to be understood in the context or any perceptive errors gathered in the social perception data set.

The PLQ are indicated as red diamonds and the data to be delivered is embedded in the green spheres as part of the contract (as part of the Employers Information Requirements (EIR)).

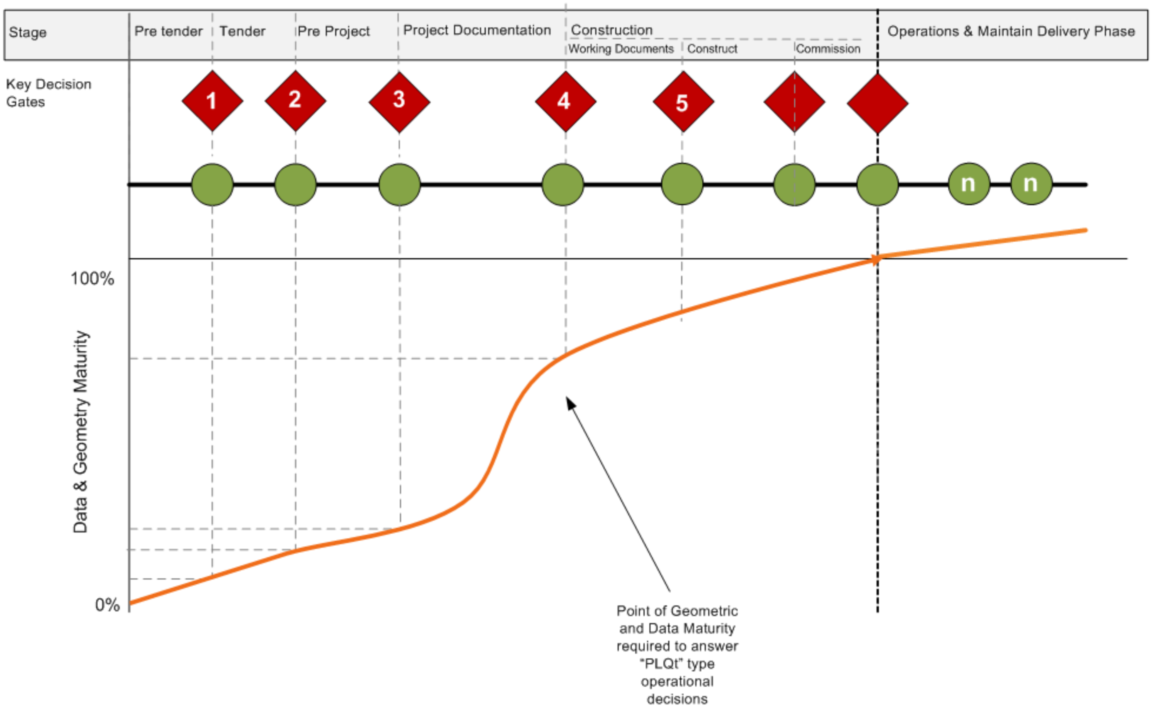


Figure 6.7 - Progressive Data Delivery Maturity Curve

The amount of data to be delivered is governed by two key variables. The first is the minimum data needed to answer the key "Plain Language Questions" (PLQ) a client has identified. These are high level governance style questions which are fundamental to the operation of the client's business. There questions are often so high level that they can be broken down into many smaller sub questions. The clear articulation of these questions is key to understanding both the client's operational needs but also the data entities required at each stage of the project. This process is illustrated in Figure 6.8 below. From the PLQ described in Table 6.2 we can develop more detail and understanding of what data is needed to be acquired to service the queries. To achieve this there is more work to be undertaken to establish the data entities and attributes. The questions need to be decomposed as shown in figure 6.9.

The PLQ is broken down into the actual series of detailed questions that are being asked and these sub-questions or "Actual Detailed Questions" (ADQ) are then analysed to create "Digitally Compliant Questions" (DCQ).

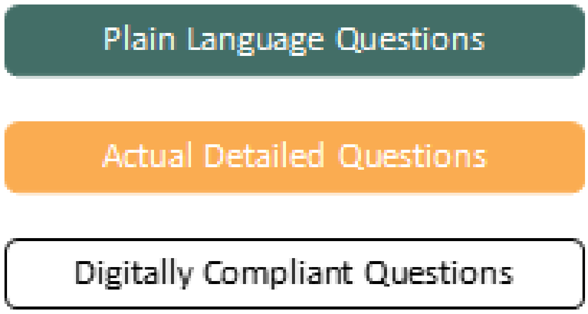


Figure 6.8 - Question to Attribute Decomposition

Once the DCQ are identified they can be mapped to the COBie Schema as shown in figure 6.7. The schema can be thought of as the "Information Required" from the supply chain delivering the asset. This information required or "demand" schema can then be used to validate all future data deliveries. The “digital Plan of Work” (dPoW) been developed to automate this process. There are a number of emerging toolkits to assist with this development of these data "demand" schema, such as the NBS BIM Toolkit. Additional information such as the data sources and formats as well as key responsibilities enable this schedule to be used for commercial and procurement activities.

Questions Data and Information Definition Schedule

Client: University College London Hospitals
Project: Generic Two Stage Tender - this is full case and we will need to look at the reality of what can be answered for the stages for the varying phases?
Coordination Versic 0.4.1 *(Version coordinated with respective End-to-End Business Process Map)*

UID	Q Type	Decision / Question	Digital Query	Deliverable	D Type	Responsibility	System	Source	Assumptions	Application: Phase 4 / PBT	Application: Phase 5	Application: Future Projects
		COST										
1.1.2	ADQ	What is the budget for the capital works and installations?	Non digital - human collation of information	Capital Works and Installations Cost Report	Document	Cost Consultant	PDF combing various outputs	Capital Works and Installations Cost Schedule Interpretive Report on Capital Works and Installations Area Shift Interpretive Report on Capital Works and Installations Rate Shift	Budget is based on cost of space rather than components at this stage. An outline report should be available for current projects, but may bnot be informed by the BIM information.	✓	✓	✓
1.1.2.1	DCQ	What is the cost?	Multiplication of current Capital Works and Installations Briefed Areas and Capital Works and Installations Cost Rates	Capital Works and Installations Cost Schedule	Data	Cost Consultant	MS Excel	Current Capital Works and Installations Briefed Areas and Cost Rates data.		✗	!	✓
1.1.2.2	DCQ	What is the shift in cost since the last data drop?	Delta between current Capital Works and Installations Cost Schedule and previous Capital Works and Installations Cost Schedule	Delta Table on Capital Works and Installations Cost Shift	Data	Cost Consultant	MS Excel	Current Capital Works and Installations Cost Schedule and previous Capital Works and Installations Cost Schedule		✗	!	✓
1.1.2.3	DCQ	Why is there a shift in areas since the last data drop?	Non digital - human interpretation	Interpretive Report on Capital Works and Installations Area Shift	Document	Project Manager	MS Word	Review of Delta Table on Capital Works and Installations Area Shift.		✗	!	✓
1.1.2.4	DCQ	Why is there a shift in rates since the last data drop?	Non digital - human interpretation	Interpretive Report on Capital Works and Installations Rate Shift	Document	Cost Consultant	MS Word	Review of Delta Table on Capital Works and Installations Cost Shift.		✗	!	✓
1.1.2.5	DCQ	What are the space areas as designed?	What are the net and gross Capital Works and Installations Briefed Areas?	Briefed Capital Works and Installations Areas	Data	Project Manager	MS Excel	COBie from federeated model - see schedule		✗	!	✓
1.1.2.6	DCQ	What are the cost rates?	What are the known, unusual and novel Capital Works and Installations cost rates?	Capital Works and Installations Cost Rates	Data	Cost Consultant	MS Excel	Known element rates from Cost Consultant database Unusual element rates from market specilaists consultation Novel element rates derived from Cost		✗	!	✓

Figure 6.9 - PLQ - Entity - Attribute Relationship Matrix

6.4.3.1 Purpose and Relationship with the digital Plan of Work (dPoW)

The progressive delivery of data during the lifecycle is a key part of the asset delivery process. At the beginning of the project, the information will be a brief and have very basic details of common components and concepts. This is important to enable the design team the opportunity to be flexible and innovative in the design of the asset to meet the client's needs but is very wasteful in that much "new" design is actually reconstituted old thinking. The concepts of standardisation and componentisation are key to this process if the desire is to concentrate on the unique value adding elements of the asset but the dangers of over standardisation can in the extreme stifle innovation and new thought and opportunities to add value will be missed. The interpretation and understanding of the brief at this stage may be achieved by offering options to engage user's thorough processes such as Soft Landings or other user engagement activities.

6.4.4 Asset, Facilities & Operational Systems

The impact of well-maintained clean and vibrant cared for buildings and those which are tired and run down have a massive impact on the inhabitants and users wellbeing and effectiveness. Around 80% of the costs of an asset are expensed during its lifetime not during its delivery. However, with clear potential for good results the good application of Asset and Facilities Maintenance still eludes many businesses and assets, with many buildings operating sub-optimally with the associated fiscal and social costs.

"Infrastructure Asset Management" is defined by the Institution of Civil Engineers (ICE) as; "The integrated, multidisciplinary set of strategies in sustaining public infrastructure assets such as water treatment facilities, sewer lines, roads, utility grids, bridges and railways. Generally, the process focuses on the later stages of a facility's life cycle specifically maintenance, rehabilitation, and replacement. Asset management specifically uses software tools to organise and implement these strategies with the fundamental goal to preserve and extend the service life of long-term infrastructure assets which are vital underlying components in maintaining the quality of life in society and efficiency in the economy".

"Facilities Management" is defined by British Institute of Facilities Management (BIFM) as:

"Facilities management is the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities". Facilities management encompasses multi-disciplinary activities within the built environment and the management of their impact upon people and the workplace.
Effective facilities management, combining resources and activities, is vital to the success of any organisation. At a corporate level, it contributes to the delivery of strategic and operational objectives. On a day-to day level, effective facilities management provides a safe and efficient working environment, which is essential to the performance of any business – whatever its size and scope.

Facility Management (or facilities management or FM) is an integrated multidisciplinary, interdisciplinary field devoted to the coordination of space, infrastructure, people and organisation, often associated with the administration of office blocks, arenas, schools, convention centres, shopping complexes, hospitals, hotels, etc. However, FM facilitates on a much wider range of activities than just business services and these are referred to as non-core functions. Many of these are outlined below but they do vary from one business sector to another. In a 2009 Global Job Task Analysis, the International Facility Management Association (IFMA 2009) identified eleven core competencies of facility management. These are: communication; emergency preparedness and business continuity; environmental stewardship and sustainability; finance and business; human factors; leadership and strategy; operations and maintenance; project management; quality; real estate and property management; and technology.

The involvement of operational and facilities teams in the design, delivery, commissioning, training and handover of assets is known as "Soft Landings". This process ensures good communication, awareness and capability at the point of handover to ensure the operator receives an effective working asset. The application of Asset and Facilities Management services are discrete business services which require the formal application of "strategic Plans" and organisational capabilities. Effective delivery is enabled through the processing of data. New assets may receive data from the delivery process, however existing assets will require digitally surveying to establish a minimum manageable dataset to enable useful analysis to take place.

6.4.5 Operational Performance Management - Telemetry, SCADA, Sensors, BMS and IoT

The performance of an asset delivering it's in service lifecycle is a complex concept to effectively measure. The variables that can be measured are vast, the position and type of sensors are almost infinite and the ability to measure consistently between spaces as well as buildings is difficult due to differences in calibration of sensors and differences in environmental conditions and asset usage. There are a vast number of methods to collect data and data has been collected discreetly in many building for several decades. Standards vary for this activity but the common systems include SCADA, IoT, BMS and other proprietary methods a summary is contained in Table 6.3.

Table 6.3 - Data Collection Options

Number	Method	Observations
1	SCADA (Supervisory Control and Data Acquisition)	SCADA is a system operating with coded signals over communication channels so as to provide control of remote equipment (using typically one communication channel per remote station). The control system may be combined with a data acquisition system by adding the use of coded signals over communication channels to acquire information about the status of the remote equipment for display or for recording functions. It is a type of industrial control system (ICS). Industrial control systems are computer-based systems that monitor and control industrial processes that exist in the physical world. SCADA systems historically distinguish themselves from other ICS systems by being large-scale processes that can include multiple sites, and large distances. These processes include industrial, infrastructure, and facility-based processes, as described below: • Industrial processes include those of manufacturing, production, power generation, fabrication, and refining, and may run in continuous, batch, repetitive, or discrete modes. • Infrastructure processes may be public or private, and include water treatment and distribution, wastewater collection and treatment, oil and gas pipelines, electrical power transmission and distribution, wind farms, civil defence siren systems, and large communication systems. • Facility processes occur both in public facilities and private ones, including buildings, airports, ships, and space stations. They monitor and control heating, ventilation, and air conditioning systems (HVAC), access, and energy consumption.

Number	Method	Observations
2	IoT (Internet of Things)	The Internet of Things (IoT) is the network of physical objects or "things" embedded with electronics, software, sensors and connectivity to enable them to achieve greater value and service by exchanging data with the manufacturer, operator and/or other connected devices. Each thing is uniquely identifiable through the allocation of a unique IP and MAC address. They may have their own embedded computing system but are able to interoperate within the existing Internet infrastructure.
3	BMS (Building Management Systems)	A Building Management System (BMS) or a (more recent terminology) Building Automation System (BAS) is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems. A BMS consists of software and hardware; the software program, usually configured in a hierarchical manner.
4	Other Proprietary Systems	There is also a vast array of systems which are proprietary based, using such protocols as C-bus, Profibus, and so on. Vendors are also producing systems that integrate using Internet protocols and open standards such as DeviceNet, SOAP, XML, BACnet, LonWorks and Modbus or Cube Sensors

As the researcher's example project is a relatively simple asset with little embedded technology it was decided that a temporary mobile approach should be selected. As the project was research based cost was also a significant issue to a market analysis identified several proprietary products including a Slovenian product called Cube Sensors, which was the only product in the economy price band that was capable of measuring Volatile Organic Compounds which was one of the key measures identified in section 5.6.

6.4.5.1 Cube Sensors

Each Cube Sensor is fitted with seven sensors. They send measurements from each location to a base station every minute. Each of the measurements is recorded in a database for access by the Test Bench via a web service. Data is accessed via an applications programming interface (API) with the following data attributes available.

Table 6.4 - Smart Sensor Data Properties

Attribute	Notes
Temperature	Temperature recorded in degrees Celsius. Temperature in °C * 100 (example: 2130 means 21.30°C)
Humidity	% relative Humidity Relative humidity in % (example: 45 means 45% relative humidity)
Air Quality	Measured as a factor of Volatile Organic Compounds
Noise	Recorded in dBA
Light	Recorded in Lux
Atmospheric Pressure	Recorded in mBar
Battery	Battery Condition in %
Cable	Either true or false, indicates whether the Cube is on cable and thus charging or not
RSSI	Wireless signal strength indicator (RSSI), the higher the number (closer to 0), the stronger the signal
Time	returned in UTC in the format year-month-dayThour:minute:secondZ (example: "2013-09-27T01:06:17Z")

The values collected from the API property set shown in Table 6.4 are passed to the Test Bench data model entity "Sensor_Data1".

6.5 Social Feedback - Data Capture and Processing Strategy

Social data has always been a challenge to collect, as we have discussed the differences in quantitative and qualitative data give us complex processing and the actual data selection (design) and collection processes are prone to inconsistencies and high errors. By its very nature the human element introduces a level of unpredictability which needs an appropriate response. A number of tools and approaches were reviewed in Chapter 3 and 4 and as described the Spheres of Influence (SOFI) approach has been adopted for this research. The following observations and descriptions have been variously derived from work published by Cousins & Downs (2002). The material drawn from the SOFI patent application and information provided by the inventors are used here for the purposes of this research with permission of the authors.

As described in Chapter three the SOFI tool through its design executes a number of discrete processes within the systems scope and structure, these are data collection, data processing, data storage (via the data server) and data presentation. These functions are described in detail below.

6.5.1 Introduction and Overview to the SOFI Approach and Analysis Tools

The system is designed to measure and represent aspects of the collaborative reasoning process. The specific embodiments described here are optimised for a decision making process relating to organisational change, however as Cousins & Downs (2002) states, it should be understood that the principles employed may be applied to build models of other collaborative reasoning processes. The system incorporates the following tools

- Interface-tools that permit users to interact with the data
- Functions designed to store, retrieve send and display data objects used to perform operations with the data
- An ability for users to validate and test the accuracy of their perceptions
- An interface to present output results, including relationship maps and graphical output to assist with the interpretation of derived results
- Social perception data and convergence data analytics to enable the analysis of social and physical data

Figure 6.10 provides a high level context model for the various parts of the system. This basic context is useful to understand how the SOFI system would be integrated into the managing not only social data, but also the addition of building physics data records and the relationships between the two types. The scope of this research generalises the notion of analysis of quantitative data from sensors and qualitative data from observers or users.

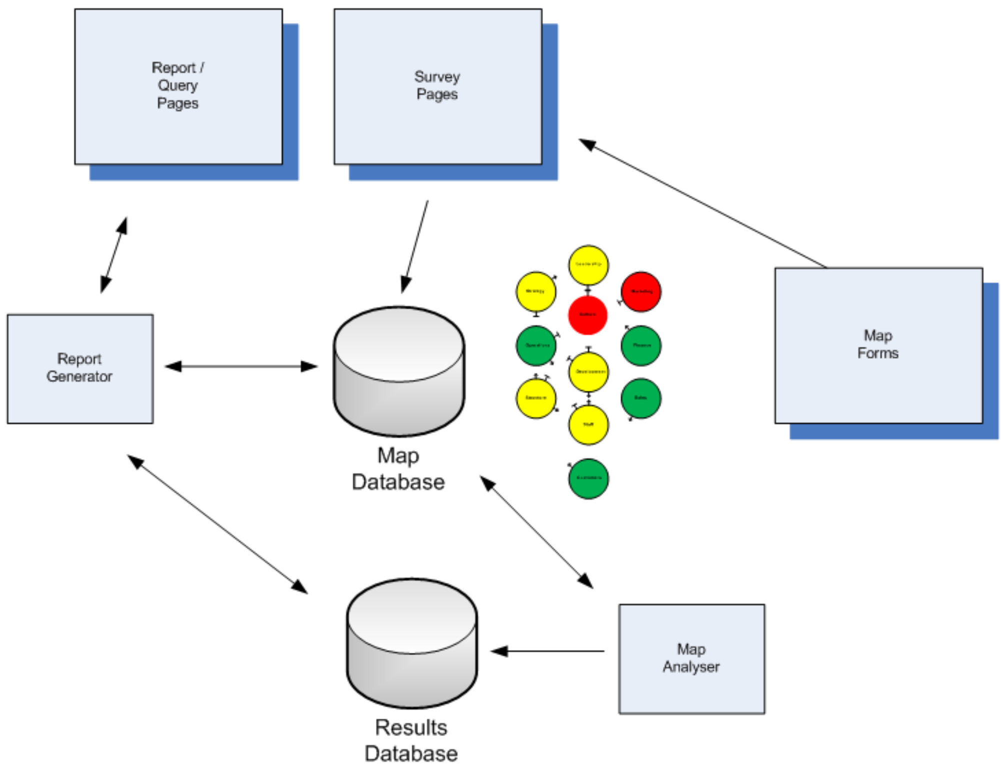


Figure 6.10 - High-level Process Context Diagram for the SOFI System

The user inputs answers into the survey pages and the information is stored in the map database. This includes a specification for how to store the responses as influence objects, as well as user perceptions as to the states of influence objects and their interrelationships with one another. The user may then request the map analyser to process the influence objects and record results to the results database. The report generator uses the map database and results database to present the user with a display of the results of the map analyser via the report/query web pages. The system provides the following specific functions.

Data Capture

The map forms and survey pages provide a data capture function which can capture, compile and analyse information continuously from a web based survey page file, but also any other practical source (informal discussion, mails, interviews, surveys, minutes of meetings, mission debriefing, forums, etc.). The compiled information is stored in a data structure referred to by SOFI as influence objects.

Map Generation

The map database and map analyser generates reports that contain visual descriptions of analysis that can be discussed and shared between stakeholders.

Identify Issues

Resulting views provided by the report pages allow users to identify potential issues and appropriate corrective actions, based on general rules, ad-hoc rules or related examples stored in the knowledge base.

Generate Summaries

The report pages also provide executive summaries of organisational situations and project status to trigger and sustain strategic initiatives. Specific actions taken with any given strategic initiative by decision makers are defined by the organisation actors. (Argyris 1982) calls such actions “interventions”

Measure Performance

Usage of the system permits measuring key performance indicators, performing gap analysis and identifying practical opportunities for improvement.

Monitor Change

Usage of the system permits monitoring the level of organisational awareness and responsiveness from regular internal and external surveys as well as monitor key performance indicators.

6.5.2 Data Structures Data Dictionary

The SOFI system is a generic model which needs to be configured into a given scenario as required. This approach is viable as most businesses have similar processes but all have specifics which make them unique. The first activity in setting up a SOFI analytic is to ensure the Spheres are names with representative labels for the scenario being modelled. For example; in the generic model the first sphere is named "customer". In a school this would be identified as a student and in a hospital, a patient.

Definitions for the Generic "Spheres of Influence" Objects

The SOFI system contains data structures that represent human input on key determinants of organisational or enterprise change, represented by data objects called influence objects or "Spheres of Influence". A first step in devising an appropriate organisational model is to develop a set of Spheres definitions that are appropriate to the enterprise, community or organisation. The labels and definitions for each Sphere are thus adapted to the use in the organisation from a lexicon of the end user. From the literature one specific set of spheres and lexicons that have been found to be useful in modelling the interaction among functions or departments in many organisations include eleven such determinants such as those shown in Table 6.5.

Table 6.5 - Organisational Characteristics

Influence	Observation
Culture	Standards, quality of service, quality standards, values
Leadership	Direction, management
Marketing	Marketing, communication, information, presentations, competition, market capability, market share
Strategy	Any activity planning. This includes references to specific strategies that have been documented or implemented as well as strategies that have been discussed but not yet written down
Finance	Strategy, planning, advising, milestones, feasibility studies, review finance indicators, measures, performance levels, reports, costs, penalties, evaluation, risks, analysis, validation
Operations	Operations, performance, methodologies, processes, implementation, technology
Development	Development, R&D, training, design,
Sales	Negotiating, buy-in, needs, expectations, account teams, pre-sales support, post-sales support, RFPs, offerings
Structure	Agreements, contracts, commitments, services, policies, procedures, accountability, service requirements, infrastructure, data-warehouse Staffing consultancy, service delivery, human resources
Staff	Material relevant to issues such as recruitment, hiring, removal, promotion, workload, motivation and individual employee's needs
Customer	Customer, prospect, customer requirements.

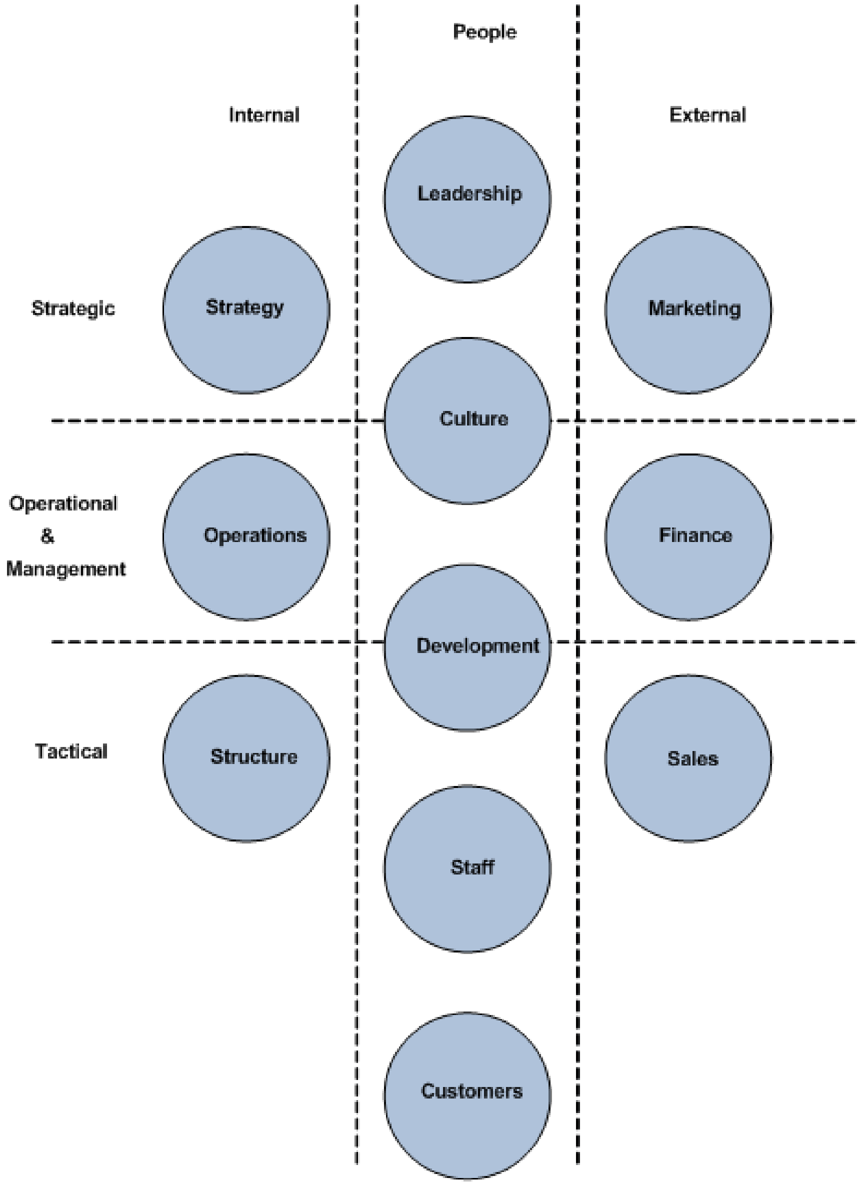


Figure 6.11 - Generic implementation of the Influence Map that is used for perceptive data visualisation.

A graphical representation of one example of such a Spheres model is shown in Figure 6.11. This arrangement of eleven spheres on the Influence Map was derived from the analysis of frequency of examples that illustrate the Spheres that are most likely to have influence on each other appear as neighbours. This means that those parts of the community that are more likely to have a direct relationship are positioned closer to each other than those which typically do not. In a typical spheres model representation, a traffic signal system is used to indicate survey responses. Thus, the surveys are preferably configured so that responses may be graphically coded as a sphere with a green, yellow or red visual indicator. The green indicator is typically used to indicate a positive response, yellow to indicate that the respondents feels this is an area that requires caution or further investigation and red to indicate a problem or urgent concern.

The spatial distribution of Spheres in this manner can also be used to reveal relationships among the eleven Spheres, classified according to Extended and Remote. The neighbourhoods represent relative distance between the Spheres. These spatial neighbourhood relationships are further defined using a Scoring Matrix for the overall Influence Map for example, a chart or "Scoring Matrix" can be developed that shows the neighbourhood definitions for each sphere in the illustrated in one such scoring matrix or palate shown in figure 6.12, the immediate neighbours are coded in green, extended neighbours are coded in yellow and remote neighbours are coded red.

Sphere	Destination:		
	Customer	Staffing	Structure
Culture	R43	R44	59
Leadership	R38	R39	R40
Marketing	R33	R34	R35
Strategy	R28	R29	R30
Finance	R25	37	R26
Operations	R22	30	31
Development	R20	22	23
Sales	16	17	18
Structure	10	11	Structure
Staffing	4	Staffing	5
Customer	Customer	1	2
Spheres Labels			
Neighborhood links:			
immediate	1	4	3
extended	2	2	3
remote	7	4	4
total:	10	10	10

Figure 6.12 – SOFI scoring matrix showing how the relationships between the influence objects are defined.

Virtually all survey responses in a large, complex organisation appear as Immediate and Extended Neighbours. In the display (as shown in Figure 6.12) only the first two Neighbourhood links are typically populated with data. The Remote Neighbours will not typically be able to be populated without a special enabling function; this avoids unnecessary complication of the data object models. The restriction to populating

Immediate and Extended Neighbourhoods also prevents visualisation problems using the Influence Maps and populates the model with data instances that are relevant to the interaction of the closest neighbours.

The neighbourhood property of the sphere object relates to various functions in the map analyser. Neighbourhood analysis provides feedback on the structure of a questionnaire and on the complexity of an individual's reasoning and other attributes. The scoring matrix analysis can also be reported upon. The colour of the cells in the scoring matrix which are used to represent the neighbourhood to which the relationship has been assigned in the examples shown in figure 6.12. For example, the Development/Staffing cell is coded "green" to indicate that these are immediate neighbours. However, the "Sales/Structure "cell is coded yellow, to indicate an extended neighbour relationship. The "Sales/Operations" cell is coded red, to indicate a remote neighbour relationship. Also, note that the absence of a number in the cell indicates that the designer of the survey has provided no associated survey question for this cell. The result generates up to the possible measurement points. However, in an eleven Sphere model, it is typically not the case that all possible combinations of extended neighbours are represented or needed in the scoring matrix. Further properties of the spatial array are revealed in a neighbourhood matrix, shown in Figure 6.13.

Sphere of	Destination:				
Origin:	Customer	Staffing	Structure	Sales	Development
Culture	R43	R44	O-59	O-60	S-61
Leadership	R38	R39	R40	R41	R42
Marketing	R33	R34	R35	R36	S-49
Strategy	R28	R29	R30	R31	S-44
Finance	R25	O-37	R26	O-38	S-39
Operations	R22	O-30	O-31	R23	O-32
Development	R20	T-22	T-23	T-24	Development
Sales	T-16	T-17	T-18	Sales	T-19
Structure	T-10	T-11	Structure	T-12	T-13
Staffing	T-4	Staffing	T-5	T-6	T-7
Customer	Customer	T-1	T-2	T-3	R1
Spheres Labels					
Neighborhood links:					
R = remote	7	4	4	4	2
total:	10	10	10	10	10
Neigbborhood Orientation on Influence Map with number of links:					
S=Strategic					4
O=Operational		2	2	2	1
T=Tactical	3	4	4	4	3

Figure 6.13 - Extract of a neighbourhood matrix illustrating the relationships between influence objects and the arrangement of the influence map array.

The matrix is used to examine clusters of influence objects along the axis from top to bottom of the influence map in Figure 6.13 “Strategic" activities tend to cluster toward the top of the map, operational in the middle and tactical toward the bottom. Using this approach to modelling survey responses, robust measurement procedures can be used to get reliable data to analyse soft issues like customer satisfaction and awareness. Tools and procedures can also be specified to collect hard data such as financial metrics. The data collection procedures include design specifications for survey instrumentation, data collection and configuration of questions relating to each influence object.

In Figure 6.12 and Figure 6.13 the relationship between the adjacencies and the questionnaire is discussed. The questionnaire needs to be similarly analysed and prepared to be relevant and meaningful to the community who are going to be asked to use it. The use of "yes", "no", "don’t-know" type answers does make this much easier but can position the researcher with a little context as to why an answer was given and what could be done to improve the situation. This is improved when the context is further enhanced through the use of free text notes from the respondent. This is a particularly important issue if we are going to make sensible use of the tool as part of the overall Test Bench methodology. Consideration also should be given to the number of questions. The 11*11 nature of the SOFI structure does drive the user to a potentially large number of questions, so they need to appear relevant and concise. This is of particular importance with the reciprocal questions which are very easy to slip into the mistake of asking a question that is too similar to the direct one. This not only leads to a failure in establishing the required information, but also gives the user a feeling that he may be wasting his time, which may influence the quality of their work.

The identification of SOFI Worlds is an important design consideration. The Worlds allow the data to be analysed from the point of view of a single community group. Clearly as a tool to understand perception and its implications it is important to see the data from each of these points of view.

6.5.3 SOFI Questionnaire Distribution

The distribution of the questionnaire can be undertaken in traditional paper mode or electronically. Clearly the preference is electronic as this is simpler to administer and ensures complete control over anonymity and security. Paper mode is however useful for members of the community who are yet to be connected or are in some other way excluded as their views are often amongst the most valuable. A time scale is set on the period that the questionnaires are out to minimise the impact and alignment of environmental factors. i.e. both building physics sensor and SOFI data should be collected in the same time scales.

6.5.3.1 Approaching Sample Organisations

For any organisation to subject itself to the type of scrutiny this type of process takes is a significant commitment however carefully thought out and planned. Firstly, the selection of an asset and organisation type, the location, size and diversity of community and service all need to be considered. The Test Bench and SOFI are by design generic, but the scope of this research has enabled us to limit the test experiment to a single asset and community.

The approach to the organisation should be clear and open and fully compliant with the ethics statement agreed as part of the research.

6.5.3.2 Ethical Considerations

The ethics procedures set out by the University were strictly applied throughout. An ethics statement based on the guidelines set out by the British Educational Research Association (BERA) was approved covering the following key issues

- Project Focus
- Project Objectives
- Research Strategy
- Project Rationale
- External Organisations Ethic Procedures
- Approach to dealing with Individuals
- Gaining informed consent
- Data protection
- Dealing with young people
- Sample volumes
- Ethical methods

The primary rule of modelling for the survey designer is to remember that they are building the interviewee's model, not their own. This means that modellers must guard against inserting their inferences into the questions or reading things into survey responses. Modellers should attempt to use the interviewee's actual words in the model and not the modeller's shorthand for what the respondent said. The second aspect of devising an effective survey question in particular is to remember to look for the "big topic" that the organisation is talking about in their illustration. Often it is easy to get overwhelmed by details. Mentally, modellers must be able to step back from the details and focus on the larger issues that are described by the details. Big topic issues are indicated by key words that relate to the sets of activities contained in each sphere. When listening to a client describing the events that prompted their colour choice for a particular sphere, the modeller is listening with that sphere's neighbours in mind. Detecting the input of such data will then generate proper links between spheres, whether they are a block or a connection. There are generic questions that a modeller can use to generate items to insert into the system by urging the interviewee to provide more data or clarity without leading any participant or putting words in their mouth.

Staff and teachers make good use of school resources. - impacts (Building Resources)

Agree	0 (0%)
Disagree	0 (0%)
Don't Know	1 (100%)

Evidence / example :
"Staff and teachers make good use of school resources available."

Suggestions :
None

Organisation & Design

How do you feel about the quality of the school building design?
Red = 0 (0%) Yellow = 1 (100%) Green = 0 (0%) Blue = 0 (0%)

The school building design eables the policies and processes of the staff to effectively deliver the needs of pupils. - impacts (Pupils & Community)

Agree	0 (0%)
Disagree	0 (0%)
Don't Know	1 (100%)

Evidence / example :
"The school building design eables the policies and processes of the staff to effectively deliver to the needs of pupils."

Suggestions :
None

The quality of the school building and its systems helps me carry out my tasks. - impacts (School Staff)

Agree	0 (0%)
Disagree	0 (0%)
Don't Know	1 (100%)

Evidence / example :
"The quality of the school and its systems helps me carry out my tasks."

Suggestions :
None

The building provides enough rooms and spaces and I can move easily between classes. - impacts (Programmes & Services)

Agree	0 (0%)
Disagree	0 (0%)
Don't Know	1 (100%)

Evidence / example :
"The building provides enough rooms and ability to move easily between classes."

Figure 6.14 - List of generic survey sample questions and provided responses.

Cousins (1986) provided the following examples for guidance. Example one identifies that during a set of questions in the area of Culture (i.e. in the Culture Sphere), one survey respondent (manager) made the comment" The Culture direction was communicated very well to the sales force through the documentation we used". In this first example, the client is in the Culture Sphere, so that is the Sphere of Origin for the link. The key words include references to data points and in this case include: "direction", "communicated" and "sales force". The big topic, aside from the details of direction and communication, is the sales force "responding positively" to the corporate Culture. There are no indications that this was a marketing program, although a question to the client would have made that clear. So looking at what the client said, the score is a connection from Culture to Sales. If this had been a marketing push or a communications program, then the link might be different. Again, in populating the Scoring Matrix, the modeller stays with the actual text of what was said, avoiding reading into the response.

In example two the topic was staffing; the respondent reacted negatively, e.g. chose a blocked (red) response, to a statement, saying that, "We are hitting problems because everyone is so task-oriented that they are not taking the wider view" (and by inference not aligning with the vision/strategy). In the second question, the Sphere of Origin is Staffing. The key words are "task oriented". What are tasks, if not the way the enterprise gets its work done? Getting work done is the Operations Sphere. There are follow on implications of being task oriented, to be sure, as the client's inference implies with "that they are not taking the wider view" (and by inference, not aligning with the vision/strategy). But in looking at the data and not what it might imply, survey questions pertaining to the link would be scored as a block from Staffing to Operations. The survey database also allows responses to be analysed by grouping respondents into six "Worlds of Work". The classification and Naming of the organisational groups that are associated with each World mentioned in the text below must be verified for the accuracy and completeness of their respective World classification: Enterprise : entire company Executives: Senior Executives, Office of the Chairman Virtual Teams: Vice President functions, cross-geographical projects, cross-functional teams Work Systems: managers with resource allocation decision authority, regions, engineering units, operational units, help desks; service delivery; operations; finance; legal department; marketing; customer service units Work Groups: account teams, work groups, project teams, technical consultancy teams, customer support Individuals: grouped by role, responsibility, demographics, consultants, technical staff, support staff, administrative assistants, customers.

6.5.3.3 Survey Self Scoring

When the user is in the system they select a traffic signal colour for a given sphere of activity and/or a colour to represent their forecast of another user or group, once this is completed a pick list menu appears. The list shows the closest Spheres first immediate neighbours followed by those further away on the map Extended neighbours. The order of Spheres on the list will vary with the spheres in each neighbourhood ordered according to a master sequence.

After making the Traffic Signal colour choice, an instruction appears asking the person to "Answer Yes or No" to a list of pre-defined questions. The system administrator can configure the "Examples Pick List "menu according to several options. The Examples Pick List menu could show Survey items and/or historical examples from a previous data set stored as an Enterprise Model and/or allow the person to modify their previous responses and/or update the last Survey that the person completed. The "title bars" (labels) of the pick list menu window identifies the type of survey configuration. At the end of the Examples Pick List menu the user may invoke an option to add their own new example in a text box attached to each link, for example, by clicking on its number code. With this option the user enters their illustration in a text box. The pre-configured examples and the new examples are thus scored automatically. "There may be positive and negative examples for the same Spheres. A write-in item will allow additional comments, with a prompt such as, do you have anything to add about the relationship between [Sphere of Origin] and [Destination Sphere]? The person may offer additional examples for the same two neighbouring Spheres, creating different types of links (Connections, Blocks and Opportunities) for the same neighbours.

6.5.3.4 Knowledge Representation Methods Description of Data Structures for Maps that are used as System Outputs

This section sets forth the functionalities that specify user interface procedures and underlying rules of a generalised system to measure organisational change. To accomplish this, operational definitions are made testable and able to be validated by the concerned parties for the following terms: organization-defined by specifying labels for eleven key determinants or "spheres "of whole systems change, that may be defined as an 'enterprise shown in figure 6.11. Perception-defined by an operation to designate, collect, quantify and compile qualitative and quantitative data (subjective judgments and supporting facts) in differentiated states, that may be rendered with the use of a "Traffic Signal code "as a proportion of colour within a sphere; dynamics-defined by quantifying the state of relationships between various activities or events to specify the rate, level and direction of interactivity between them, that may be called "links"; view-as defined by a stratified levels of responsibility which cluster data according to working units, or social groups, that may be called "worlds" value-specified (in the discipline of systems dynamics) as a virtuous cycle of exchanges of energy (resources over time) among three activities, that may be called "triangulation" a process-specified as a system that has definable inputs; methods; mechanisms; procedures; controls and outputs, comprising a six step business process model.

The interactive adaptive design of the architecture is enabled through the use of Maps that are not only used to represent and input perceptions, but also to display output of the data analyser. The Maps may include embedded links to an online agent that functions as an intelligent Guide (agent functions). Users have the ability to modify various items to provide interpretive guidance, or generate new or updated input for the system. Users can validate and test the accuracy of their perceptions and the validity of this so-called "factual" data. Maps comparing the interaction of two data sets (perceptions and facts) can also be used to measure the change process.

6.5.4 Output Data Structure

In a preferred embodiment, the maps use the underlying display and positioning of eleven spheres, as shown already in figure 6.11 and described in Table 6.5 indicating a general layout. This layout is called the "Influence Map ". The configuration of the Influence Map is used as the user interface infrastructure. The visual layout of the Maps is specified as a style sheet in XML, in which data are encoded and placed in various positions on the Map via the respective objects on the map. The Map Page object is also called a "World.” The border around the Map Page designates the World that the user is viewing and/or is a member. Additional objects, which may cross reference to other objects, attached to the Map page include eleven Spheres Array objects. The Spheres may be defined with variable size, variable labels, and variable colours. Spheres are named, coded and reported in sequence from highest to lowest code number.

The order of Spheres is maintained through the different Map types. It is possible to use other labels for describing the function of the Spheres in other embodiments. The map objects may contain other elements or objects such as:

- Map identification (eg Title)
- Enterprise (eg A identification of the organisation, to appear in the upper left-hand corner of the page
- Name (eg Name of respondent or the world)
- Date (eg Of transactions or recordings)
- Time Frame (ie the period under analysis)

The Map may also include a Map legend or Dynamic key object. The keys may include a variable text or graphic legend. The keys on the six different display maps use different combinations of interactive icons that control various viewing functions for the particular Map from a control panel. Icon functions may also appear in the “key" on each map. An "Activity level "indicator displays at least three lines with lowest (lo), medium (med), and highest (hi) thickness appearing on the respective Map and the number of links associated with the varying thickness. This format uses proportional thickness to overcome a visualisation problem of having some links that appear so thick that they mask other data or make the Map difficult to read. A Focal Point object may appear as a text box with square comers. The label "Focal Point" appears in the upper left-hand comer of the text box. The layout specification of an Influence Map object includes typically the following data:

- Influence Map <Title>
- Perception Map <Title>
- Enterprise <Name of the Enterprise>
- Focal Point <Name of the Focal Point>
- Individual's Family <Last name of the person interviewed>
- Individual First <Name of the person interviewed>
- Date < dd/mm/yy >
- Sphere <Names>

The name attribute of each Influence Map object also affords a way to implement access restrictions. This provides an important function, such as being able to guarantee that an individual's response data remains confidential. Access is restricted to the Individual respondent. The system also allows the individual respondent to "publish" or make public their results, with the option to share Traffic Signal colours, links, survey or text responses.

6.5.5 Reporting Services

The presentation of the processed data in a graphical format to make interpretation possible is a key requirement. The SOFI analysis has the following capabilities.

6.5.5.1 Perception Map

Figure 6.15 displays a scored and compiled input of an individual person/respondent the Perception Map; this is a visual representation of a particular person's response to survey questions. The colour of a sphere may be red, yellow, or green. The colour blue is also used to indicate certain other responses such as "don't know” or "empty".

The links illustrated in the Perception Map can be of several types. These include an Individual positive link "Connection", which is graphically displayed as a black arrow, as shown. An Individual negative link "Block" is graphically illustrated as a black "hammer" in the Perception Map. Although not shown in the examples another type of link, known as an "Opportunity link" can be made part of the Perception Map. The Opportunity type link is graphically indicated as violet dotted lines, with an option to show directionality with an arrowhead, connecting two Spheres. In cases where there is more than one Opportunity link between two Spheres, the respective lines will vary in thickness. Links may also have various properties attached, including: text, colour, pointers to other maps, locations, or databases, a time clock, counters, the name of a World or person, thickness, an arrowhead (pointed arrow or flat hammerhead). A Perception Map has attributes similar to those in its corresponding Influence Map, such as:

- Title
- Enterprise
- Focal Point
- Individual's Name
- Date

The specification for a Perception Map object as stored in the database is as follows

- Perception Map Title
- Perception Map Enterprise Name
- Focal Point Name of the Focal Point
- Person's Family Last name of the person surveyed
- Person's First Name of the person surveyed
- Date dd/mm/yy
- Sphere names

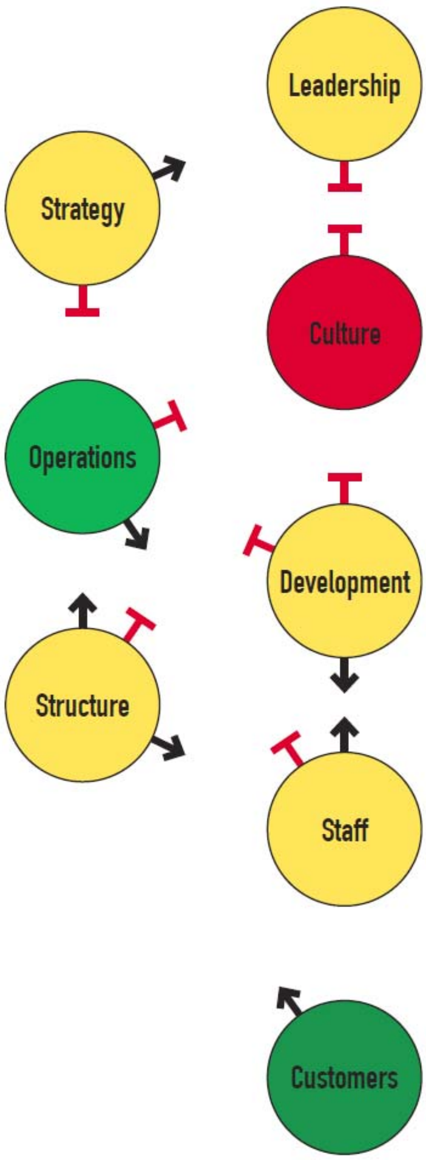


Figure 6.15 - Potential set of values of a Perception Map that makes use of the influence map structure showing survey responses compiled for a single respondent

6.5.5.2 Reflection Map

Figure 6.16 shows compiled Traffic Signal (colour) data represented proportionally for each colour and shown inside each sphere for Worlds or other combinations of Influence Maps. This view is known as a Reflection Map; it is used to illustrate compiled Traffic Signal (colour) data for a group of related Influence Maps. The Reflection Map is generated by determining statistics from the group, such as may be contained in a specific World. In the graphic depiction of a Reflection Map, the circles representing each Sphere are coloured in a range of different colours, depending upon the aggregate statistics. For example, in the Structure

Sphere in the figure 6.16 example, the compiled responses were approximately 15% green (the bottom coloured portion of the Sphere), 60% yellow (indicated by the central yellow portion) and 25% red (indicated by the upper portion). The Sales Sphere statistics for this World indicated 3% blue (or unanswered), 24% green.

A Perception Map has attributes like those in its corresponding Influence Map, such as:

- Reflection Map Title
- Reflection Map Enterprise Name of the Enterprise
- Focal point Name
- World Name of the World
- Date dd/mm/yy
- Sphere names

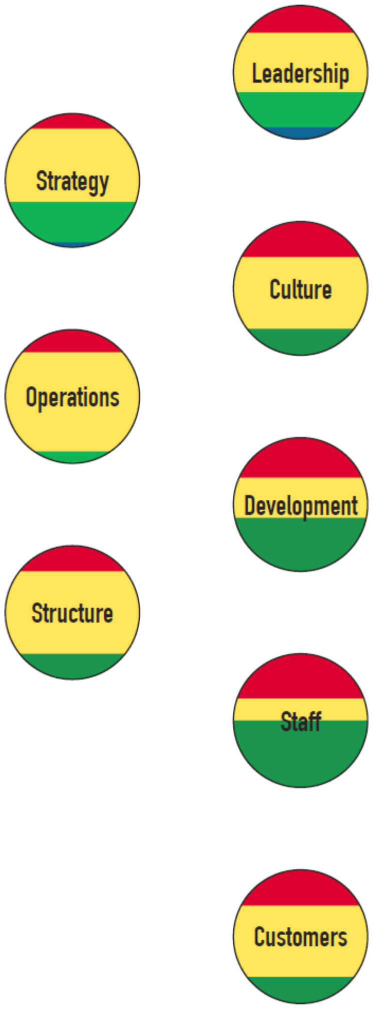


Figure 6.16 - Reflection map that is used to combine individual perceptions into a group view, also based upon the influence map model

6.5.2.3 Circuit Board Map

Figure 6.17 shows a Circuit Board Maps are used to illustrate different compiled links for each World. A Circuit Board Map is principally used to represent Complied Connections (green connecting lines), Compiled Blocks (as red lines (Blocks)) or cancellations (equal number of connections and blocks, shown as dashed blue lines). A compiled Connection may be rendered as a green line with varying thickness, including an option to make an arrowhead visible to show directionality of the link. The thickness of the green line indicates how many of the underlying Influence Maps indicated a Connection. A proportional thickness sizing function may be used to represent many instances.

Similarly, a compiled Block may be indicated as a red "hammer", with a varying thickness. A Cancellation may be indicated on the Circuit Board Map as a blue dashed line with varying thickness (the Circuit Board Map shown in figure 6.17 uses a solid line to illustrate a Cancellation between the Leadership Sphere and the Marketing Sphere and does not show in the dash format). The Cancellation may include an option to make the arrowhead visible to show directionality. Several rules can be devised that control the generation of a visual representation of a Circuit Board Map object by the analyser.

Example

Given Pab = the total number of positive links between Sphere A and Sphere B

Given Pba = the total number of positive links between Sphere B and Sphere A

Given Nab = the total number of negative links from Sphere A to Sphere B

Given Nba = the total number of negative links from Sphere B to Sphere A, then

1. If Pab + Pba > Nab + Nba then the compiled link between A and B is a green line (Connection) whose thickness = (Pab + Pba)- (Nab + Nba).
2. If Pab + Pba = Nab + Nba then the compiled link between A and B is a blue line (Cancellation) whose thickness = (Pab + Pba) + (Nab + Nba).
3. Pba < Nab + Nba then the compiled links result in one of the next three possibilities:
   3.1. If Nab > Pab and Nba > Pba then there is a negative link [red Block] from A to B whose thickness = Nab-Pab AND a negative link (red Block) from B to A whose thickness = Nba-Pba
   3.2 If Nab > Pab and Nba <= Pba then there is only one negative link (red Block) from A to B whose thickness = (Nab + Nba)- (Pab + Pba) 3.3.) If Nab <= Pab and Nba > Pba then there is only one negative link [red Block] from B to A whose thickness = (Nab + + Pba)
4. Finally, if the compiled links among three Spheres are all green lines, then the combination forms a triangle that is coded and labelled as a Knowledge Asset (Ka).

Key elements of a Circuit Board Map object.

- Name of the Enterprise
- Focal point Name of the Focal Point

- World Name of the World
- Date dd/mm/yy
- Sphere names

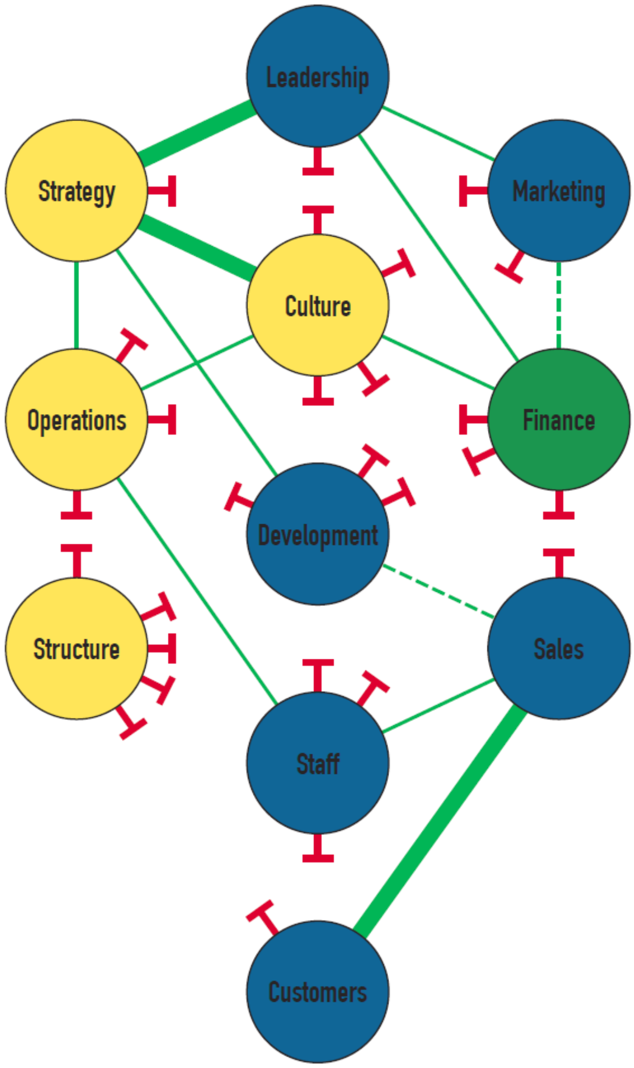


Figure 6.17 - Circuit board map further providing an additional visualisation that is used to show the perception evidence cited in. the survey in conjunction with individual perceptions

6.5.2.4 Hemisphere Map

Figure 6.18 shows a comparison of two World Views with data compiled inside of the same sphere, this view is known as a Hemisphere Maps. They are a technique for displaying compilations of two sets of perception data in one Map. In the visual representation, the text boxes showing the date, Enterprise, World Name, Focal Point, Time Frame are "doubled up "to indicate the data elements from each set. The preferred format shows text separated by a forward slash mark, showing both variables side by side (e. g. Enterprise A / Enterprise B.) Only the variables that relate to the variables under comparison appear on the screen.

For example, if the comparison is for the same Enterprise with the same Focal Point on two different dates, only the date box will show the doubled text. Variable boxes that are relevant to the comparison shown on the Hemisphere Map are highlighted/outlined in blue and the text changes from black to blue. The colours of the Spheres in a Hemisphere Map are typically some sort of mix of the colours that would be rendered in each of the two corresponding Reflection Maps. For example, as shown in figure 6.18, a Hemisphere Map displays each Sphere with a dividing line. Each half of the Sphere, one on the left, one on the right is then rendered in the colours that would be rendered for the corresponding Sphere in a Reflection Map.

Data object definitions for representing a Hemisphere Map

- Hemisphere Map Title
- Hemisphere Map Sphere names
- Hemisphere Maps display only one set of names (otherwise the Map would not be readable).

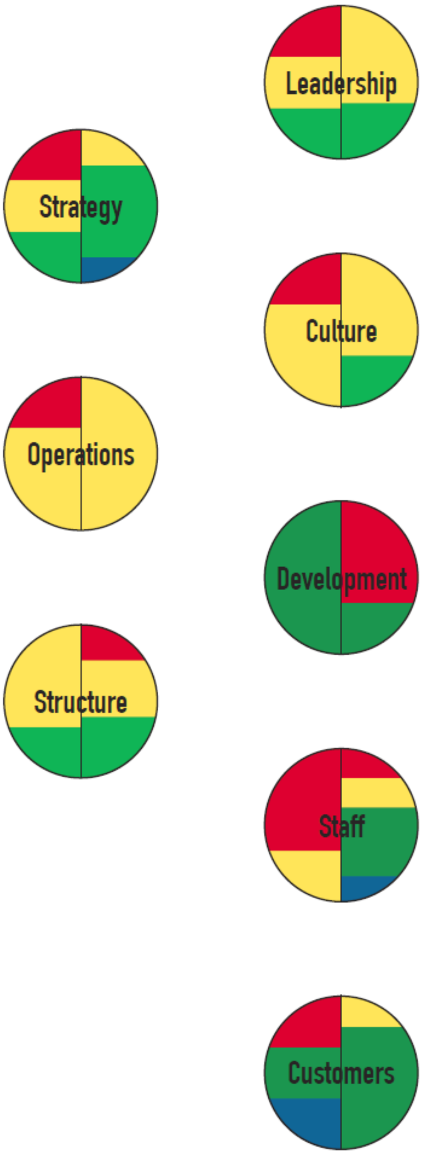


Figure 6.18 - Hemisphere Map that permits comparison of perceptions.

6.5.2.5 Opportunity Map

Figure 6.19 shows the places where a Connection can be created, following rules that build triangulations among three Spheres, this is known as an Opportunity Map. An Opportunity Map as illustrated in figure 6.19 is useful for showing Opportunities that have been selected to have resources assigned-including an Initiator eg, the person responsible for overseeing or taking the Action, milestones, timetable, budget, etc. An Opportunity may be rendered as a violet dotted line with an arrow with varying thickness similar to the solid lines as shown in figure 6.19 (which does not show the dotted format).

By way of an example, if an Opportunity exists between Operations and Finance; an Action link may also be represented as a violet line comprised of alternating dots and dashes, with an arrowhead, and with varying thickness, as shown, to indicate its relative importance. Although not shown separately in the example of figure 6.19, another type of link, known as Triangle which is graphically indicated as a combination of Opportunity links among three Spheres where three dotted violet lines, with an option to show directionality with an arrowhead, or the addition of one or two violet dotted lines to Spheres whose neighbours already have solid links connections) already in place, creates a triangle among three Spheres. In cases where there is more than one Opportunity link between any of the three Spheres, the respective lines will vary in thickness.

- An Opportunity Map data object includes
- Opportunity Map Title
- Opportunity Map Enterprise Name of the Enterprise
- Focal Point Name of the Focal Point
- World Name of the World
- Date dd/mm/yy
- Sphere names

Connections may exist between one or two of the three Spheres. Where Connections already exist, the dotted violet line overlaps with the solid green line. The Analyser prioritises and sequences Opportunity Triangles according to the colour of the Spheres, the number and type of links that are already in place, the World in which the Action will take place, the number of triangulations the Opportunity will create. Once an Opportunity is selected, it is considered as a link that can be used as part of a new Opportunity Triangle. Note: The Actions between Sphere of Origin and the Destination Spheres that have been selected as actionable appear on the Action Map that follows. "Actionable" means that one or more of the Members can initiate an Action that will accomplish something with the resources available. This person is called the Action Initiator.

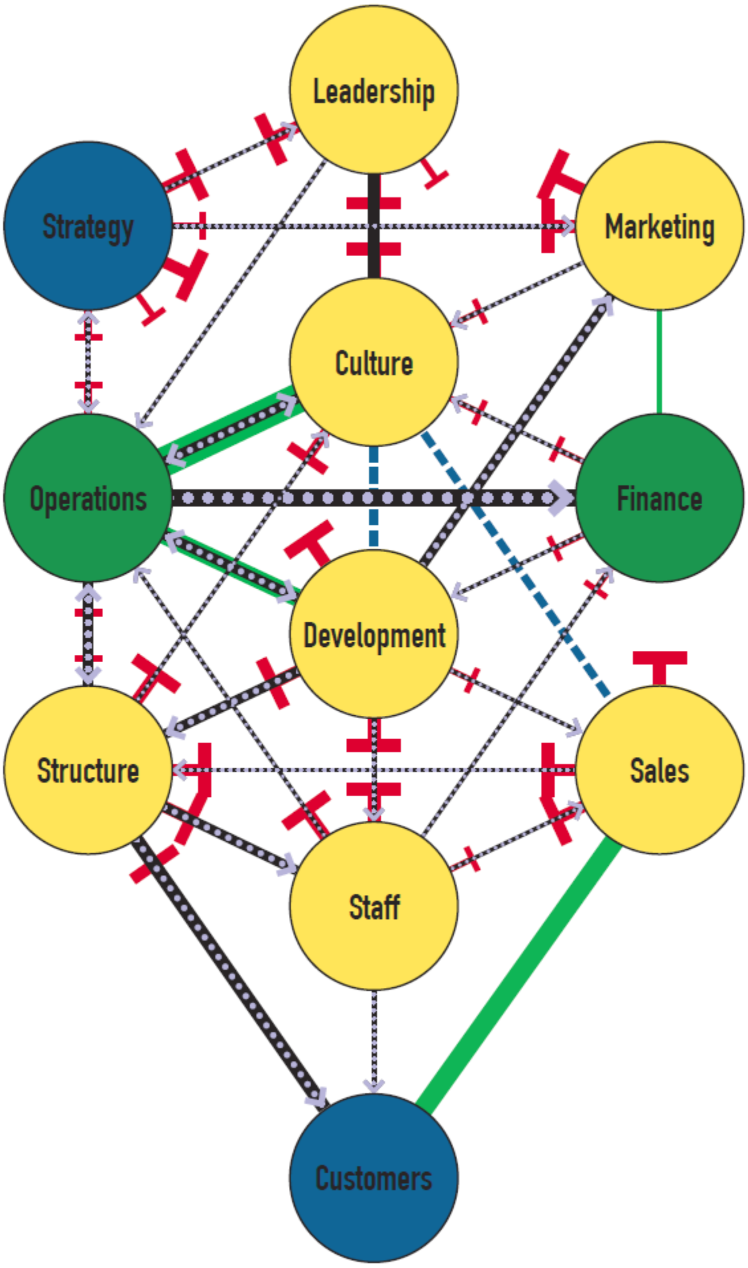


Figure 6.19 - Opportunity map used to reveal positions on the influence map where new actions could be taken, combined with a visualisation technique used to examine the interaction effects among display layers

6.5.2.6 Action Map

Figure 6.20 shows the opportunities that have been selected for action as dashed lines; this map is known as the Action Map. The Action Map is a complement to the Individual Map. It provides an output that the individual responsible for taking action uses to guide and track progress, and report results. Once an Action is completed, the Action Initiator cycles the completed task back into the system as input for an updated model.

- Action Map Title
- Action Map Enterprise Name of the Enterprise
- Focal Point Name of the Focal Point
- World Name of the World
- Date dd/mm/yy
- Sphere names

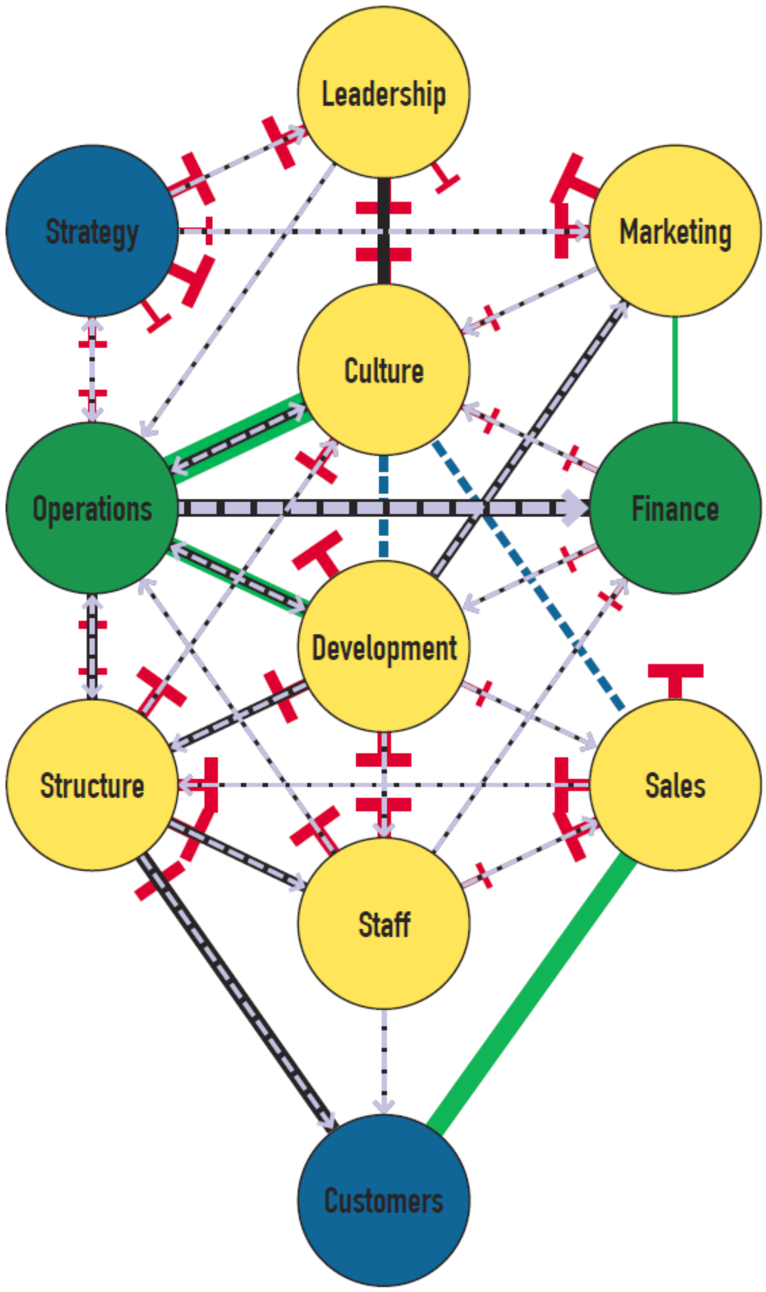


Figure 6.20 - Action Map used to combine the tasks that individuals have agreed to undertake, used to examine their interaction effects among actions and with the other layers of data

The Knowledge Assets appear as solid green lines with or without arrows among three Spheres. Connections may already exist between one or two of the three Spheres. Where Connections already exist; the green Knowledge Asset line overlaps with the green Connection line. The Analyser prioritises and sequences Knowledge Assets according to the colour of the Spheres, the number and type of links that are already in place, the World in which the Action will take place, the number of Knowledge Assets the Action will create. Once an Action is completed, it is considered as a link that can be used as part of a new Knowledge Asset.

Note: The Actions between Sphere of Origin and the Destination Spheres that have been selected as actionable. "Actionable" means that one or more of the Members can initiate an Action that will accomplish something with the resources available. This person is called the Action Initiator.

6.5.6 Data Integration and Processing

6.5.6.1 Introduction

All data collected by the data collection instruments needs to be held in a suitable repository to enable access for later analysis and processing. Due to the immaturity of the BIM market with respect to the process and manufacturing industries there are relatively few commercially available tools. To address this and avoid the complication of focusing on a data serving research a simple database has been created in MS Access to hold data collected. If this research was to be commercialised a significantly more robust approach would need to be taken to address capacity, security, identity and processing requirements.

6.5.6.2 Data Management

The data server is required to hold data from three key "systems", the briefing system, the BIM systems and the SOFI social data system. To keep focus on the research system design from existing systems and research has been modified and integrated to provide a data repository which is suitable for demonstrating the data sets but not for commercial purposes as described above.

The database system has been developed from the material discussed in the literature review, namely the COBie 2.4 standard, PREMMIS, Post Occupancy Evaluation and datasets analysed from the SOFI methodology.

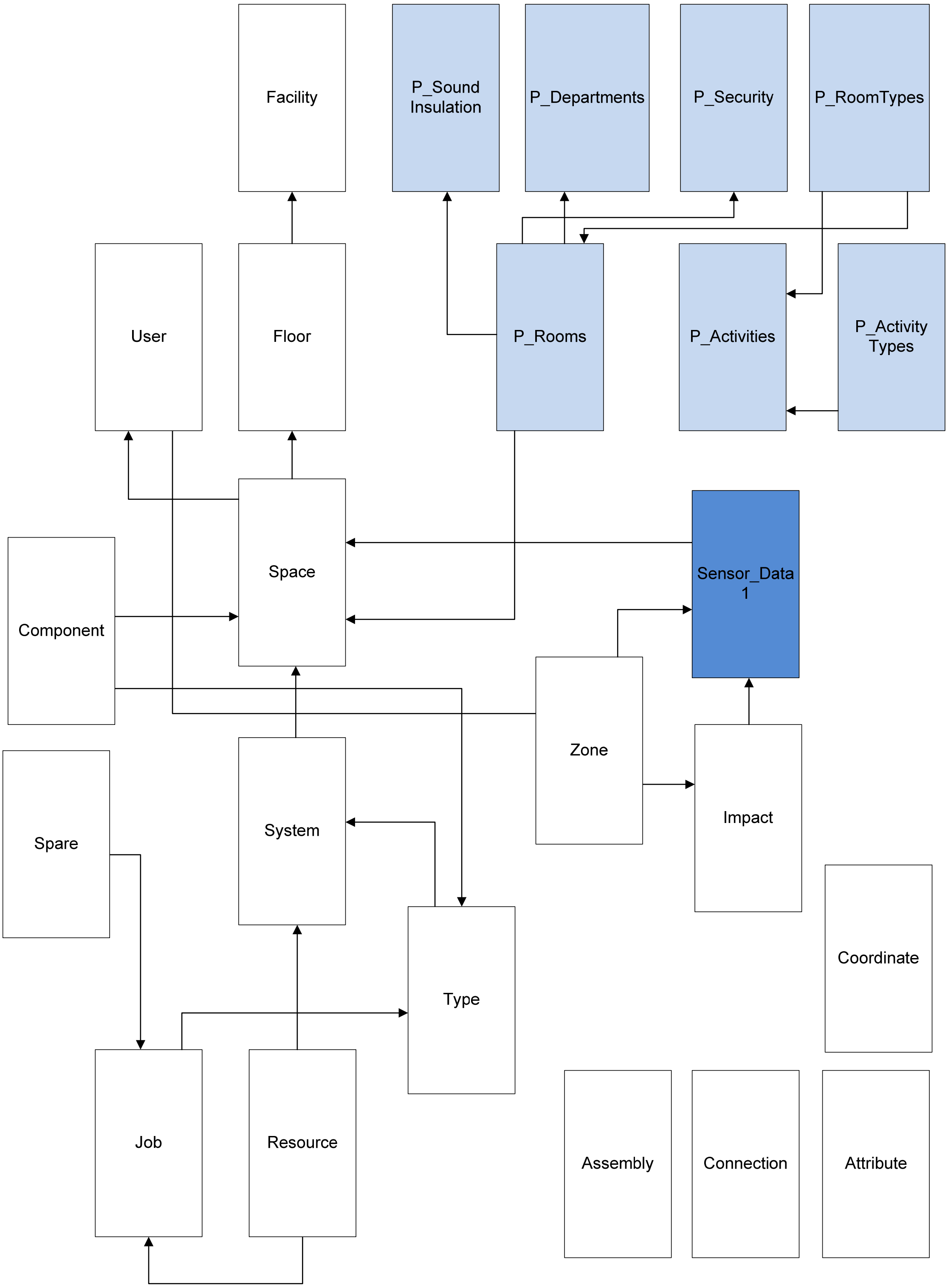


Figure 6.21 - Data Server - Entity-Relationship Diagram

Data derived from the design, procurement and construction process are created in any suitable BIM tool available from the open market. Data is collected from the BIM tool into an Open Format. The format selected for the purposes of this research is COBie (Construction Operation Building information exchange). This format has been selected for a number of key reasons, including its open nature, human readable format and increasing availability in the UK due to the mandating by the UK Government by 2016.

The relevant data Tables from COBie have been illustrated in Figure 6.21 towards the centre of the entity-relationship diagram shown in white. The data derived from the PREMMIS briefing system are indicated by the notation "P_" and are mostly on the left hand side of the ERD in light blue, with the Cube Sensor environmental and fiscal data being held in the "Impacts" and "Sensor_Data1" entities shown at the middle right of the model in White (for the COBie Impacts entity and dark blue for the additional sensor data collection entity. A More detailed ERD and Data Dictionary are contained in Appendix six.

6.5.6.3 Process Management

As discussed previously the process of asset delivery is a relatively well defined in the industry as discussed with definitions such as the RIBA Plan of Work, APM, GRIP etc. However, many businesses fail to adopt the processes effectively. The impact of this is there is poor understanding of data requirements and delivery. From a data point of view this creates a complex data quality challenge. Data maturity increases from the beginning of the project through to handover and continues on through operations, this concept is illustrated in Figure 6.7. This presents a criticality when acquiring and processing the data to ensure transactions are not executed on data that is not yet mature enough to sustain a result that is correct enough for the purpose required. IDEF0 is a process mapping methodology which is used to identify processes and their sequence through time. This is essential to enable the processes to be synchronised with data of an appropriate maturity and quality. This concept was discussed above and the "state" attribute held in the Test Bench

Figure 6.22 shows the IDEF1 level 0 (Top Level) model which indicates the highest view of the overall end to end processes. The process diagram incorporates the additional user perception and building physics data not shown in the overview model shown in Figure 6.3.

More detailed processes definitions should be developed for areas of process specific to this research. It is assumed that all other processes executed will conform to these overall Level 0 views.

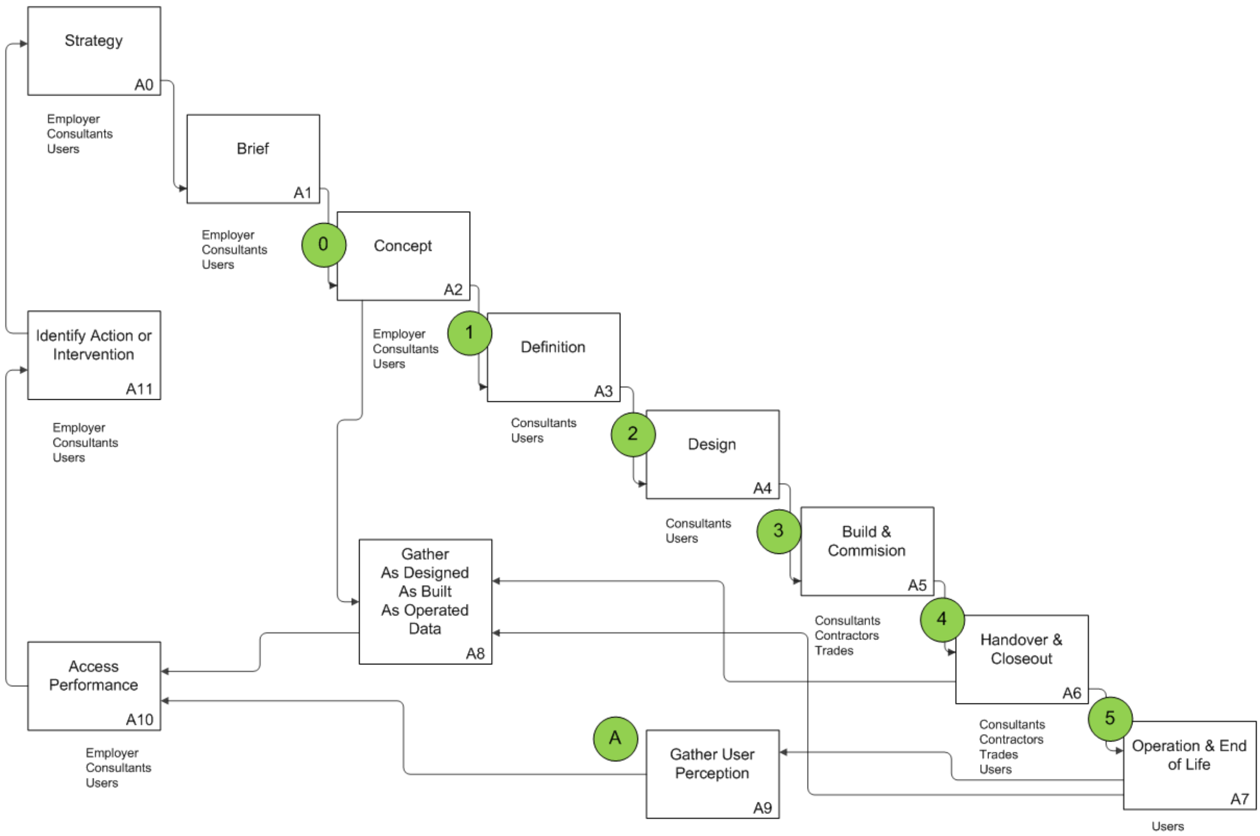


Figure 6.22 - Data Server - IDEF 0 Data Flow Diagram

6.5.6.4 Data Interpretation Instruments

There are three key tools that will be used to interpret the data in the Test Bench; The building physics will be created in a BIM tool as the data requirements are based on open standards the selection of the tool is also open. The COBie data is accessible in XML or XLS and can be read as an XL spreadsheet. If the COBie is derived from an IFC record, it can be viewed either as a native dataset or via a standard IFC viewer. If the data is viewed as IFC it will be possible to view the geometric data content as well. The analysis for the Test Bench will be possible in the database, a modelling tool such as SOFI or for straight forward examples in XL.

The social perception data will be collected and processed in a separate database as shown in Figure 6.10. Data analysis for the perceptive elements will make use of the pre-processed building physics data and the collected perceptive data to providing reporting direct from the SOFI toolset. There are some reports available from SOFI which will be augmented by other methods such as XL for this research.

6.5.6.5 Integrating the Instruments

The process requirements, data maturity and quality, entities and attributes to allow for the full lifecycle of physical and social measurements have all been described in detail above. However, for these systems and tools to operate in a manner that will satisfy the experiment defined in this research they need to be combined into a working Test Bench. The Test Bench will set up a system that specifies, designs, builds and operates an optimally performing asset, in an environment where the data can be inspected and tested. The design of the Test Bench is based on many of the existing methods employed in the construction industry, the data exchange principles of the UK Government BIM Level 2 and a number of ideas regarding the continuous briefing and operational assessment methodologies discussed in the literature review. It is designed to enable data from projects being designed, delivered or operated to be placed in the system and analysed to indicate how well the asset is performing with respect to cost, carbon or social indicators with respect to the "as required" (brief), "as delivered" and "as used". The data drops are derived from those designed by the UK BIM Task Group and are aligned with the APM/RIBA Plan of Work delivery stages.

Figure 6.1 showed the Continuous Briefing Process Model which is a development of the ideas posed by (Ahmed A et al 2010), where the concept of "continuous commissioning" is raised. Here the concept of a continuously measuring and monitoring an asset against its brief and standard reference "norms" are presented. It is this fundamental closed loop process model which will form a fundamental concept of the "Test Bench". Figure 6.23 takes this model and all of the components described in this Chapter and brings them into a single Test Bench platform. Physical data from the brief and the as built buildings are derived from the BIM. The as operated data is collected from the Cube Sensors. All of these datasets are indicated in black in the diagram below. The "As Perceived" data is collected using the SOFI data collection tools, this is shown in green. All of this data is held in the database and analysed by using data analysis tools for the collected data and SOFI for the processed data.

The configuration of the Test Bench using SOFI interfaces the social perception and building physics data resulting in a double loop test of the convergence of between the building asset performance and the building users experience.

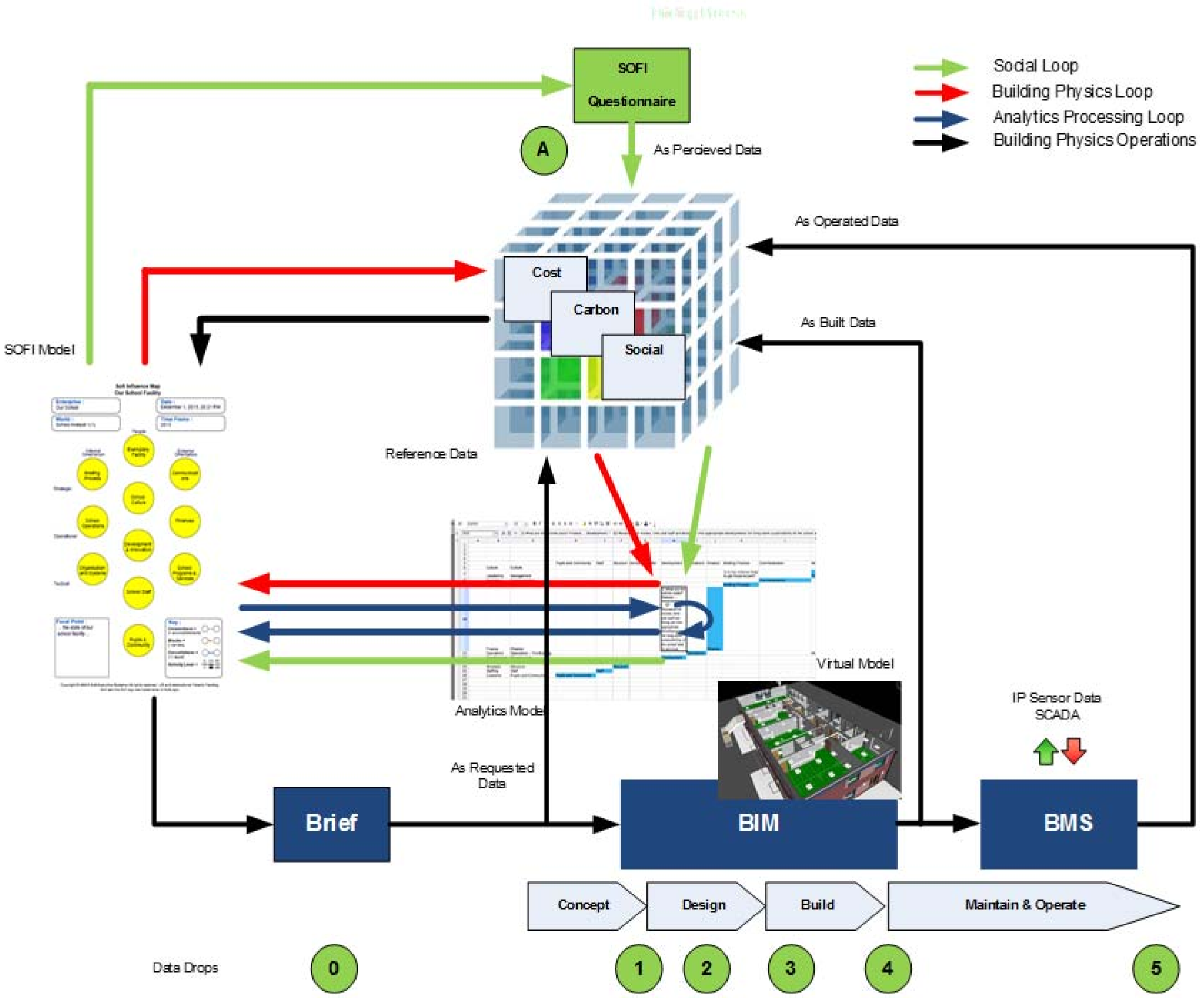


Figure 6.23 - The Production Test Bench - Overall Context

6.5.7 Time Horizon

The delivery of an operational asset varies greatly with need, design, specification and use. Infrastructure assets are very long term commitments with design, delivery and operational lives of many decades. An important consideration to the research philosophy is our approach to the time horizon as, for this research, it has significant impact.

There are two time horizons recognised in the literature; longitudinal and cross sectional. A longitudinal research process examines particular phenomena over a given period of time, where-as cross sectional is focused on a single or number of particular moments in time. Due to the long lead-times to the asset lifecycle we will be confining this research to cross sectional approaches. The cross slices will be made at coincident points with the project stages as required. These are as documented by the HMG BIM Task Group and are consistent with the Association of Project Management (APM) and Royal Institute of British Architecture (RIBA) new stages and dPoW. It will be possible to identify these data sets as the Test Bench will identify each dataset to the appropriate stage. This will allow appropriate data views to address the research question. It is recognised that this does not answer all of the questions that such a research poses and would identify that as part of the "next steps" a follow up in the future would elicit a number of new pieces of information. Key areas of interest in this additional research would include;

- Different seasons
- After the "newness" of the building wears off in 2-5 years' time
- After a significant change of use
- After a longer more significant period of time

6.5.8 Sampling

As part of developing the Test Bench we will be gathering suitable test data. To fully test the methodology a number of potential opportunities were explored as potential options, Chapter seven indicates how these options were exploited for the purposes of this research. As discussed in the scope section in Chapter one the test scenarios will be limited to an educational environment for this research.

Scenario One

- Use existing data derived from existing published data
- Use live data sampled taken from existing assets

Existing sources already identified include The National Audit Office and Partnerships for Schools. The scope of an analysis will be bounded by the completeness and accuracy of the available data. The fragmentation of the education sector through the devolution and localism agenda does offer challenges as there is much fragmentation of capability, spend and resultant performance. This is further compounded by the divergence of the public and private sector markets and their ability to fund infrastructure.

This approach is attractive as it will enable a large sample of data over many different types of asset in geographically diverse locations. However, there is very little useful perceptive data as the EfA has only recently commenced collection and is yet to make it publicly available. There is also no useful briefing and building sensor information available on a consistent basis.

Scenario Two

- Identify and develop a relationship with a school that is building or has recently built an asset to acquire data

This scenario is attractive as it will be more likely that briefing and asset design, delivery and performance information will be available. There is also a greater likelihood of the individuals responsible for the design decisions to still be in the community. A potential disadvantage will be the number of assets that can be processed within the scope of this research.

6.5.9 Validity & Reliability

Assuring the quality and trustworthiness of research is one of all researchers' largest challenges. The value of qualitative research needs to be justified against established criteria. Without this Ballinger (2006) reminds us that it would be possible to be open to being criticised for presenting merely subjective assertions unsupported by scientific methods. The work described regarding the digital Plan of Works is the first attempt at creating a data validation strategy in the construction industry. Up until now all evaluation of information completion or quality has been purely manual and often subjective. The data reviewed as part of the Test Bench data will be validated using the dPoW methods and principles. The validation of the qualitative data from SOFI will be managed through the careful selection and structure of the questions and through manual inspection.

6.6 Summary

Chapter six has described the journey from the theory of physical and perceptive data management in the built environment into the practicalities of an experiment which could be carried out in a real world environment. The Chapter has documented how each of the social and physical data sets can be collected and used in a structured feedback methodology which works both for subjective and objective information. It has further applied the approach described by Argyris (1982) incorporating both double loop feedback and learning as well as the concept of "action" based interventions to provide practical improvement interventions.

In Chapter seven there is a description as to how the Test Bench is configured and applied to a real world environment (including the selection of that environment) to identify how well the approach and mythology works in practical application and how well the outcomes support the research objectives.

Chapter 7

Application of Defined Methods and Tools in a Practical Experiment

7.1 Introduction

The purpose of Chapter seven is to take the components and methods described in Chapter six that make up the Test Bench and to configure them for the specific application of an experiment. The choice of an experiment was made in Chapter five as it represented the best way of articulating a complex set of disparate scenarios in a real life setting. In any experiment there are many variables in play and careful consideration as to the scenario to form the experiment must be given. Chapter seven describes these considerations and how they formed the final design of the experiment and how it was applied.

7.2 Selection of Target Asset & Community

To apply the Test Bench to an experimental scenario consideration of the many types of asset that could be selected must be made, as well as considering the need to access a community of users or individuals who can be influenced by the operation of the asset. These considerations have to be made on a narrow enough band to enable practical academic inspection, but wide enough to provide useful learning regarding the approach. This would then exclude most large scale applications such as transport and healthcare based assets and residential as this would prove challenging with issues of access to the full community of players in the community. Table 7.1 describes the key considerations undertaken when selecting a target asset and community, however the comments should not indicate a lack of confidence in the application of the Test Bench approach, but merely the challenge of scoping a piece of research which can be completed in the scope of these studies.

Table 7.1 - Asset - Community Data Acquisition Selection Strategy

Asset Type	Social Data Collection	Physical Data Collection
Transport Systems	Very difficult due to transitionary communities and high data volumes which require data collection on an industrial scale. Some data is becoming available from cell phone activity, but legislation and access for this type of information is at a very immature stage.	Obtaining useful data from assets which are in public ownership is challenging. This is changing but the data available is often out of date or irrelevant. This is evidenced by the approach taken by Transport for London, where turn style data is made available for analysis, but other key performance metrics and accurate time information is missing.
Healthcare	Data analytics using healthcare data remains a sensitive area and constraints around ethical issues abound. A significant amount or work has been done in ensuring anonymity but data sets are only made available under very tight controlled conditions.	The building physics data available is not present in many older assets. It is also locked up in the proprietary conditions prescribed by many of the common building management systems. This would prove challenging to extract in the context and scope of this type of research.
Residential	The effect of the wider community is different in a residential setting. This doesn't mean that the Test Bench wouldn't work but does mean it would provide a restricted view of the opportunities available which is not the intention of this research	There are very few opportunities to gather equivalent date from residential environments. This would mean a very large sample would be required to provide a meaningful position. This would probably mean the scope of work would be beyond this research.
Educational	The social fabric of a school is by nature restricted and confined to the cohort that populates the school for the academic year. This changes each September with new intake, but a significant part of the teaching and support staff remain in place for the long term creating a well	Newer schools are often now being specified with building management systems, but they suffer the same problems discussed above. However, the environment does lend itself to collaborative data collection or the implementation of temporary sensors

Asset Type	Social Data Collection	Physical Data Collection
	scoped and interesting community	
Industrial	The effect of the consumer in the community is difficult to measure effectively. It could be possible to have proxy communities but they would be somewhat removed from the assets actual performance	The data available from complex industrial assets can be vast. However, relating these values to the community rather than the production process would require careful consideration.
Power and Energy	The effect of the consumer in the community is difficult to measure effectively. It could be possible to have proxy communities but they would be somewhat removed from the asset's actual performance	The data available from complex power generation assets can be vast. However, relating these values to the community rather than the production process would require careful consideration.

On the basis of this research and within the restrictions of the ethics surrounding the collection of personal data a school was selected. This is because it represents a relatively simple physical built asset but a relatively complex social community, but is limited in sample size by the size of the school and the fact that the community remains reasonably consistent for the duration of the academic year.

Following the principles agreed in the ethics statement a series of approaches was made to a number of schools with a view to their participation in using the Test Bench approach. Obtaining suitable senior buy in to any intervention of this type proved to be challenging and several abortive attempts have been made before a suitable location and senior team buy in was achieved.

The school that was finally selected is a private co-educational day school with 900 boys and girls aged from 2½ to 18. It combines tradition and innovation to give academic excellence. The school is situated within 40 acres of attractive grounds, overlooking Surrey's greenest countryside. It borders the three counties of Surrey, Sussex and Kent. The school has a very strong academic ethos, results in recent years have been outstanding and the curriculum is broad and diverse. There is a wealth of extra-curricular activities available and the students are encouraged to make full use of them to develop their own individual strengths and personalities. For the purposes of maintaining confidentiality for this research it will be referred to by the code “LND”.

As a private organisation the school has freedom from Government regulation regarding asset procurement. The asset which forms the focus of this research is a new sixth form block situated on the first floor of a refurbished existing building. The site location is indicated in white in Figure 7.1. The building is based on an existing asset which has been extended upwards by the addition of a first floor on an existing classroom block. The opportunity was taken to refurbish the ground floor and provide a coherent ground and first floor space, which not only provides additional space, but also an environment which is more like the open flexible spaces provided by most universities, thus further preparing pupils for their next stage of education.

Figure 7.1 - Location and adjacencies of Sixth Form Block to school buildings and transport infrastructure

The selection of a school to conduct this Test Bench experiment will inevitably require specific considerations relative only to the education sector. This will be minimised and identified where possible to ensure that the generic application of the Test Bench is not compromised as the intent of this research is to develop and approach and methodology that can be applied to any relationship between the built environment and the communities it serves.

All data described here has been carefully anonymised where necessary to protect both the school and its staff and pupils as described in the ethics methodology.

7.3 Applying the Methods of the Test Bench

The Test Bench methods set out in Chapter six have been applied to demonstrate the briefing, design, delivery, handover and operations of the LND School. The application of the Test Bench to the school is to allow a number of Time Horizon strategies to be applied to the school to observe the impact of change over time. However, the scope of this research will restrict us to a single cross section of the data, with further research opportunities for repeat reviews of the performance of the building and its community over time both in different seasons and with different academic communities.

The IDEF 0 shown in figure 6.22 showed the full top level extent of the Test Bench. To apply the principles of the process this Chapter describes how the approach has been applied to the LND School. Figure 7.2 takes the IDEF0 from Chapter six and identifies four key areas of detail indicated by the shaded boxes where the sections below describe the detailed application. As the example used here only applies a single time slice to the experiment for this research and the school building had just been commissioned, it was necessary to retrospectively trace back through documents and discussions to establish key facts and specifications.

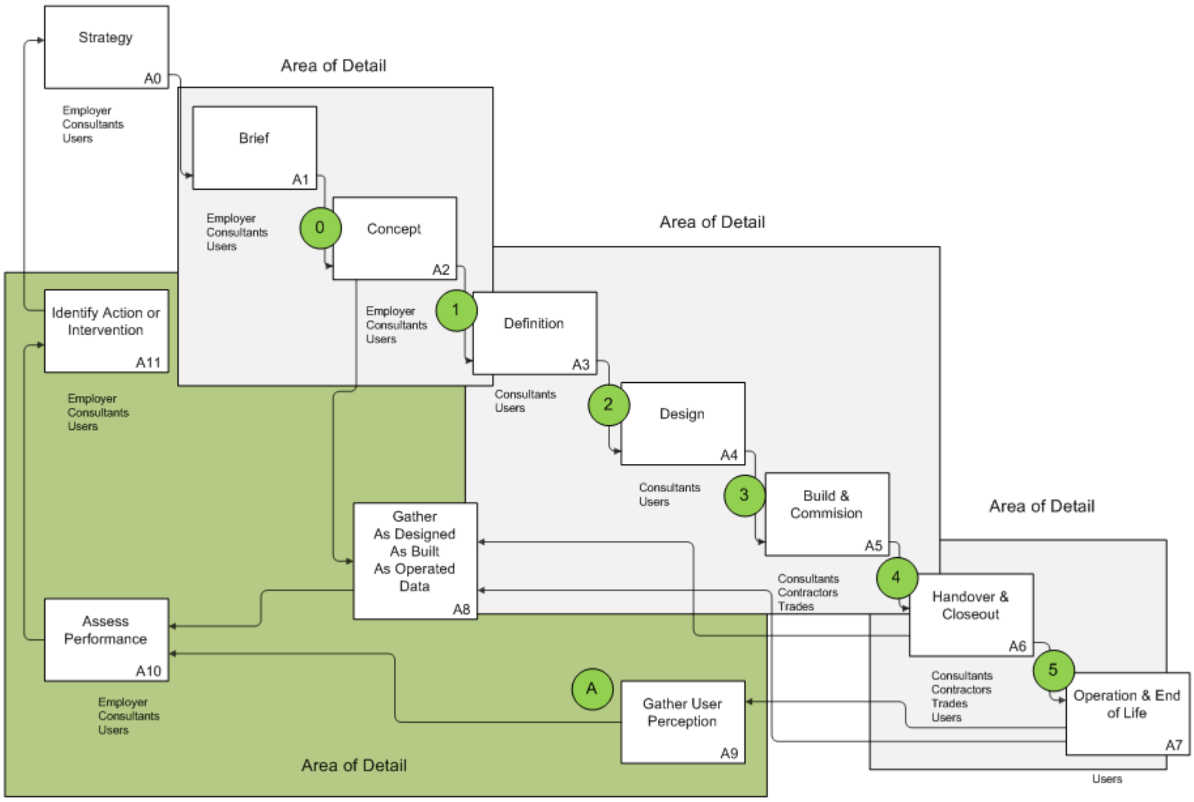


Figure 7.2 - Test Bench Process Extent IDEF 0 Model - Indicating Areas of Detail

7.4 Detailed Application of the Test Bench Data Instruments

Chapter six provided a detailed analysis of the production and operational systems and methods as defined by the Bew-Richards Level 2 definition embodied by the various artefacts described in Table 6.1. The Level 2 scope was deficient in that it is de-scoped. The management of briefing and performance measurement will not be standardised until Level 3 becomes available. To establish data for these two key feedback enabling mechanisms, work around's have been developed with the Test Bench and it is this Test Bench scenario that will be applied to the test school for the purposes of this experiment. The following narrative showing how the Test Bench has been applied to the LND experiment is specifically laid out in the same structure as Chapter six for easy reference.

7.4.1 The Briefing

7.4.1.1 Overview

James (2011) sets out the significant issues that have been identified with the process of capital allocation of both developed and targeted programmes and the maintenance of the estate as key issues with the delivery of educational assets. He also identified that the design and procurement process for the Building Schools for the Future programme was not deigned to create high quality or low cost, with the contract (capital) sum, rather than a specification being the preferred staring place for briefing. He also identified that designs have been far too bespoke and there was no evidence of an effective way of learning from mistakes. This was further compromised by poor expertise on the client side meaning that there was little opportunity to improve building methods. This was also compounded by a regulatory and planning environment which is far too complex and hostile to the building of schools.

This lack of experience and ability to brief clearly is reflected in the LND experiment. The school has a long standing and experienced estates team which has irregularly provided new built assets over the past two decades, but has been highly constrained by costs and planning restrictions. The ability of the estates team to gather and share performance information across the staff and other similar establishments is very limited and has run to the extent that due to the organisations independent nature basic specification information available from the education Funding Agency has not been considered. The brief which was developed for the LND scheme was developed between the estates team and the selected contractor. There was no evidence of a "Soft Landings" (BTG 2012) approach with interaction with the school operational and teaching staff at an absolute minimum.

7.4.1.2 Briefing Tools & Data Capture

As the work presented by Kiviniemi (2005) shows us, the impact of effective briefing on the performance outcomes of an asset are enormous. What we have seen with the impact of feedback being introduced into the process and the potential for improvement in very highly performing assets. It is clear that a good brief is an essential starting point for any building. There will always be key drivers in the delivery of any asset and schools present their own challenges critically from a fiscal and programme point of view, as well as maintaining a safe environment for current operations, especially if, as in this case, the school remains operational in close proximity to the site delivery activity.

The process model indicated in the detailed IDEF0 in Figure 7.3 shows the process of developing the brief at LND. The process shown here is the actual process as described by the facilities staff and would fall somewhat short of "Best Practice" due to the methods employed, including a low level of user engagement, no evidence of any "soft landings" processes or use of professional design advice.

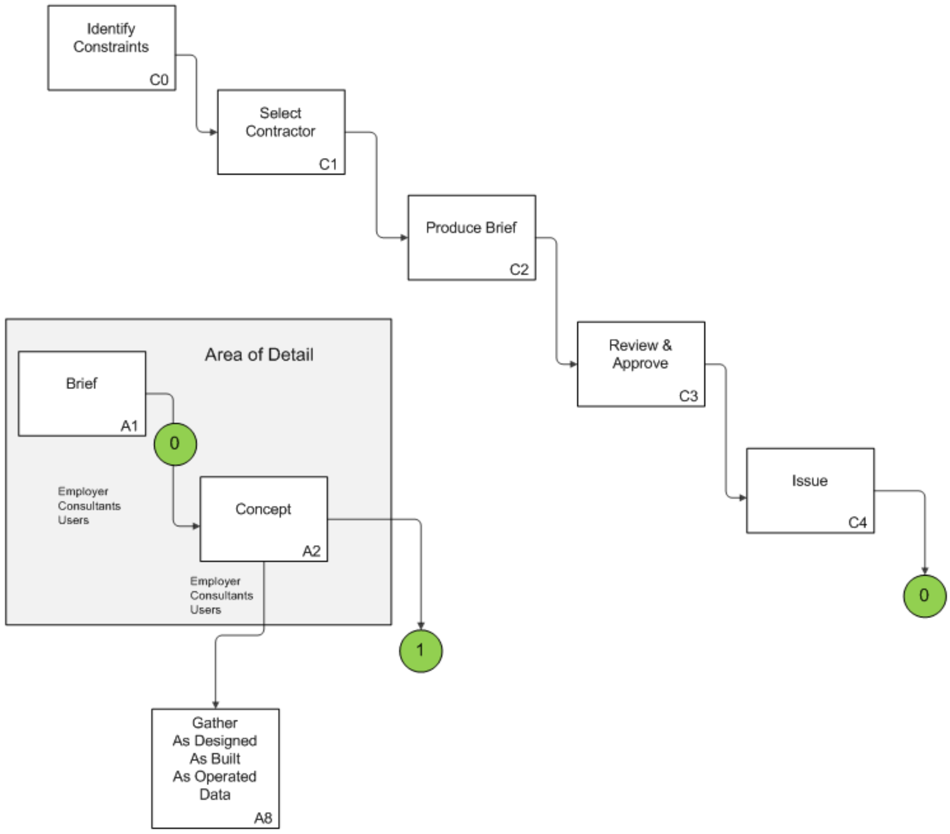


Figure 7.3 - Detailed Briefing stage IDEF0 Process Model

C0 – Identify Constraints

The constraints process was mostly confined to the identification of the site (the creation of a first floor extension on an existing building), the number of students and cost. These are very tight constraints and offer relatively little in terms of options for the delivery of such an asset. The constraints seem to have received little dialogue with the users of the asset.

C1 – Select Contractor

The main contractor was selected early and whilst early contractor involvement is not unusual and to generally be encouraged the lack of a client side design team in the guise of at least an architect is unusual. The optimal use of space, improvement in room shape and circulation would almost certainly have been improved if an architect had been employed at this early stage.

C2 – Produce Brief

The brief was created by the client and the contractor. There was limited reference to the learning from the EfA and other reference sources and this almost certainly compromised the performance of at least air quality and acoustic performance. The output of the process is shown in section 3.1.3 and was uploaded into the Test Bench database to enable future analysis and use.

C3 – Review and Approve

The principles of Soft Landings within the briefing process as laid out in BS 8536-1:2015, together with methods for understanding Stakeholder Impact Analysis. There are generally little signs of evidence that these processes were well executed with a number of questionnaire comments both eluding and stating as such. The majority of the consultation was effected by the estates team.

C4 – Issue

The information is issues ready for input into the Test Bench database. The specification and briefing data as discussed needs to be held in a form that enables checking and access to be a point of reference with which we can check the data provided by the supply chain. Data collected through this process was held both in text format shown here, but also placed inside the database described in section 5.6.2. The entities used for holding this data are shown in detail in Figure 7.4 below, which indicates a detailed subset of the full ERD shown in figure 6.21, where the briefing entities derived from the PREMMIS system have been integrated into the wider data sets. A larger and more detailed specification is shown in Appendix six.

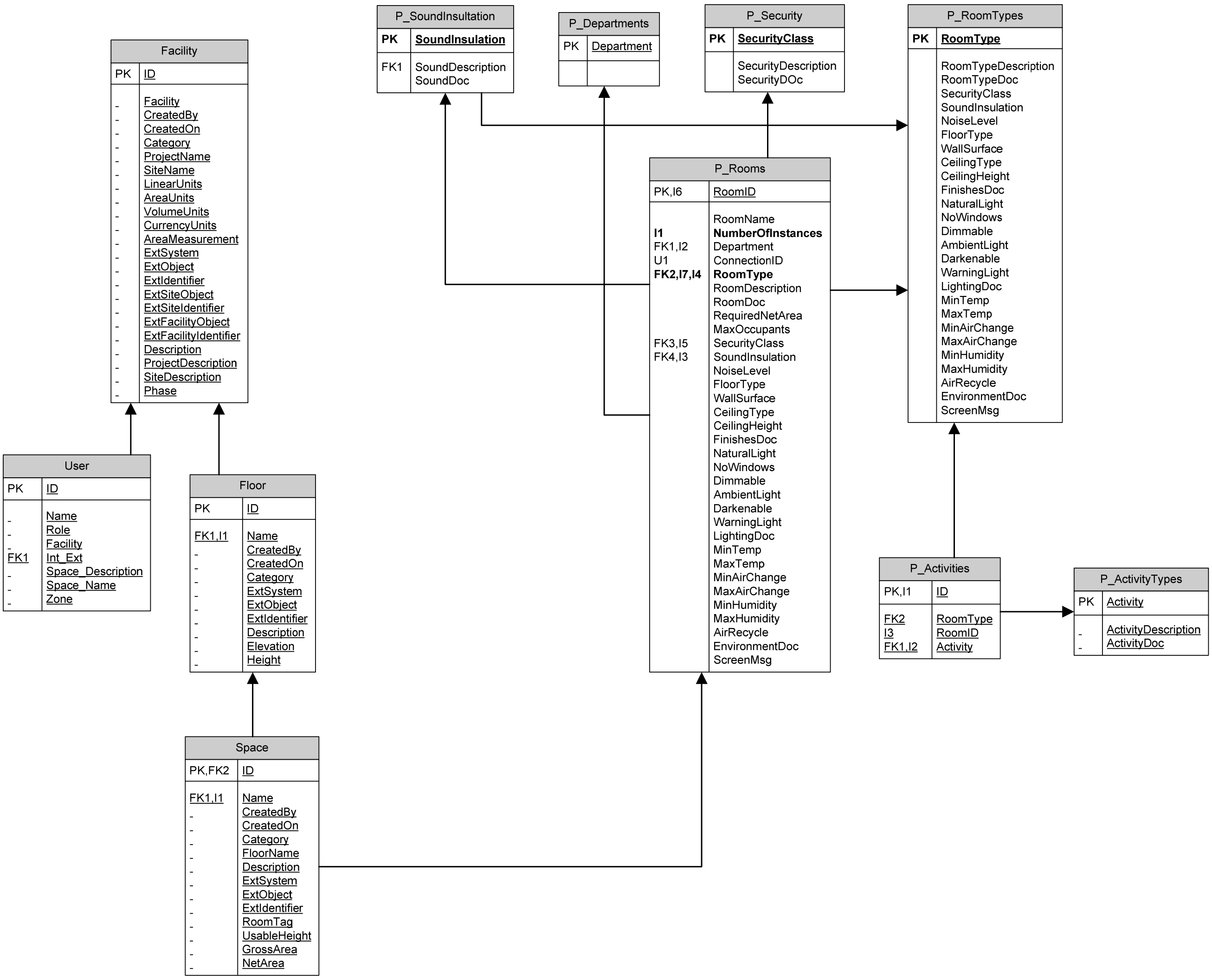


Figure 7.4 - Entity-Relationship Diagram for Entities related to holding Specification Data

The Table shown in 7.2 has also been provided to provide a description of the entities and attributes of the section of the Test Bench database derived from the PREMMIS system. This is used to hold the brief in a structured format to enable future access and use. Some of the values were established through dialogue with the estates team and do not appear to have formed part of the contract, thus making it very difficult to establish any form of recourse to the contractor as one would expect with a more common design and build contract.

The entities have been selected from the PREMMIS briefing model developed by Kiviniemi in his thesis "Requirements Management interface to Building Product Models" (Kiviniemi 2005). Here he asked the questions "How can a Requirements Model Specification for a

Client Requirement in a building be formalised? And how can the relationship between this relationship model and the design model be formalised? The requirements approach as advocated by Kiviniemi (2005) provides an objective structured definition of the user and employers requirements which are needed to provide an effective space to deliver educational services, it also for the purposes of this research provides the reference platform to measure both the physical and social performance of the asset.

Table 7.2 - Entity Descriptions for entities derived from PREMMIS

Entity	Description (as defined by BS1192:4:2015 & PREMMIS Specification tool)
Facility	A COBie entity which specifies the facility or in this case building for which the dataset represents. It describes the named distinct operational built or geographic asset, typically a building or section of infrastructure along with details and extent of the geographic site and of the temporal project
Floor	Named intermediate spatial subdivision, including distinct vertical levels and horizontal levels and sections with spaces allocated
Space	Named location from activities such as use, inspection or maintenance, including un-occupied or un-inhabited space, but not necessarily voids. Spaces may be internal or external to the building
P_ActivityTypes	Description of the types of activities a space needs to be supported.
P_Activities	Actual activities which take place in specific spaces
P_RoomTypes	This entity contains all of the specific attributes which define the physical performance properties of the space
P_Rooms	Entity describing the room (space) to be provided
P_Security	An entity with attributes describing the security requirements
P_Department	Label entity to allocated rooms (spaces) to departments for reporting purposes
P_SoundInsulation	An entity with attributes describing the acoustic requirements

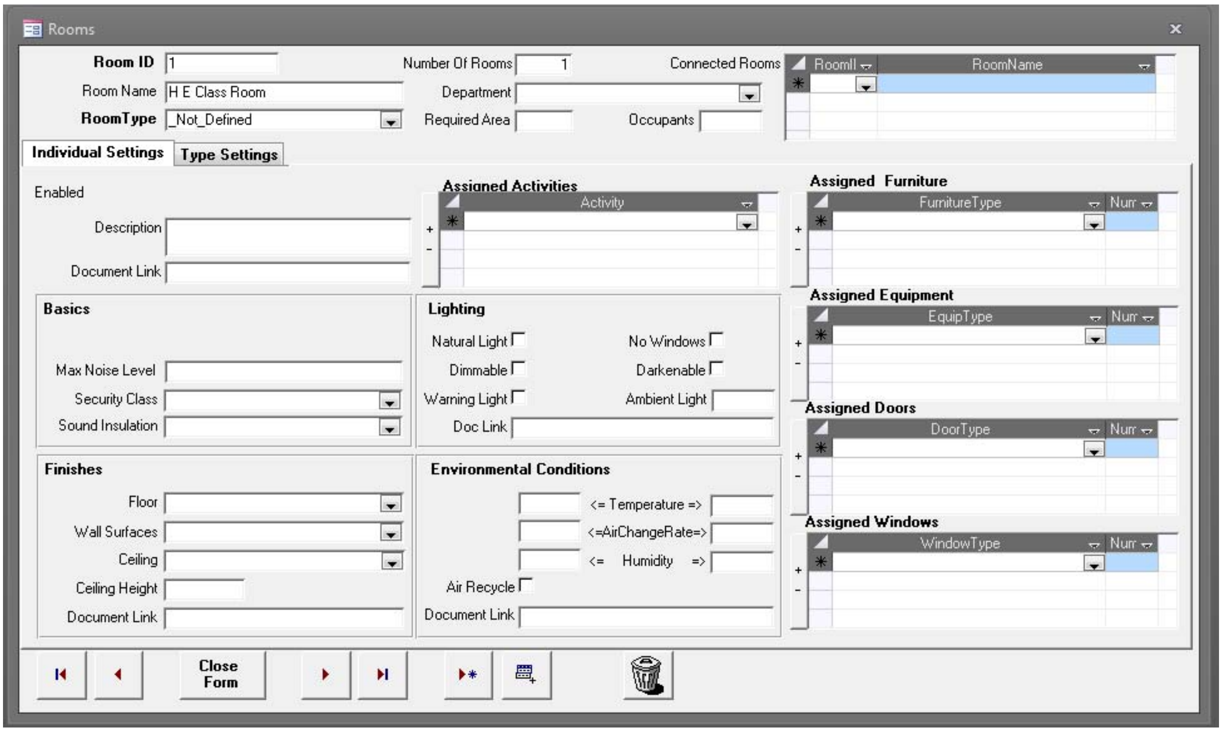


Figure 7.5 - PREMISS Database Screen Image

The entities derived from PREMMIS were focused only on the elements of direct relevance to this research. The entities were integrated into the entities derived from the COBie schema and as described below the schema from the Cube Sensors. The data was input using a modified version of the PREMMIS application as shown in Figure 7.5.

7.4.1.3 Briefing Data Content

The briefing documentation for the project was very straight forward and would be considered as an absolute minimum. The asset was provided against a very tight budget, which was in the lower quartile of the Education Funding Agency cost analysis published in James (2011).

The initial brief was developed by the school's facilities team and was bounded by two key criteria.

- Cost
- Location (a first floor extension to an existing building)

The brief was developed by a contractor who was selected on the basis of past performance and experience. The briefing has some of the key sections that would be expected but due to the private funding of the organisation is free from the specific requirements of the Education Funding Agency. The EFA (2014) Baseline designs for schools: Guidance guidelines for costs are set at £1113/m2 (excluding external works, particular circumstances and fees). The equivalent cost set for LND was £1.4M, the total area specified was 1143 m^2 which gives an indicative cost of £1225 m^2 however this cost also included the refurbishment of the ground floor, so provides an out turn cost within the guidelines provided.

The specification and briefing produced by the school was very vague in the area of air quality. The Education Funding Agency has published Bulletin 101: Ventilation from school buildings (EFA 2014), which is designed to be used in conjunction with Part F of the Building Regulations. The Bulletin provides methods for specifying schools to comply with Part F. The paper specifies that, in general terms, the requirement may be achieved by providing a ventilation system which

a. extracts, before it is generally widespread, water vapour from areas where it is produced in significant quantities (e.g. kitchens, utility rooms and bathrooms);
b. extracts, before they are generally widespread, pollutants which are a hazard to health from areas where they are produced in significant quantities (e.g. rooms containing processes or activities which generate harmful contaminants);
c. rapidly dilutes, when necessary, pollutants and water vapour produced in habitable rooms, occupiable rooms and sanitary accommodation;
d. Makes available over long periods a minimum supply of outdoor air for occupants and to disperse, where necessary, residual pollutants and water vapour. Such ventilation should minimise draughts and, where necessary, should be reasonably secure and provide protection against rain penetration;
e. is designed, installed and commissioned to perform in a way which is not detrimental to the health of the people in the building; and
f. is installed to facilitate maintenance where necessary.

It also recommends:

a. All occupied areas in a school building shall have controllable ventilation at a minimum rate of 3 litres of fresh air per second for each of the maximum number of persons the area will accommodate.
b. All teaching accommodation, medical examination or treatment rooms, sick rooms, isolation rooms, sleeping and living accommodation shall also be capable of being ventilated at a minimum rate of 8 litre of fresh air per second for each of the usual number of people in those areas when such areas are occupied.
c. All washrooms shall also be capable of being ventilated at a rate of at least six air changes an hour.
d. Adequate measures shall be taken to prevent condensation in, and remove noxious fumes from, every kitchen and other room in which there may be steam or fumes.
e. Ventilation should be provided to limit the concentration of carbon dioxide in all teaching and learning spaces. When measured at seated head height, during the continuous period between the start and finish of teaching on any day, the average concentration of carbon dioxide should not exceed 1500 parts per million (ppm).
f. The maximum concentration of carbon dioxide should not exceed 5000 ppm during the teaching day.
g. At any occupied time, including teaching, the occupants should be able to lower the concentration of carbon dioxide to 1000 ppm.
h. There should be no more than 120 hours when the air temperature in the classroom rises above 28°C
i. The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on average)
j. The internal air temperature when the space is occupied should not exceed 32°C.

The document also recommends the measurement of volatile organic compounds (VOC). This is due to the greater insights this data provides and the ability to understand how the space is performing. VOCs are emitted from a wide range of products including: building materials and furnishings (for example, surface finishes and paints), cleaning products and from markers, glues and paints used in art classes. Common VOCs in schools include:

- formaldehyde
- decane
- butoxyethanol
- isopentane
- limonene
- styrene
- xylenes
- percholoethylene
- methylene chloride;
- toluene; and
- vinyl chloride (Aerias 2010)

Some VOCs are known to be toxic and can adversely affect children in vulnerable groups (for example, those that suffer asthma and allergies). There are also suggested links between VOC levels and behavioural problems in children. At the levels found in school buildings, however, their most likely health effect is short-term irritation of the eyes, nose, skin and respiratory tract. Odour generated by VOCs is usually of more concern to the occupants. Formaldehyde is a particularly strong smelling VOC. Although formaldehyde is carcinogenic, the concentrations in buildings do not represent a significant risk. Approved Document F (Building Regulations) (DOE 1991) suggests that concentrations of 0.1 mg/m^3 may cause throat and nose irritation.

Potentially harmful emissions from can be reduced by avoiding sources of pollutants; for example, careful selection of materials can minimise VOC emissions. This may allow ventilation rates to be lowered, thus providing a potential saving in energy use. Emission control is not considered within the main guidance of Approved Document F, due to limited knowledge about the emission of pollutants from construction and consumer products used in buildings, and the lack of suitable labelling schemes for England and Wales. Some construction products such as glass, stone and ceramics have low emissions. Some paints are now labelled for their VOC content, and some wood-based boards are available with low formaldehyde emission BS EN 13986:2002 (2002). Labelling allows suitable products to be chosen in ensuring good indoor air quality, but it is not currently practical to make an allowance for use of these products in the ventilation requirements.

As part of this study the researcher has applied a value for the accumulation of VOC derived from guidance from the sensor vendors and other literature. The specification above includes values for the measurement of VOC as a key measure for the reasons described above. The values used have been derived from both the literature review and the recommendations identified by the sensor product manufacturers.

Further to this the specification for the control of acoustics as described in EFA (2014-3) states that

“Each room or other space in a school building shall be designed and constructed in such a way that it has the acoustic conditions and the insulation against disturbance by noise appropriate to its intended use.” and “The acoustic conditions and sound insulation of each room or other space must be suitable, having regard to the nature of the activities which normally take place therein.”

The specific guidance for sound attenuation is identified both within the space being specified and the surrounding spaces, requiring the need to provide adequate sound attenuation between spaces, through the use of acoustic damping devices.

EFA (2015) sets out a number of objectives for managing acoustic performance, these being to provide suitable indoor ambient noise levels (IANL) for:

- clear communication of speech between teacher and student
- clear communication between students
- learning and study activities

The IANL includes noise contributions from:

- external sources outside the school premises (including, but not limited to, noise from road, rail and air traffic, industrial and commercial premises)
- building services (e.g., ventilation systems, plant, drainage etc.). If a room is naturally ventilated, the IANL is calculated and measured with ventilators or windows open as required to provide ventilation. If a room is mechanically ventilated or cooled, the plant should be assumed to be running at its normal operating duty.
- actuator and damper noise

The IANL excludes noise contributions from:

- teaching activities within the school premises, including noise from staff, students and equipment within the building or in the playground (noise transmitted from adjacent spaces is addressed by the airborne and impact sound insulation requirements)
- equipment used in the space (eg machine tools, CAD/CAM machines, dust and fume extract equipment, compressors, computers, projectors, fume cupboards) as these noise sources are considered as operational noise
- rain noise - however, Building Regulation submissions should demonstrate that lightweight roofs and roof glazing have been designed to provide suitable control of rain noise reverberant sound pressure level in a space (calculated using laboratory test data with 'heavy' rain noise excitation as defined in BS EN ISO 140-18). Levels during heavy rain should not be more than 25 dB above the appropriate indoor ambient noise level

The acoustic requirements for the school and identified a maximum noise level of 80dB with a recommendation to follow the EFA guidelines described above.

The remainder of the specification of the building can be found in Appendix five. This document details all aspects of the physical manifestation describing functional, regulatory and operational requirements. It is a contractual point of reference for the delivery of the building. It is also the digital point of reference or control for the experiment and will be the point of reference to compare the physical performance once the asset id in operation and is occupied.

The room data sheets are a useful summary of this specification information and are provided for all spaces in the school. The example shown in Table 7.3 is for a generic room space. It describes the physical materials and the mechanical properties of the structure and the performance the space is expected to achieve in normal usage.

Table 7.3 - Room Data Sheet

Specified Item	Description
Project name	LND
Room Name	Group Rooms – Generic
Room Ref	001
Size of Rooms	
Room Occupancy	
Ceilings	Either suspended or painted plasterboard. (Above ceiling void easily accessible for future maintenance and adaptation of services. (Moisture resistant)
Walls	Paint or other easily cleanable finish, should be easily re-paintable
Floors	Combination of anti-static carpet and non-slip vinyl (or equivalent) surface
Joinery	Timber or equivalent, skirting's, architraves and window boards, painted finish.
Fittings	1 * standard double cupboard sink unit, including stainless steel single drainer and separate hot and cold taps. Units to be of high quality standard kitchen units. Selection of cupboard front to be agreed from ranges selected with the school, with robust cupboard hinges
Fixtures	Blinds to all external windows
Windows	Double glazed, solar reflective, lockable, restricted openings (Maximum glazed area to maximise natural light)
Doors	Internal flush faced, solid, top and bottom, anti-shatter glass vision panels, finger guards, lockable door. External doors predominantly anti shatter glazed, threshold with a level transition from inside to out, lockable and openable from the inside without a key
Ironmongery	3 No hinges, push plate, pull handle, kick plate, metal barrel latch, deadlock,

	escutcheons (no snib). Keys to be on a master key system for whole block. Door closer, vision panel, room sign holder system
Storerooms	
Whiteboards	Supplier by client
Pin Boards	5 Pin boards 1200 * 900 Locations to be selected by school
Notes	Client / end user to order loose furniture
Temperature Summer (Min)	19
Temperature Summer (Max)	21
Temperature Winter (Min)	19
Temperature Winter (Max)	21
Ventilation VOC (Max)	1000
Ventilation VOC (Min)	450
Humidity (Max)	45
Humidity (Min)	55
Heating	
Noise Level (Max)	60
Air Conditioning	
Water Services (Cold)	
Water Services (Hot)	Tepid water supply to sink unit
Water Services (Drinking)	Drinking water supply to sink unit
Special Items	
Sprinkler	As specified by Building Control
Lighting (Luminaire Type)	
Type of Lamp	
Minimum Lux	300 Lux Min, limiting glare rating 19, minimum colour rendering 80 and uniformity ration 0.8
Power Outlets 240v (Non IT)	8 No DSO ideally 2 on each wall within each room
Power Outlets 240v (IT)	5 No DSO
Power Outlets 240v	
Power Outlets 120v	N/A
Other	Audio visual connection for interactive whiteboard
Data Outlets (RJ45)	4 No Data Outlets
Telephone	1 RJ45 for telephone connection
Fire Alarm	
Emergency Lighting	Yes, as specified by Building Control
Smoke Detector	
Security System	

7.4.2 The Delivery (Concept, Design and Building Stages)

The delivery stage is where the supply chain take the brief and project outcomes described above and delivers the employer a working asset ready for him to conduct his business. In the case of the LND school the estates team acted as a proxy to the Headmaster to provide a layer of interpretation of the new buildings users to the construction industry and vice versa. This challenge of ensuring adequate understanding between the supply and demand sides of the market is a perennial challenge to enabling the industry to improve as discussed in Latham and Egan. The Soft Landings approach described by both the Government and BSRIA is designed to form a lasting collaborative relationship between the two sides to ensure effective communication and understanding. The use of BIM tools and visual techniques is as defined in Chapter six defined by a delivery process. This process as defined in the IDEF0 model figure 6.22 identifies a number of data drops. These data drops are specified in the procurement process as defined in the Level 2 documentation. The BIM Toolkit, (BTK 2015) was used to prepare the shadow documentation to define data deliverables at each data drop. The key data drop for this experiment are numbers one, four and six as they define the as required information (brief), as built and as operated data.

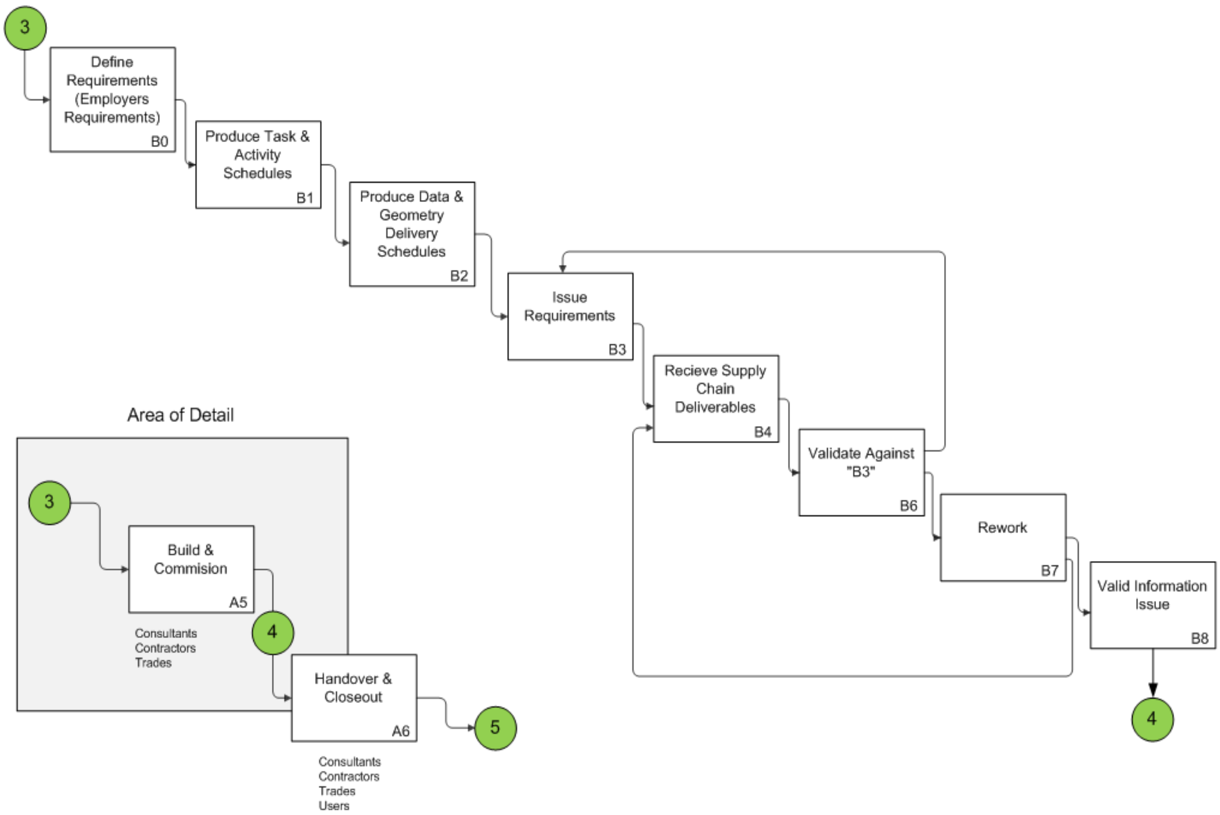


Figure 7.6 - IDEF0 Process Model showing the detail of how data is procured and delivered from the supply chain

The IDEF0 in Figure 7.6 shows by example between data drop 3 and 4 how the process of data procurement is accomplished. The stages are deployed through the use of a number of tools to enable the effective implementation of the processed described in Chapter six.

B0 - Definition of Requirements (Employers Requirements)

The Employers Requirements (ER) are the documents embodied by the construction contract to define the final deliverables of the project. The choice of procurement methodology will have an impact on the detailed phasing of the data deliverables but as discussed above the LND procurement strategy of engaging the contractor very early moves the onus onto the contractor to provide information early to substantiate the commitment made to ensuring key criteria such as the budget are achieved.

B1- Produce Task and Activity Schedules

The definition of tasks by both the client and the supply chain is essential to demonstrate the methodology for delivery. This activity can and has been for many years carried out through the use of a standard set of duties such as those offered by the RIBA Plan of Work, RIBA (2013). The BIM Toolkit has enabled the automation of this process and the screen image in Figure 7.7 shows the base RIBA definitions in the tool awaiting update and responsibility allocations prior to being output into a schedule as shown in Table 7.4.

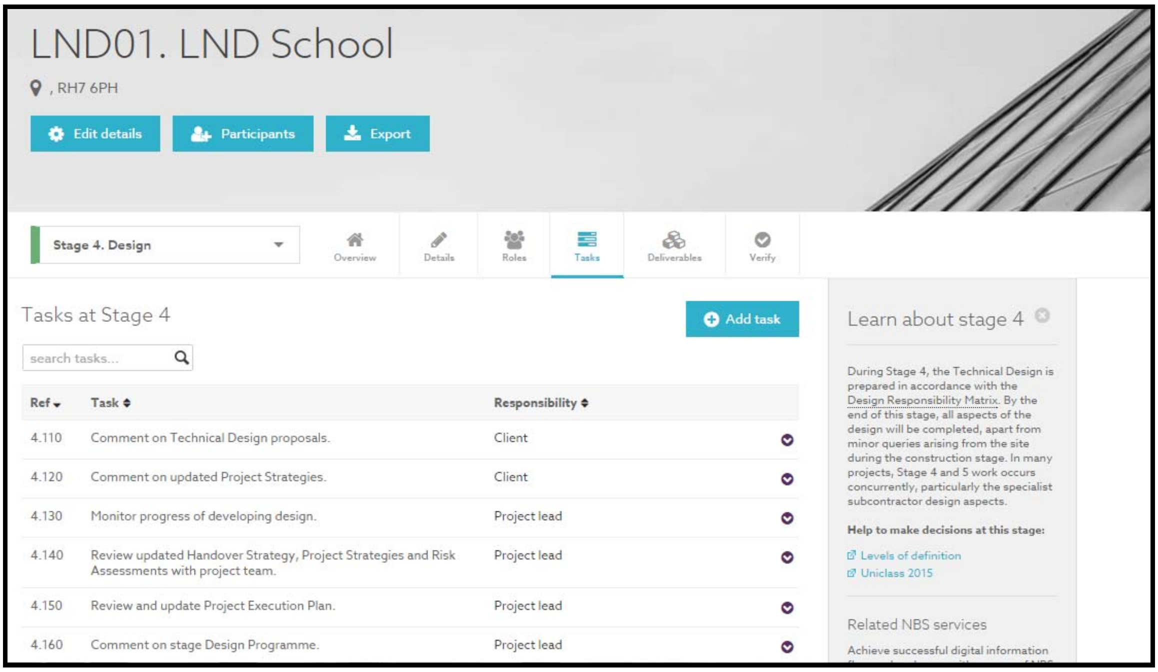


Figure 7.7 - BIM Toolkit Screen Image of Stage 4 Task allocation

Table 7.4 - BIM Toolkit Task Output file

	Activity	Owner	Notes
4.110	Comment on Technical Design proposals.	Client	The Client must have the opportunity to comment as the proposals develop and progress.
4.120	Comment on updated Project Strategies.	Client	The Client must have the opportunity to comment as the proposals develop and progress.
4.130	Monitor progress of developing design.	Project lead	This should be measured in accordance with the Design Programme.
4.140	Review updated Handover Strategy, Project Strategies and Risk Assessments with project team.	Project lead	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.150	Review and update Project	Project lead	All members of the Project Team will have an

	Activity	Owner	Notes
	Execution Plan.		input, but one member takes responsibility for organising the process and coordinating the results.
4.160	Comment on stage Design Programme.	Project lead	The Project lead must have the opportunity to comment as the proposals develop and progress.
4.170	Manage Change Control process.	Project lead	Change Control Procedures should be implemented to ensure that any changes to the Concept Design are properly considered and signed off, regardless of how they are instigated.
4.180	Monitor and review progress and performance of project team.	Project lead	This should be measured in accordance with the Project Programme.
4.190	Review Technical Design proposals and Project Strategies as they progress and integrate the design work specialist subcontractors.	Design lead	This should be measured in accordance with the Design Programme.
4.200	Update Sustainability Strategy and Maintenance and Operational Strategy.	Design lead	This will be carried out with input from project team as required.
4.210	Prepare stage Design Programme in conjunction with other design team members	Design lead	This will be carried out with input from project team as required.
4.220	Monitor and review progress and performance of design team	Design lead	This should be measured in accordance with the Design Programme.
4.230	Liaise with specialist subcontractors.	Design lead	As necessary.
4.240	Prepare architectural Technical Design.	Architect	In accordance the Design Responsibility Matrix incorporating Information Exchanges, Design Programme and comments from Design lead.
4.250	Submit Building Regulations Submission (Building Warrant in Scotland)	Architect	
4.260	Undertake third party consultations.	Architect	This will include the conclusion of any Research and Development aspects.
4.270	Assist Design lead with preparation of stage Design Programme	Architect	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.280	Provide information for update of Project Strategies	Architect	This will be as requested from the Project lead.
4.290	Liaise with specialist subcontractors.	Architect	As necessary.
4.300	Prepare building services	Building	in accordance with the Design Responsibility

	Activity	Owner	Notes
	Technical Design.	services engineer	Matrix incorporating Information Exchanges, Design Programme and comments from Design lead.
4.310	Undertake third party consultations as required and any Research and Development aspects	Building services engineer	This will include any Research and Development aspects as required.
4.320	Assist Design lead with preparation of stage Design Programme	Building services engineer	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.330	Provide information for update of Cost Information and Project Strategies	Building services engineer	This will be as requested from the Cost consultant or Project lead respectively
4.340	Liaise with specialist subcontractors.	Building services engineer	As necessary.
4.350	Prepare Civil Engineering Technical Design.	Civil engineer	In accordance with the Design Responsibility Matrix incorporating Information Exchanges, Design Programme and comments from Design lead.
4.360	Undertake third party consultations.	Civil engineer	This will include any Research and Development aspects as required.
4.370	Assist Design lead with preparation of stage Design Programme	Civil engineer	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.380	Provide information for update of Cost Information and Project Strategies	Civil engineer	This will be as requested from the Cost consultant or Project lead respectively
4.390	Liaise with specialist subcontractors as necessary	Civil engineer	As necessary.
4.400	Prepare Structural Technical Design.	Structural engineer	In accordance with the Design Responsibility Matrix incorporating Information Exchanges, Design Programme and comments from Design lead.
4.410	Undertake third party consultations as required and any Research and Development aspects	Structural engineer	This will include any Research and Development aspects as required.
4.420	Assist Design lead with preparation of stage Design Programme	Structural engineer	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.430	Provide information for update of Cost Information and Project Strategies	Structural engineer	This will be as requested from the Cost consultant or Project lead respectively.

	Activity	Owner	Notes
4.440	Liaise with specialist subcontractors as necessary	Structural engineer	As necessary.
4.450	Update preliminary Cost information	Cost consultant	
4.460	Assist Design lead with preparation of stage Design Programme	Cost consultant	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.470	Update Construction Strategy	Construction lead	Based on Project Strategy
4.480	Prepare Building Contract, agree with contractor and arrange completion	Contract administrator	
4.490	Update Health and Safety Strategy	Health and safety adviser	All members of the Project Team will have an input, but one member takes responsibility for organising the process and coordinating the results.
4.500	Check Sustainability assessment.	Project lead	Is the formal sustainability assessment substantially complete?
4.510	Check airtightness and continuity of insulation	Project lead	Has an audit been carried out?
4.520	Check energy assessment.	Project lead	Has the energy assessment submission been made and the design stage carbon/ energy declaration been updated and the future climate impact assessment prepared? This may be a statutory requirement.
4.530	Check user guide	Project lead	Has a non-technical user guide been drafted and have the format and content of the Part L log book been agreed?
4.540	Check outstanding design stage information	Project lead	Has all outstanding design stage sustainability assessment information been submitted?
4.550	Check monitoring technologies	Project lead	Are building Handover Strategy and monitoring technologies specified?
4.560	Check review of changes	Project lead	Have the implications of changes to the specification or design been reviewed against agreed sustainability criteria?
4.570	Check sustainability compliance	Project lead	Has compliance of agreed sustainability criteria for contributions by specialist subcontractors been demonstrated?
4.580	Contribute to Health & Safety Strategy.	All roles	As required. Additional project roles will depend on the procurement strategy adopted.
4.590	Provide information for and contribute to contents of Project Execution Plan.	All roles	As required. Additional project roles will depend on the procurement strategy adopted.
4.600	Liaise with project Lead and Design lead.	All additional project roles	As required. Additional project roles will depend on the procurement strategy adopted.
4.610	Provide information.	All additional	As set out in the Design Responsibility Matrix

	Activity	Owner	Notes
		project roles	incorporating Information Exchanges in accordance with Design Programme
4.620	Exchange technical design.	Project lead	Technical Design including outline structural and building services design, associated Project Strategies, preliminary Cost Information and Final Project Brief.

B2 - Produce Data and Geometry Delivery Schedules

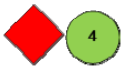
The specification and delivery of data as defined in Chapter six is driven by the employer’s risk, governance and procurement strategy. The project delivery and task allocations are defined in the BIM Toolkit as shown in Figure 7.7. This process is undertaken for each stage of the delivery process and allows the user to derive a "target" or "demand" data definition as shown in Figure 7.9. This document can then be used to compare and validate proposed deliveries to ensure the data content is valid for use. It does not however set out to achieve and checking process for design integrity, quality or effectiveness, which is the purpose of this research. The deliverables are derived from the work described in Table 6.2 which defined the Plain Language Questions (PLQ) for a Generic asset. The Table shown in Table 7.5 has been developed specifically for the needs of the LND educational asset and the needs of being able to gather data to undertake the user perception analysis.

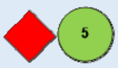
Table 7.5 – Data Requirements for LDN derived from PLQ Analysis

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
0 – Strategy	1) Is the scheme likely to get Planning Permission?		x		
	2) What are the outline costs?				x
	3) Has Market research been carried to determine demand for the new facility?		x		
	4) What is the likely revenue income and cost constraints?				x
	5) Have we got the resources to deliver the project?		x		
	6) What are the social imperatives the project seeks to achieve?		x		x
1 – Brief	1) What are the site extents?			x	x
	2) What is the Project type? – commercial, residential, mixed, educational, transportation, maintenance operational		x		x
	3) What are the Site layout options? – Routes, adjacencies, servicing, building position and massing model	x		x	x
	4) What is the resettlement and decant plan?		x		
	5) What is the latest target cost?				x
	6) What is the design and construction programme?				x
2 -Concept	1) Is there accurate survey data of the site?	x			x
	2) What is the latest target cost?				x

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	3) What are the forecast revenues?				x
	4) What is the selected site?				x
	5) What physical constraints are there on and around the site?	x			x
	6) What services constraints (water / drainage / electricity) exist?	x			x
	7) What site-specific safety and security considerations need to be made?		x		
3 –Definition	1) Do the concepts being considered meet clients brief?		x		
	2) Has the market research been carried out suitably on the proposed suppliers?		x		
	3) Do the proposed suppliers meet pre-qualification criteria?				x
	4) Do the proposed suppliers have adequate BIM and data management capability?		x		x
	5) What is the latest target cost and programme?				x
4 – Design	1) What is the pre-design solution? In particular, what are the layouts and adjacencies?				x
	2) Does the architecture meet the vision of the employer and the users (Have you used Soft Landings?)			x	x
	3) Does the design's performance meet the design brief?		x		x
	4) What is the outline proposal for structural design?			x	

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	5) What are the output requirements from services systems?			x	x
	7) What targets are to be used for Post Occupancy/Operational Evaluation?		x		x
	8) What is the commissioning strategy and how can it be tested?		x		
	9) Can the designers show the project can be delivered safely, does it comply with CDM regulations?		x		
	10) Has the concept been designed for efficient manufacture and assembly?		x		x
	11) How easy is it to build?		x		
	12) What is the latest target cost and programme?				x
	13) Does the design optimise the use of standard library components?		x		x
	13) Is the Architectural, MEP and Structural design spatially coordinated?				x
	14) Can the MEP services and structure be combined within the Architectural Design within the proposed 3D volume strategy?			x	x
	15) Has the market research, prequals and assessments been carried out suitably on the proposed suppliers?				X
	16) Do the proposed suppliers meet pre-qualification criteria?				X

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	17) Do the proposed suppliers have adequate BIM capability				X
5 – Build & Commission 	1) Have all the deliverables of the design brief been met?		x	x	x
	2) Is the Architectural, Structural and MEP design coordinated?			x	
	3) Is the design developed to demonstrate detailed proposals for site layout?			x	x
	4) Is the design developed to demonstrate detailed proposals for planning and spatial arrangements?		x	x	x
	5) Is the design developed to demonstrate detailed proposals for external design?			x	
	6) Is the design developed to demonstrate detailed proposals for environmental systems?			x	
	7) Is the design developed to demonstrate detailed proposals for buildability?			x	
	8) Does the design meet other aspects of statutory standards, specs and brief?		x	x	x
	9) Has value management/engineering taken		x		

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	place?				
	10) Is the design safe to construct (CDM)?		x	x	
	11) Is the design safe to use and maintain (CDM)?		x	x	
	12) Does the design optimise the use of library components versus bespoke components?		x		x
	13) How are the facilities/asset built?		x		
	14) What are the task durations?				x
	15) How will the client be consulted with respect to detailed changes to designs during construction?		x		
	16) Is the information complete enough to procure the package contractor?		x		x
	17) How are defects controlled and managed?		x		
6 Handover & Closeout 	1) Do the systems integrate and operate as the brief defined?		x		
	2) Is the data ready to hand back to the client/operator		x		x
	3) What are the Asset Management Datasets required to operate the asset?				x
	4) Do the systems being commissioned meet clients brief?				
	5) What are the actual costs?				
	6) What is the actual carbon				

Key Client Decision at Information Exchange Points	Plain Language Questions	Native BIM Model	Reports	Drawings and Specifications	Other Data Sources
	created?				
7 –Operation & End of Life 	1How do the users perceive the performance of the building?		x	x	
	2) What changes have been incorporated?				
	3) What has been actually built? (As Built models and Drawings)				x
	4) Does the asset perform to its sustainability and output specifications		x		
	5) Are the operational data feeds working?		x		x
	6) How does a specific product / element perform?				x
	7) How is the facility/asset being operated?		x		
	9) How has the GSL and POE performance worked?				
	10) Does the project meet the brief?		x	x	x

Chapter six described the manual process of converting the PLQ into data sets for data specification and validation purposes, with a detailed example shown in figure 6.8, describing the method of analysis, by taking the PLQ and decomposing it down to the Actual Detailed Question (ADQ), then further down to the Digitally Compliant Question (DCQ) and then into the entity and attribute definitions and expected values. To simplify the production of this process the NBS part of RIBA-E (RIBAE 2015) published the BIM Toolkit. This tool enables much of the labour intensive analysis to be automated to simplify the production of the deliverable demand COBie templates. The screen shown is Figure 7.8

indicates the landing page for defining the stage three deliverables. An example of the output for this process is shown in Figure 7.9.

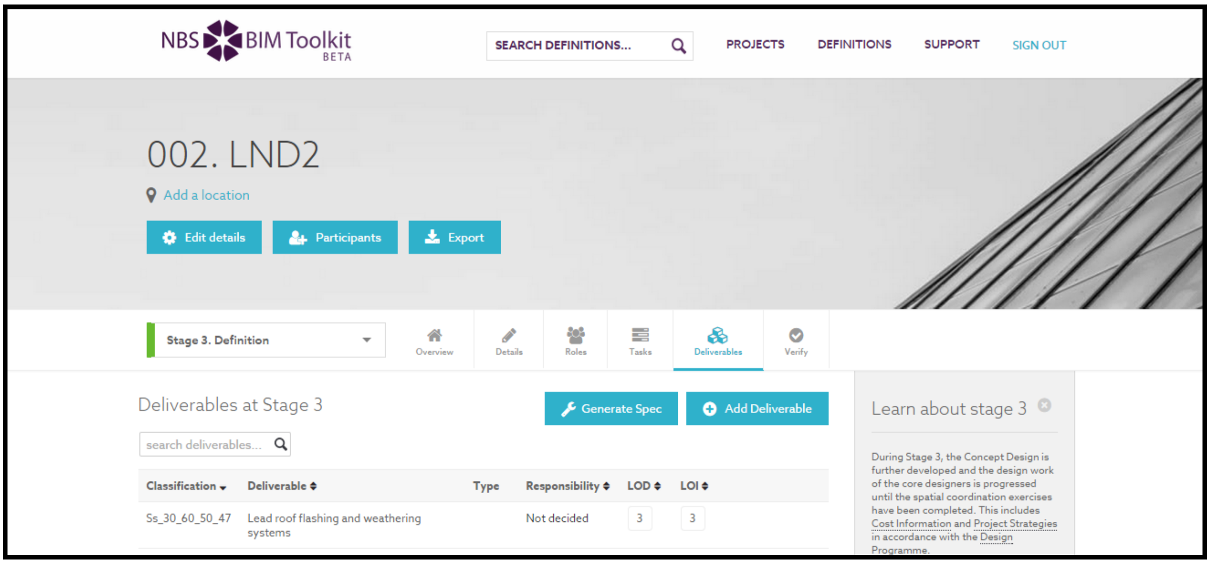


Figure 7.8 - BIM Toolkit being used to define design deliverables

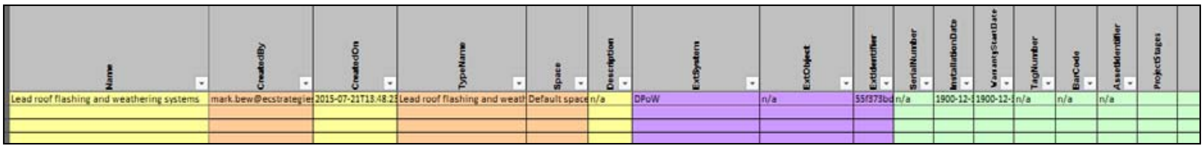


Figure 7.9 - COBie Demand data definition

The BIM Toolkit is a Level 2 tool so is not designed to manage real time data sets. These are defined as a requirement in the Level 3 (DBB 2015) strategy direction document, which is due to be standardised by 2020. To enable the collection of data from the near real time (60 second cycle time) cube sensors, consideration needs to be given to a work around to provide suitable validation strategies. However, in this research the cube sensors collect a relatively simple dataset and as the data set is timestamped retrospective validation would be a relatively easy task to effect a validation strategy once the records were in the database.

B3 - Issue Requirements

Depending upon the specifics of the contract the schedules and requirements documentation would be issues as part of the contract. As in the relationship between the employer (asset owner) this process would be repeated by the main contractor procuring services from the supply chain providers. In the case of LND only a paper brief was issued with no duties so these have been specifically developed in retrospect for this research. There is no evidence of the LND main contractor specifically requiring any information from downstream suppliers.

B4 - Receive Supply Chain Deliverables

Once the contract is underway the employer should ensure that there are adequate facilities in place to receive and store the information.

The delivery of the design, procurement and delivery information is specified using the methods described in Chapter six, this provides clear definition of geometric and data attribution and maturity. To generate these datasets with integrated data and geometry data indicates that the design would need to be developed using a Building Information Modelling (BIM) tool. The selection of COBie as a data transfer data format (as defined by Level 2) insulates the user from the proprietary selection process of data development tools. However, a decision does need to be made and key to the selection process is a tool which is productive in the domain of interest (education) and can provide compliant data to effect a valid transaction. The selection process of such tools is beyond the scope of this research as the function of the research is to study the underlying data.

The briefing information has been used to develop a Building Information Model using a BIM product supplied by Autodesk called Revit. As discussed, a key requirement is the ability to output the data in a COBie format for validation with the digital plan of works delivery validation and onward analysis. This can be accomplished in a number of ways either directly or via intermediate stages via formats such as IFC (Industry Foundation Classes). In the development of the model it is essential that consideration is given to the data requirements of each of the elements of the design.

Deliverables from the BIM take a number of forms, including 2 dimensional geometry, three dimensional geometry and tabular reporting data. It is also possible to provide a combination of these formats in the form of reports as shown in the floor space reports shown in Figure 7.10.

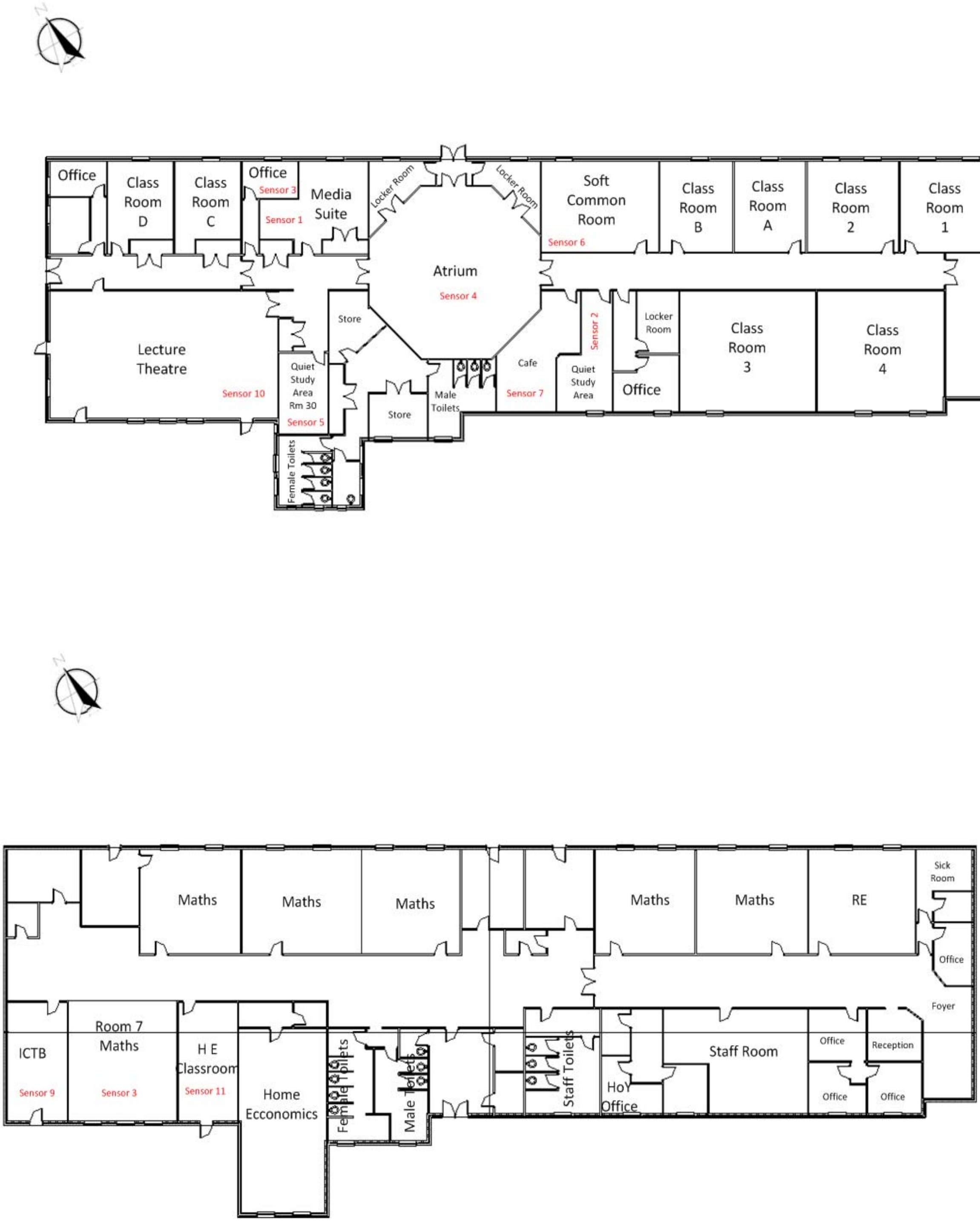
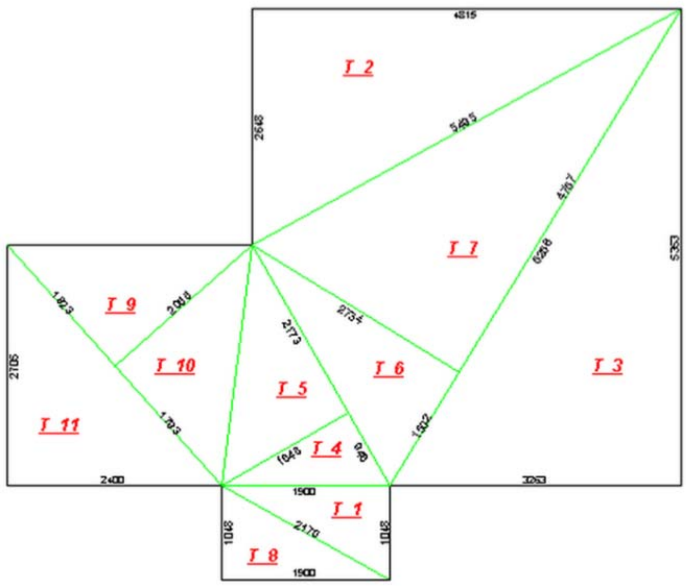


Figure 7.10 - 2D General Arrangement Drawings derived from the BIM to indicate first and ground floors, room allocations and sensor locations

The two dimensional data deliverables are shown in Figure 7.10**.**, They are used to describe general arrangements and adjacencies. The drawings show the spaces specified in the brief and the circulation, adjacencies and services. Also shown is the location of the sensors which were used to measure the performance of the asset in service. The areas of each space are required to be measured to establish compliance with the brief and provide functionally effective spaces. Figure 7.11 below shows a report generated from the BIM tool to demonstrate the use of combining attribute and geometric data. This is one of the data sets used in the analysis of the school performance to assess performance.



#	Calculation	Area
Triangles		
1	½ * 1900 * 1048	1 m²
2	½ * 2648 * 4815	6 m²
3	½ * 5353 * 3263	9 m²
4	½ * 1648 * 946	1 m²
5	½ * 1648 * 2173	2 m²
6	½ * 2734 * 1502	2 m²
7	½ * 2734 * 4767	7 m²
8	½ * 1900 * 1048	1 m²
9	½ * 2055 * 1823	2 m²
10	½ * 2055 * 1793	2 m²
11	½ * 2400 * 2705	3 m²
Gross area is 35 m².		

Figure 7.11 - Geometric Space Calculated from BIM

The three-dimensional geometry generated by the BIM tool is a fundamental enabler for the delivery of many delivery functions, including

- Spatial Co-ordination
- User and employers understanding
- Soft Landings

The human mind has far more ability to interpret three dimensional images, which are extremely life like, rather than two dimensional drawings which are perceived as being very complex. This enables lay users to interact with detailed engineering concepts with a much deeper understanding and ability to positively interact, offering significant value with respect to usability and day to day asset functionality.

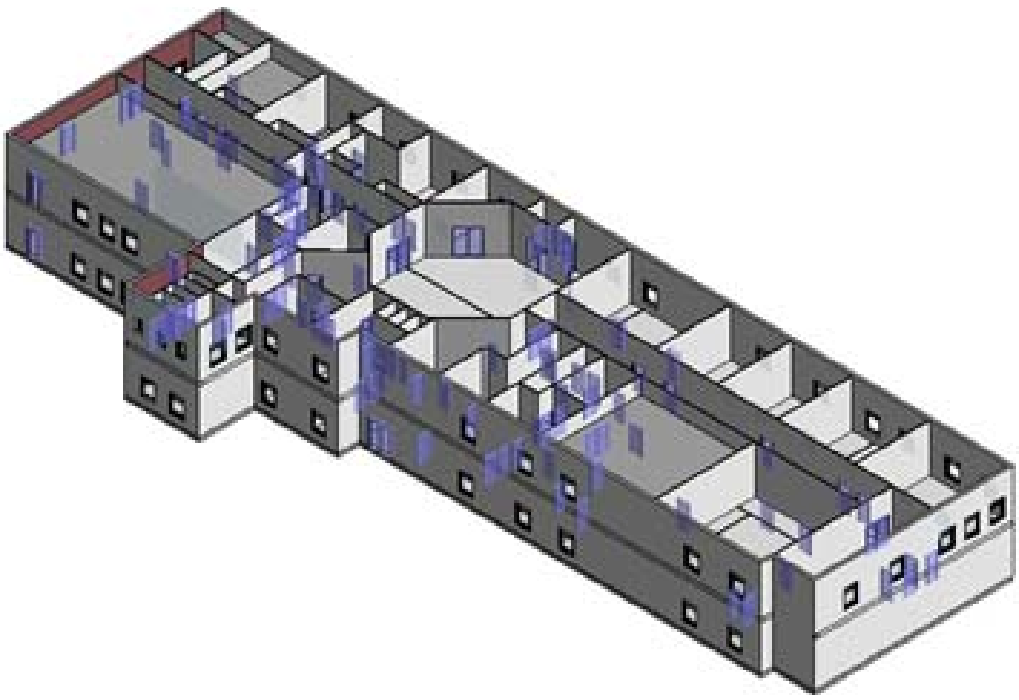


Figure 7.12 - 3D Geometry view derived from BIM indicating isometric view from the South

B5 - Verify and Validate Deliveries against Requirements

The process of verification and validation is specifically in place to ensure the data and information delivered as was requested. Boehm, B.W. (1989) expressed the difference between

- Verification: Are we building the product right? (This is static method for verifying design and code. Software verification is human based checking of documents and files)
- Validation: Are we building the right product? (This is dynamic process for checking and testing the real product. Software validation always involves executing the code)

This is equally applicable to the verification of the supply chain delivering the information and data that has been asked for verses validating the delivered information is representing a good design that in the case of LND will provide an effective and challenging educational environment.

There are a number of methods and implementation strategies, at the most simplistic a visual inspection will enable some level of verification. However, even the simplest of assets will have may hundreds of data rows output from the BIM, especially if poor attention has been paid to data normalisation. The approach to verification according to the UK BIM Task Group indicated following at least the following

- Completeness - Are the fields you expected to complete filled in?
- Compliance - Is the data provided correct with respect to the data reference standard BS1192:4:2014?
- Continuity - Is there data at one data drop that is missing at the next?

This approach was deployed in the LND example using a modified set of tools from the BIM Task Group Website "Labs" area (AEC3 2013), the tool used is a derivation of the demonstration tool provided. The screen image in Figure 7.13 indicates the user interface.

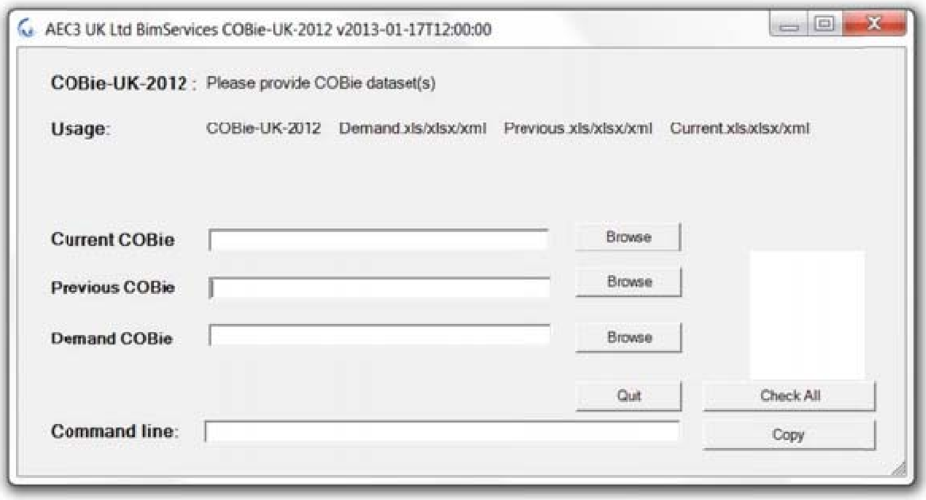


Figure 7.13 - COBie Validation Tool Interface

When COBie deliverable spreadsheets or datasets are validated the tool identifies no-conformance by colouring in the data cells red, amber or green, to indicate the type of failure. It is the contacted data originators responsibility to rectify these errors. COBie data has been extracted from the BIM using the Autodesk BIM COBie Toolkit. The toolkit enabled the data to be formatted with Zone information to identify staff and student areas of the building, as well as other key features. The COBie data provides a digital representation and description of the building as indicated through the "space" entity shown in Figure 7.14.

Name	CreatedBy	CreatedOn	Category	FloorName	Description	ExtSystem	ExtObject	ExtIdentifie	RoomTag	UsableHeigl	GrossArea	NetArea
1	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264874	n/a	n/a	51.2819	51.2819
2	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264877	n/a	n/a	n/a	n/a
3	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264881	n/a	n/a	31.8623	31.8623
4	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264897	n/a	n/a	31.2375	31.2375
5	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264900	n/a	n/a	n/a	n/a
6	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264907	n/a	n/a	39.984	39.984
7	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	264910	n/a	n/a	n/a	n/a
8	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	265982	n/a	n/a	78.5681	78.5681
9	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	265985	n/a	n/a	73.7435	73.7435
10	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	265988	n/a	n/a	40.5579	40.5579
11	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	265991	n/a	n/a	13.4266	13.4266
12	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	265994	n/a	n/a	14.0258	14.0258
13	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	265997	n/a	n/a	116.827	116.827
14	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266000	n/a	n/a	12.5057	12.5057
15	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266003	n/a	n/a	15.6937	15.6937
16	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266006	n/a	n/a	24.4321	24.4321
17	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266009	n/a	n/a	32.6382	32.6382
18	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266012	n/a	n/a	14.8095	14.8095
19	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266015	n/a	n/a	12.1879	12.1879
20	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266018	n/a	n/a	26.7126	26.7126
21	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266021	n/a	n/a	13.67	13.67
22	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266024	n/a	n/a	19.1656	19.1656
23	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266027	n/a	n/a	139.9034	139.9034
24	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266030	n/a	n/a	35.1945	35.1945
25	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266033	n/a	n/a	26.0906	26.0906
26	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266036	n/a	n/a	9.9548	9.9548
27	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266039	n/a	n/a	26.143	26.143
28	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266042	n/a	n/a	9.48	9.48
29	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266045	n/a	n/a	10.8225	10.8225
30	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266048	n/a	n/a	10.1001	10.1001
31	mark@markbew.co.uk	2015-04-10T09:53:03	n/a	First Floor	r	Autodesk Revit 2014	Autodesk.	266051	n/a	n/a	5.815	5.815

Figure 7.14 - View of the "Spaces" entity tab in COBie format (shown in XL format)

B7 - Rework

Any errors are passed back to the data originator for rework and resubmission to the process.

B8 - Valid Information Issue

Once the data reaches this point it is ready for use in either downstream processes of analytics. Data was then transferred from the COBie spreadsheet into the Test Bench Database (shown in figure 6.23) for analysis. As this toolkit is for research purposes only native application tools were use manually to transfer the data. In a production environment, this would need to be automated.

7.4.3 Physical Performance Measurement & Analysis

7.4.3.1 Overview

Data drop five is purposed to gather information regarding the operational, maintenance and performance of the LND School asset. To deliver the scope of this research only the performance data for a number of locations will be gathered. The normal operational and maintenance functions although related and having an integral impact do not form part of the research scope. As described in Chapter six, section 4.4.1 Cube Sensors were identified as being suitable for the collection of performance data at LND. The as operated data for the new building has been collected through the use of a series of mobile sensors accessed via and internet hosted application. The sensors were selected in preference to the existing building management system as this was based on passive temperature only monitoring. The sensors selected also need to provide the ability to gather environmental data to satisfy all elements of the assets functional brief.

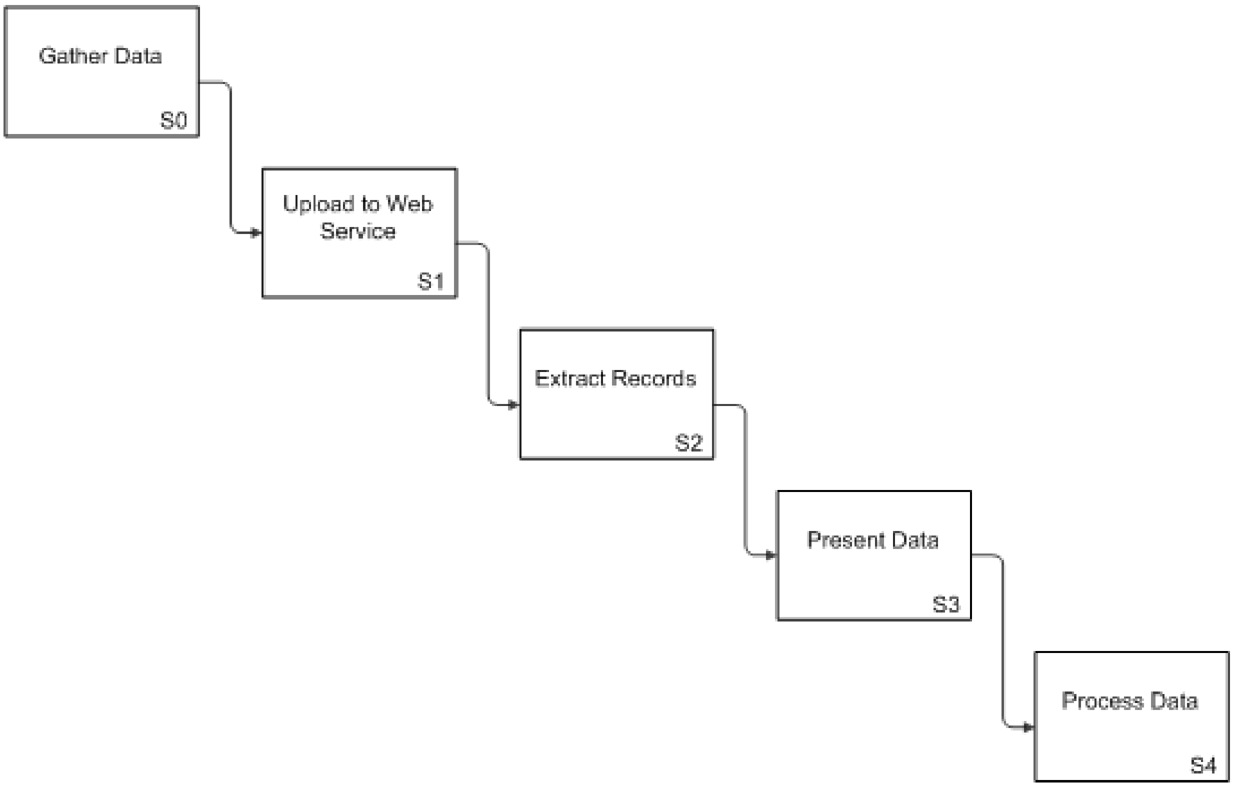


Figure 7.15 - IDEF0 Process for Data Collection & Processing

S0 Gather Data

The Cube Sensors selected are small unobtrusive devices which are locally or battery powered and link to the hosting application via standard wireless protocols. The sensors provide the following measurements

- Temperature
- Humidity
- Light
- Noise
- Volatile Organic Compounds (VOC)

Figure 7.16 - Cube Sensor

The location of the sensors required careful consideration for the following reasons.

- The location of the sensors needs to be representative of the actual building.
- The sensors need power and be in range of the site wide wireless data network.
- The sensors needed to be in a location where they would not be tampered with.
- The sensors should be out of direct sunlight and other influences which may corrupt the readings

The constraints of the time slicing strategy and the need to gather results over a reasonable length of time meant that it was only possible to install four sensors at a time for a period or about a fortnight. This gave a reasonable sample but does mean that it will be necessary to revisit the LND School at a later date to acquire data that enables longer term comparisons across multiple seasons and academic years.

S1 Upload to Web Service

This made the sensors suitable for the purpose of establishing how the asset and its functional spaces perform with respect to usage and the functional specification. As the locations of all of the sensors is known it is also possible to use this data to feed the SOFI model to analyse the relationships between the perceptive information collection and the physical sensor data. The data was sampled from the sensors every minute and collected in a data centre based application. The data was extracted and added to the Test Bench database for analysis. The data was aggregated and a series of average, peak high and low values calculated on a daily basis. By way of example the results from Sensor 1 - Media Suite have been described in full here along with the summary from the remaining sensors, the remaining detailed results can be found in Appendix one.

	A	B	C	D	E	F	G	H	I	J	K
1	time"temp""pressure""humidity""voc""light""noise""noisedba""battery""shake""cable""voc_resistance""rssi"										
2	2014-12-02T00:00:00Z21021007444520435FalseFalse41953-89										
3	2014-12-01T23:59:00Z21021007444560435FalseFalse41893-89										
4	2014-12-01T23:58:00Z21021007444540435FalseFalse41953-89										
5	2014-12-01T23:57:00Z21021007444510435FalseFalse42073-89										
6	2014-12-01T23:56:00Z21021007444500435FalseFalse42073-88										
7	2014-12-01T23:55:00Z21021007444500435FalseFalse41833-89										
8	2014-12-01T23:54:00Z21031007444500434FalseFalse41653-89										
9	2014-12-01T23:53:00Z21031007444520435FalseFalse41474-89										
10	2014-12-01T23:52:00Z21031006444500435FalseFalse41534-89										
11	2014-12-01T23:50:00Z21031006444530435FalseFalse41295-89										
12	2014-12-01T23:49:00Z21041007444510435FalseFalse41355-89										
13	2014-12-01T23:48:00Z21041007444500433FalseFalse41414-89										
14	2014-12-01T23:47:00Z21041006444500435FalseFalse41414-89										
15	2014-12-01T23:46:00Z21051007444500435FalseFalse41355-89										
16	2014-12-01T23:45:00Z21051006444500435FalseFalse41295-89										
17	2014-12-01T23:44:00Z21051007444500435FalseFalse41295-89										
18	2014-12-01T23:43:00Z21051007444510435FalseFalse41295-89										

Figure 7.17 - Data gathered from the Cubesensor data sensor application

Data gathered from the application as shown in Figure 7.17 shows the raw gathered records prior to processing. The columns indicate the data types and the 17 rows indicate the sixty second time sliced data records. Via the application API some code was developed to transfer the relevant records to the Test Bench entities identified in the ERD shown in Figure

7.18. This allowed the records to be indexed where appropriate and related to the spaces and zones for the LND built asset.

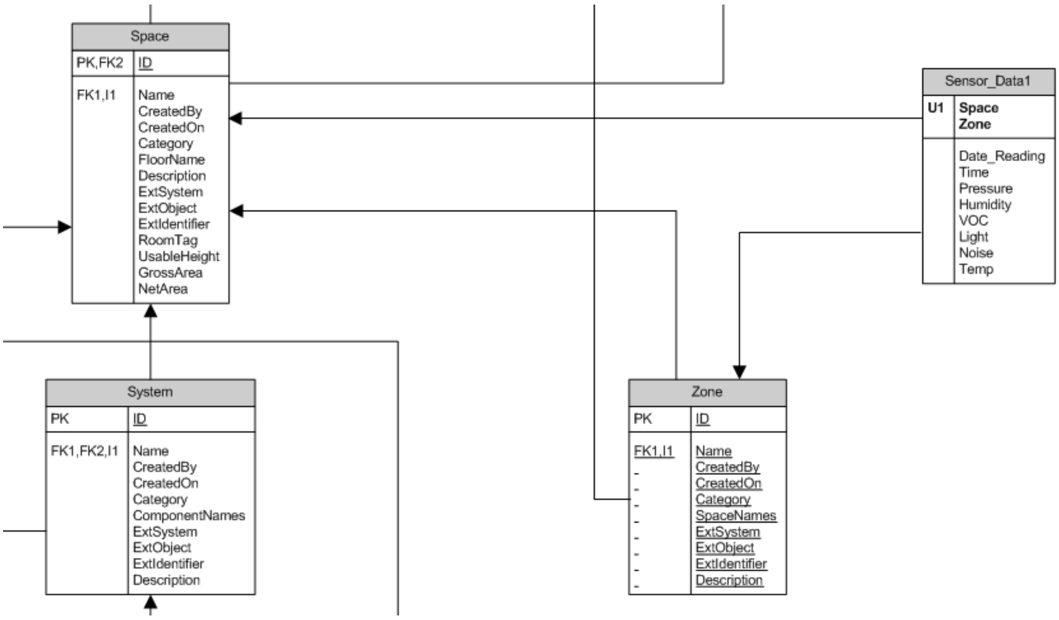


Figure 7.18 - ERD for Entities Relating to Performance Data

S2 Extract Records

Once the records are in the Test Bench it is possible to extract records in a form that makes them more accessible and useful to analyse, standard database development tools were used to achieve this. As can be seen not all records have been used in the Test Bench tool, however the use of these data types may be of use in a further development to help engage users in becoming more aware of their environmental surroundings. The data that is loaded into the Test Bench data base can then be used to provide a summary view as shown in Figure 7.19**.**

Sensor	S1																
Location	Media Suite	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M
Date		01/03/2015	02/03/2015	03/03/2015	04/03/2015	05/03/2015	06/03/2015	07/03/2015	08/03/2015	09/03/2015	10/03/2015	11/03/2015	12/03/2015	13/03/2015	14/03/2015	15/03/2015	16/03/2015
	Temperature (Sensor)																
	High	26	25.2	26.5	27.1	27.1	31.2	23.7	27.1	27.5	28.8	28.6	29.2	28.4	25.1	27.1	24.3
	Low	19	20.1	24.9	22.1	22.1	23.4	22.9	22.1	21.8	22.9	22.5	22.1	23	20.8	22.1	24.2
	Average	23	22.3	25.7	24	24	23.4	23.7	24	23.6	24.7	24.8	24.6	24.5	21.6	24	24.3
	Temperature (Outside)																
	High	5.1	6	7	8	10	10	13	13	10	12	12	12	11	7	10	8
	Low	3.2	3	4	4	6	5	7	11	4	6	6	6	2	4	6	4
	Average	4.5	4	4	5	6.5	6	9	12	8	8	8	8	5	5	6.5	6
	VOC																
	High	802	791	1300	1752	1300	926	643	1251	1570	1106	1134	3676	1046	510	1300	455
	Low	512	453	450	450	450	400	450	420	450	450	450	450	450	450	450	450
	Average	670	650	568	864	750	508	534	657	693	601	608	589	672	456	750	453
	Light																
	High	101	99	572	497	2390	1793	477	2390	2192	2390	2313	2410	2390	1892	2390	2410
	Low	5	2	0	9	0	0	0	0	0	0	0	0	0	0	0	0
	Average	51	50	325	352	416	775	106	416	305	416	369	288	375	9	416	288
	Noise																
	High	44	47	54	72	57	74	56	57	72	57	69	78	80	49	57	43
	Low	43	45	41	42	42	42	42	42	42	42	42	42	42	42	42	42
	Average	43	46	44	51	44	47	43	44	46	44	46	45	45	43	44	42
	Humidity																
	High	40	45	33	33	39	33	32	39	40	39	38	42	35	30	39	33
	Low	36	32	26	10	29	25	25	29	27	29	27	20	22	23	29	33
	Average	37	36	28	27	35	28	30	35	35	35	33	31	27	28	35	33
	Pressure																
	High	1011	1018	1016	1028	1027	1029	1026	1027	1023	1027	1027	1024	1019	1025	1027	1018
	Low	1006	1010	1010	1025	1016	1023	1016	1016	1014	1016	1019	1014	1012	1019	1016	1015
	Average	1010	1012	1013	1026	1022	1026	1021	1022	1019	1022	1023	1020	1016	1022	1022	1016

Figure 7.19 - Data gathered from the Cubesensor data sensor application

S3 Present Data

The data can then be presented and processed to enable the insights we require. As can be seen this data was also augmented with other external data from the Metrology Office to indicate local outside temperature, thus allowing the researcher to derive the impact of outside environmental effects. This data was manually harvested but could be automated through data provided by the Metrology Office (Met Off 2016).

Data services available from this data feed include:

- Wind direction (16-point compass)
- Wind speed (mph)
- Wind gust (mph)
- Temperature (degrees Celsius)
- Weather Type
- Visibility (m)
- Pressure (hPa)

The data analytic selected identifies the high and low data points and a rolling eight working hour average of the data readings. This was selected as the data set most directly impacting the time the asset was occupied and impacting the users of the space. It is not the full data set that may have been used to look at the detailed performance of the buildings physical performance.

To enable useful comparators this data is shown plotted against time in Figure 7.19. These graphs show a number of potential relationships between the physical performance of the asset and the key influencers on its performance. In the case of sensor 1 as would be expected the impact of occupation and outside weather has a significant impact on the performance of the asset. This is confirmed when in conversation with the site maintenance team, the building was commissioned whilst empty and all subsequent changes have been made on an ad-hock basis.

The VOC levels at peak time are clearly well above the maximum specified 1000, with several peaks at nearly twice this level. These are due to the high density of users at peak teaching times, in a relatively small space with a lot of electrical equipment being used. It is noted that the equipment was all modern low energy specification, but even so due to poor ventilation the performance was poor. Average values of 630 based on 5-7 hours' usage indicate again a high concentration of VOC which could be detrimental to performance.

Temperature performance was relatively stable with an average of 24°C. However detailed study of all sensor locations indicated a very steep drop in temperature once the heating system had been switched off in the evening to the lower figure, indicating significant heat loss through the fabric of the building. The impact of the outside temperature, which averaged from around 4 - 9°C had little effect on the average temperature, with the heating plant clearly capable of managing these levels of outside difference.

Light average falls well above the minimum level at 350 Lux with a peak at 2400. It is clear that the lights are turned off at night with a minimum value of 0 and a peak of 2410 Lux.
Noise is clearly driven by occupation, with peak noise levels being around 80dB. This by way of equivalent is about the same as a dustbin lorry or a loud alarm clock. However, the durations are very low and are unlikely to result in the types of industrial injury which can occur with prolonged exposure to noise at this level. Average values are around 45dB which is 5dB above the lowest level.

Humidity has a large impact on both the fabric of the asset and the quality of the air on those occupying the spaces. The average value recorded was very low at 32%, with a specified minimum of 45. Peak values fluctuated between 41 and 80%. This put the space at the bottom of the recommendations by Arundel et al (1986), who stated that spaces need to be kept within the 40-60% thresholds to ensure the majority of poor health effects could be avoided. Significantly lower periods of exposure can lead to eye irritation. They also cite low humidity as being responsible for the improvement of survival rates for viruses and their opportunities for transmission.

Atmospheric press was the final value to be measured and as can be seen the sample period was relatively stable for the time of year with an average value of just under 1020 mB.

Figure 7.20 - Sensor 1 - Media Suite daily peak and average data plotted by time

Trends in the data collected is more easily seen if plotted by time and the rolling eight-hour average figures have been presented graphically for all sensors in Appendix one. Sensor 1 is shown in Figure 7.20 by example.

The values described above are of interest in isolation for the observation as to how the asset is performing with respect to specification and usage. However, to be able to answer our research aims we need to further analyse this data to provide input data to the SOFI analytic tools, which form the final part of the Test Bench. The Table shown in Figure 7.21 has further summarised the daily data we discussed above and has created a series of rolling overall and weekday averages as week as identifying the absolute values for high and low performance for each sensor extent. These have been compared with the specified values applicable to the space and on the basis of their performance to specification have been allocated a red, amber or green rating. These are the values which will be used to populate the SOFI analysis.

S1								
Media Suite	Actual				Specification			
	Average Overall	Average Weekday	Peak High	Peak Low	High	Low	RAG	Ave
Temperature (Sensor)								
High			31.2		26			
Low				19.0		23		
Average	23.9	24.2						
Temperature (Outside)								
High			13.0					
Low				4.0				
Average	6.6	6.2						
VOC								
High			3676.0		1000			
Low				400.0		450		
Average	626.4	632.4						
Light								
High			2410.0		8000			
Low				0.0		300		
Average	309.8	359.9						
Noise								
High			80.0		60			
Low				41.0		40		
Average	44.8	45.5						
Humidity								
High			45.0		55			
Low				10.0		45		
Average	32.1	31.6						
Pressure								
High			1028.0					
Low				1006.0				
Average	1019.5	1019.5						

Figure 7.21 - Average values analysed and scored with respect to specification

S4a - Process Data (Sensor Derived Data)

As described in Chapter six the SOFI analysis tool set requires the development of a relationship palate, to configure the tool to process collected data. This palate describes the relationship between each of the various members of the community and the corresponding relationship of the physical measures that are relevant to the space where that community occupies. These are configured from the standard SOFI configurations to become specific to the needs of the LND school. From a review of the LND school community and from existing literature on the SOFI analysis tools it is apparent that there is relatively little literature describing these types of activity. In the area of building physics analysis there is no experience or literature at all and this confirms the unique element of this research.

To enable to development of the palate or scoring matrix it is first necessary to configure the SOFI "spheres" with appropriate names and references. The generic terms given to the implementation shown in figure 6.11 does not use terms and labels relevant to a school, so the following mapping Table was derived, using familiar terms. The details of these terms were developed with dialogue with LND school users and stakeholders. Figure 7.22 and Table 7.6 both describe this configuration process and resultant influence map output reports.

Table 7.6 - SOFI influence mappings configured for LND School

Generic Term	LND School Specific Term	Comments	Community Aspects
Strategy	Planning	The strategic development process for a school is much longer than for many types of asset and organisation. There are many regulated and standardised variables such as the curriculum and examination regimes, so the term planning seems more appropriate	The process of consultation, between users, staff, project managers and suppliers including designers, contractors and trade suppliers of all services including the school building
Operations	School Operations	The cohesiveness of the business between the teaching staff and the management and support staff	The structure and methods by which the school operates
Structure	Organisation & Design	The physical aspects of the organisation and its community viewed from a structural, hierarchal perspective	The functional structure of the school and its staff, including governance and reporting
Leadership	Exemplary Building	The building is the point of focus in the experiment and it is important to measure how effective this is in providing a cohesive and effective environment	The expected impact of the school if all of the briefed elements are delivered as expected
Culture	Culture	Culture is a common term between the two models	The derived result of all of the interactions of the community
Development	Development & Innovation	Even with the constraints described above placing significant pressure on schools the need to innovate is ever present to ensure continued funding, intake and external audit (OFSTEAD) results. This places a continual focus on innovation and effectiveness across the sector	The ability of the school to adapt and innovate with the constraints of the resources
Staff	School Staff	School Staff refers to teaching and non-teaching staff	The employed individuals who provide support and teaching capacity
Customers	Pupils & Community	Pupils are the ultimate clients of the schools services	The customers of the overall service of the school

Generic Term	LND School Specific Term	Comments	Community Aspects
Marketing	Communication	Whilst schools to need to market themselves, this in the context of a school is more aligned to the process of good communication especially external	The ability of the school to communicate with its community in the widest sense, including students, parents, employers, high academia and the local community
Finance	Building Resources	In the context of this research the application of funding to the built asset is the main research focus. The impact of staff resources is a significant player in this domain but not part of this scope	The impact of both fiscal and physical resources on the school to operate
Sales	Programme and Services	The sales sphere has been related to the curriculum or the programme and services the school offers	The curriculum delivered by the school

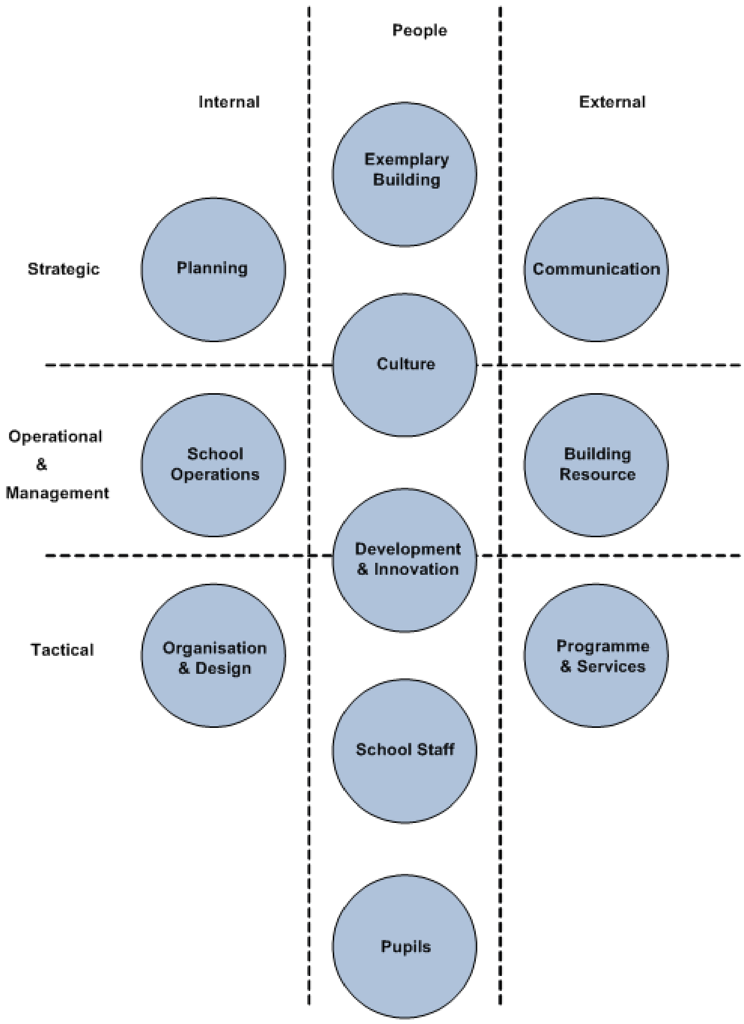


Figure 7.22 - SOFI Influence Map configured for use on LND School

The first stage of the development of the Scoring Matrix Palate is to map out the defined community areas into an eleven by eleven matrix as shown in figure 7.7. Where like community locations coincide at an intersection the cell is coloured blue, this indicates there is no relation as the communities are coincident. All remaining cells are analysed and a statement describing the relationship between the two spheres is recorded in the cell. This process sets the fundamental relationship between the spheres and the basis for the questions to be asked and rules established to test the nature of each relationship.

For example, if we take the intersection between "resources" and "pupils and community" we see the statement "Are there enough staff to service the needs of the pupils and community?" This is asking a clear question regarding the key constraints of performance in this relationship. Too little resource (funds) would mean too few staff to effectively service the needs of the pupils.

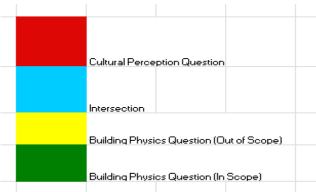
Table 7.7 shows these key influencers in the "Initial rules matrix or palate". Each influencer has a relationship with each other and a reciprocal. The reciprocal is used to implement the double loop functions described in chapter six. The development of these statements was carried out in consultation with the school and in the process of this activity and number of key stakeholders were interviewed. These stakeholders were pre-briefed with a short overview document (see Appendix two) and included the following roles.

- Head teacher
- Head of Estates
- Facilities Manager
- Teaching Staff
- Alumni 6th Form Pupil
- School Governors

Table 7.7 - SOFI Matrix Palate

Sphere of Origin:	Destination: Pupils & Community	School Staff	Organisation & Design	School Programme & Services	Innovation	Operations & Design	Resources	Planning	Communications	Exemplary Building	School Culture
School Culture											School Culture
Exemplary Building	Temperature and Light levels are as designed	Temperature and Light levels are as designed	Defined spaces = As Briefed	Spaces Support Service requirements		Down Time criteria	Operational Costs =< Brief	As Operated Building = Briefed Building	Ratio of shared space to functional space	Exemplary Building	
Communications	There is enough space to talk to friends	Ratio of shared space to functional space	Signage as per brief	Logical Circulation Flow		Time to move between classes		As Operated Building = Briefed Building	Communications	As Operated Building = Briefed Building	
Planning	Was this community involved in the briefing process	Was this community involved in the briefing process		Spaces Support Service requirements	Spaces Support Service requirements	School Operations are delivered in the briefed and delivered spaces	Operational Costs =< Brief	Planning		As Operated Building = Briefed Building	As Operated Building = Briefed Building
Resources	Are there enough staff to service the needs for the pupils and community?	Temperature and Light levels are as designed	Occupation Utilisation	Are there enough staff to service the needs for the pupils and community?	Spaces Support Service requirements	Spaces Support Service requirements	Resources	Operational Costs =< Brief			
Operations & Design		Spaces Support Service requirements	Spaces Support Service requirements	Spaces Support Service requirements	Spaces Support Service requirements	Operations & Design	Operational Costs =< Brief	Was this community involved in the briefing process		Spaces Support Service requirements	
Innovation					Innovation						
School Programme & Services	Spaces Support Service requirements	Spaces Support Service requirements		School Programs & Services	Service Available?	Spaces Support Service requirements	Enough Staff and spaces for service to be delivered?	Was this community involved in the briefing process		Spaces Support Service requirements	
Organisation & Design	Spaces Support Service requirements		Organisation & Design		Spaces Support Service requirements			Was this community involved in the briefing process		Was this community involved in the briefing process	Was this community involved in the briefing process
School Staff	Are there enough staff to service the needs for the pupils and community?	School Staff	Are there enough staff to service the needs for the pupils and community?	Are there enough staff to service the needs for the pupils and community?	Are there enough staff to service the needs for the pupils and community?	Are there enough staff to service the needs for the pupils and community?		Was this community involved in the briefing process			
Pupils & Community	Pupils & Community		Spaces Support Service requirements				Down Time criteria	Was this community involved in the briefing process			

Key



Once the relationships and tests have been established and reviewed through inspection and review it is possible to devise a series of questions to test the nature of the rules. For the building physics palate shown here there are a series of mathematical calculations which act upon the results gathered by the sensors and aggregated data described above. To service the LND questions with the available data, four building physics calculations were identified. These are shown in Figure 7.23. In the left hand column there is a plain language descriptor of the derived query. This is then developed into a full digital query which is then implemented as a SQL script on the data held in the Test Bench database.

By way of a worked example, in the first row there is a query that services the rule "Operational Costs =< Brief", which is used in the relationship between Operations and Design and Resources and again between resources and planning indicated in the Initial Rules Palate in Table 7.7.

This is interpreted as a plain language query (PLQ) as "The building spaces are operating within its briefed cost envelope". The construction of this statement is critical as it need to develop the rule into a query that can both service the rule in full but also only make use of information that has been gathered by the Test Bench (or state why this cannot be done and derive further research). Once the PLQ is developed and tested the final stage of the analysis is to develop the digital query to be implemented into the Test Bench. In this worked example this query takes data from the Tables P_Rooms, user and impact and executes the query.

Where a user identified in a SOFI world is the same as a user role (linking SOFI worlds to common daily school roles) and the users allocated working spaces (or rooms in the case of the LND school) were selected a check is done to see if the actual cost of the space was greater or equal to the cost identified in the brief. This test will then successfully identify (yes or no) if the costs associated with delivering and operating that space or facility are likely to be higher than expected and therefore have a material impact on the school's ability to fund other resources such as staff, with the clear detrimental impact on the delivered service. This derived the following digital query:

Where SOFI.WORLD=user.role and user.space_description THEN
P_Rooms.Room_Target_Cost <= Impact.name.Cost

When this query is executed over the Test Bench dataset the calculated RAG values are as identified in the right hand column using data collected by sensor 1 as shown in Figure 7.23. The following three queries follow the same logic looking at the following physical values.

- Checks to establish floor space delivered was as specified, servicing the rules sets defined as "Defined spaces = As Briefed" and "Spaces Support Service Requirements"

- The rule "Temperature and light levels are as defined" is serviced by the third query
- The fourth query answers the rule "As operated building = as briefed building"

Figure 7.23 is a full worked example for Sensor 1 situated in the Media Suite on the first floor. As can be seen three values have achieved are score and one a red. The red score is derived from the reduced space from the specification and the space actual in use. On further observation it is also likely that the rather odd shape to the room making line of sight to all students a challenge for staff would fail to meet the usable teaching spaces clause in the EfA specifications discussed above. It would be possible to extend the query set here to encompass all of these rules and also building control rules, but this is out of scope of this research.

Direct Building Physics	Direct Building Physics	
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	

Figure 7.23 - SOFI Building Physics Analytic Result for Sensor 1 - Media Suite

In Chapter six the concept of developing the relationships between the spheres and the process of identifying "immediate, extended and remote" relationships were described, these are colour coded red, amber green. This relationship property enables a relationship to be developed. Figure 7.24 identifies the neighbourhood matrix and described how the relationships were grouped into "strategic, operational, tactical or reciprocal" questions depending upon the location in the matrix and the relationships being described.

Sphere	Destination:										
	Pupils and Community	School Staff	Organisation & Design	School Programs & Services	Innovation	School Operations	Building Resources	Planning	Communications	Exemplary Building	School Culture
School Culture	R43	R44	59	60	61	62	63	64	65	66	School Culture
Exemplary Building	R38	R39	R40	R41	R42	54	55	56	57	Exemplary Building	58
Communications	R33	R34	R35	R36	49	R37	50	51	Communications	52	53
Planning	R28	R29	R30	R31	44	45	R32	Planning	46	47	48
Resources	R25	37	R26	38	39	40	Building Resources	R27	41	42	43
Operations & Design	R22	30	31	R23	32	School Operations	33	34	R24	35	36
Innovation	R20	22	23	24	Innovation	25	26	27	28	R21	29
School Programme & Services	16	17	18	School Programs & Services	19	R16	20	R17	R18	R19	21
Organisation & Design	10	11	Organisation & Design	12	13	14	R12	R13	R14	R15	15
School Staff	4	School Staff	5	6	7	8	9	R8	R9	R10	R11
Pupils & Community	Pupils	1	2	3	R1	R2	R3	R4	R5	R6	R7

Figure 7.24 - Neighbourhood Matrix for LND Test Bench

For example, if we consider the relationship between pupils and community and organisation and design there is a yellow cell with an indication that question two provides the definition of the relationship between the two communities in question, the yellow indicator confirms that this is an operational relationship. From the rules matrix in Table 7.7 we see the rule set asking "Do spaces support service requirements?" and as can be seen in the example above this is related to the second physical query in Figure 7.23 "calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards", which in turn is related to the digital query "P_room.requirednettarea >=space.nettarea".

This process is continued for all of the relationships and their reciprocals into a full sized matrix as shown in Table 7.8. As can be seen the Table shows in full all 66 possible relationships between each sphere. Further to this the calculations and their reciprocals are indicated with the relevant answer from the sensor data collected and described above. These results are displayed as a red or green cell in the spreadsheet.

Table 7.8 - Full SOFI Building Physics Analytic with results from Sensor 1 - Media Suite

Link	Sphere of Origin	Traffic Signal™ lights question for Sphere #; Destination Sphere	Direct Building Physics	Direct Building Physics	Reciprocal Building Physics	Reciprocal Building Physics
	Pupils	**How do you feel about the way that your school building serves your needs?**	**Entity & Attributes**	**Narrative**	**Entity & Attributes**	**Narrative**
1	**Pupils**	**School Staff**			p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
2	**Pupils**	**Organisation & Design**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
3	**Pupils**	**School Programme & Services**			p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
	School Staff	**How do you feel about the way staff makes use of the building?**				
4	**School Staff**	**Pupils**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	0	0
5	**School Staff**	**Organisation & Design**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	0	0
6	**School Staff**	**School Programme & Services**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidi	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					ty Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
7	**School Staff**	**Development & Innovation**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
8	**School Staff**	**School Operations**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels
9	**School Staff**	**Building Resources**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed)	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0

			Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red			
	Organisation & Design	**How do you feel about the quality of the school building design?**				
10	**Organisation & Design**	**Pupils**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
11	**Organisation & Design**	**School Staff**			p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
12	**Organisation & Design**	**School Programme & Services**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
13	**Organisation & Design**	**Development & Innovation**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	0	0
14	**Organisation & Design**	**School Operations**			0	0
15	**Organisation & Design**	**School Culture**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal <	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal <	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

			P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red		P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
	School Programme & Services	**How do you feel about the way school programmes and services use the building?**				
16	**School Programme & Services**	**Pupils**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	0	0
17	**School Programme & Services**	**School Staff**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
18	**School**	**Organisation &**	p_room.requirednett	Calculation to check	p_room.requirednett	Calculation to check if

	Programme & Services	**Design**	area >= space.nettarea	if the actual delivered spaces meet the spaces specified in the brief and standards	area >= space.nettarea	the actual delivered spaces meet the spaces specified in the brief and standards
19	**School Programme & Services**	**Development & Innovation**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
20	**School Programme & Services**	**Building Resources**	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					If No = Red	
21	**School Programme & Services**	**School Culture**	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
	Development & Innovation	**Do you feel the school building is innovative?**				
22	**Development & Innovation**	**School Staff**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

			If No = Red		If No = Red	
23	**Development & Innovation**	**Organisation & Design**			p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
24	**Development & Innovation**	**School Programme & Services**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
25	**Development & Innovation**	**School Operations**			0	0
26	**Development & Innovation**	**Building Resources**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0

			as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red			
27	**Development & Innovation**	**Planning**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
28	**Development & Innovation**	**Communications**			0	0
29	**Development & Innovation**	**School Culture**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels
	School Operations	**How do you feel about the day-to-day running of the school building?**				
30	**School Operations**	**School Staff**	Where SOFI.World = User.role AND	Comparison of identified	p_room.requirednett area >=	Calculation to check if the actual delivered

			User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	space.nettarea	spaces meet the spaces specified in the brief and standards
31	**School Operations**	**Organisation & Design**			0	0
32	**School Operations**	**Development & Innovation**			0	0
33	**School Operations**	**Building Resources**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
34	**School Operations**	**Planning**			0	0
35	**School Operations**	**Exemplary Building**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal >	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					P_Rooms.MinTemp Sensor_Data.Humidit y < P_Rooms.MaxHumid ity Sensor_Data.Humidit y > P_Rooms.MinHumidi ty Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
36	**School Operations**	**School Culture**	Where SOFI.World = User.role AND User.Space_Descripti on THEN Sensor_Data.Light = P_Rooms.AmbientLig ht +/- 10% (or tolerance as briefed) Sensor_Data.Therma l < P_Rooms.MaxTemp Sensor_Data.Therma l > P_Rooms.MinTemp Sensor_Data.Humidit y < P_Rooms.MaxHumid ity Sensor_Data.Humidit y > P_Rooms.MinHumidi ty Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0
	Building Resources	**How do you feel about how well we use the school building as a resource?**				
37	**Building Resources**	**School Staff**			Where SOFI.World = User.role AND User.Space_Descripti on THEN Sensor_Data.Light = P_Rooms.AmbientLig ht +/- 10% (or tolerance as briefed) Sensor_Data.Therma l < P_Rooms.MaxTemp	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
	Building Resources	**School Programme & Services**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	The building spaces are operating within its briefed cost envelope
39	**Building Resources**	**Development & Innovation**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidit	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					y < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
40	**Building Resources**	**School Operations**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
41	**Building Resources**	**Communications**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidit	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					y > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
42	**Building Resources**	**Exemplary Building**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels
43	**Building Resources**	**School Culture**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0
	Planning	**How do you feel about the school building's procedures?**				

44	**Planning**	**Development & Innovation**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0
45	**Planning**	**School Operations**			0	0
46	**Planning**	**Communications**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
47	**Planning**	**Exemplary Building**			0	0

48	**Planning**	**School Culture**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
	Communications	**How do you feel about communications related to the school building?**				
49	**Communications**	**Development & Innovation**			0	0
50	**Communications**	**Building Resources**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0

			+/- 10% (or tolerance as briefed) If Yes = Green If No = Red			
51	**Communications**	**Planning**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0
52	**Communications**	**Exemplary Building**			0	0
53	**Communications**	**School Culture**			0	0
	Exemplary Building	**How do you feel about the building as an example of a wonderful school?**				
54	**Exemplary Building**	**School Operations**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidi	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	0	0

			ty Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red			
55	**Exemplary Building**	**Building Resources**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	0	
56	**Exemplary Building**	**Planning**			0	0
57	**Exemplary Building**	**Communications**			0	0
58	**Exemplary Building**	**School Culture**			0	0
	School Culture	**How do you feel about the way the School Building supports school spirit and culture?**				
59	**School Culture**	**Organisation & Design**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed)	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed)	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

			Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red		Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
60	**School Culture**	**School Programme & Services**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	p_room.requirednettarea >= space.nettarea	Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards
61	**School Culture**	**Development & Innovation**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels
62	**School Culture**	**School Operations**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

					Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
63	**School Culture**	**Building Resources**			Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors
64	**School Culture**	**Planning**	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidit	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidit	Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors

			y < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red		y < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	
65	**School Culture**	**Communications**			0	0
66	**School Culture**	**Exemplary Building**			0	0

The process of allocating PLQ to relationship nodes described above and shown in full in Table 7.8 is also re-used to allocate the perceptive questions as described in section S4b - Process Data (Social Perception Feedback Derived Data).

S4b - Process Data (Social Perception Feedback Derived Data)

The collection of data to measure perceptions uses the same SOFI toolset and methodology as described above in section S4a. The method of developing the perceptive process is similar in nature to that of the building physics sensor process with a palate being created with a series of domain questions being established. The Neighbourhood Matrix for LND Test Bench shown in Figure 7.24 indicating the relationships for the questions and their reciprocals. It also allocates the same strategic, operational and tactical values as used in the sensor palate.

Data collection for a community such as a school was found to be challenging for a number of reasons. The diversity of the constituents of the community is very wide, especially when the full age range of students, staff and other stakeholders is considered and the formation of the questions needs to be concise, to the point and not easily misunderstood. The questions also have to be complete enough in scope to answer the questions being posed by the rules and relationship query. Further the questions need to be answerable by a "Yes-No-Don’t Know" set of options and need to be capable of being converted into reciprocal questions, whilst still maintaining their meaning in plain language. Further still the questions need to be asked of the community but relating the focus of the research, which is the effectiveness of the physical school building, to the community that occupies it. The method of gathering the perceptive information is a questionnaire which can be deployed either as an online form, accessible through an internet browser either on a standard PC or Tablet device, or a paper based tick sheet. The on-line method was deployed first and as discussed in the analysis in Chapter eight the response was somewhat disappointing with a low number of respondents and a large number of issues raised with both technical and user understanding challenges.

The logic for preparing the perceptive questions within the constraints described above is an iterative process, which in practice involved the SOFI development team, LND school stakeholders and repeated iteration of the shape and form of words to enable the best fit, this is demonstrated below.

For example, each set of ten relationships defined by the SOFI sphere of origin has a question about how the community in question feels about its own domain. In the case of the first community, pupils this question needs to pose a straightforward query about how they feel, to ensure it focuses on the perceived relationship with the LND School and the spaces they occupy. In this case the question posed was "How do you feel about the way that your school building serves your needs?" This makes a point of reference for the reporting system when the time comes to report on the data from the point of the various community worlds.

Once the world position is set from the point of view of the originating world (the SOFI sphere) the SOFI links are created. These are the perceived relationships between the surrounding worlds or spheres. The first example at cell number B12 in the Neighbourhood Matrix shown in Figure 7.24 marks the intersection between pupils and school staff, the cell is green indicating an operational relationship. The question originates with pupils and the destination is school staff, so the question posed needs to relate to the relationship between pupils and staff, in the context of the focus of the research question which is asking about the effectiveness of the school building. As seen in the first row of the SOFI Palate for social data collection shown in Table 7.9 the direct question from pupils to school staff developed was "The school building encourages good access and relations between pupils and staff". This succeeds in its ability to be a "Yes-No-Don't Know" answer and is clearly understandable whilst still inferring a link back to the research question concerning the LND building itself. The reciprocal (or double loop) question set out by the Neighbourhood Matrix is cell four which is the same link using the school staff as the sphere of origin or direction of questioning. This describes the nature of the perceived relationship of the school staff to the pupils in the context of the LND school buildings. This was defined as "The school building design helps teachers and staff meet the needs of the pupils". By posing this question we have then closed the perceptive double loop. This process continues for all sixty-six of the direct and indirect combinations as can be seen in Table 7.9.

Table 7.9 - Fully populated SOFI Palate for social data collection

Link	Sphere of Origin	Traffic Signal™ lights question for Sphere #; Destination Sphere	Sphere definitions: Agree/Disagree Process Questions	Reciprocal	Reciprocal Question text
	Pupils	How do you feel about the way that your school building serves your needs?	*Pupils & Community includes information about pupils and members of the community using the school, their needs and concerns, and activities.*		
1	Pupils	School Staff	The school building encourages good access and relations between pupils and staff	4	The school building design helps teachers and staff meet the needs of the pupils
2	Pupils	Organisation & Design	Pupils have enough space in the school to meet their needs.	10	The school building design enables the policies and processes of the staff to effectively deliver the needs of pupils.
3	Pupils	School Programme & Services	Pupils enjoy using the school building for learning	16	The school building has enough space to offer the programmes and services that meet the needs of the pupils
	School Staff	How do you feel about the way staff make use of the building?	*School Staff contains information related to faculty, support staff, having sufficient staff, maintenance workload and school administration.*		
4	School Staff	Pupils	The school building design helps teachers and staff meet the needs of the pupils	1	The school building encourages good access and relations between pupils and staff
5	School Staff	Organisation & Design	The building works well and supports staff needs	11	The quality of the school buildings and its systems helps me carry out my tasks.

6	School Staff	School Programme & Services	The school design enables staff and teachers make effective use of the space and facilities to deliver their programmes and services.	17	The school building enables our teachers and staff to support the programmes and services offered to pupils properly.
7	School Staff	Development & Innovation	Staff and teachers use the school building in creative, energy efficient ways.	22	School building innovations and systems training help create an effective work environment for teachers and staff.
8	School Staff	School Operations	The staff find the school building easy to use and operate.	30	Day-to-day operations of the school building help teachers and staff work effectively.
9	School Staff	Building Resources	Staff and teachers make good use of school resources.	37	The school building is a great resource for school staff.
	Organisation & Design	How do you feel about the quality of the school building design?	*School Building Design includes the way the space is designed, structure, service agreements, roles, responsibilities, reporting relationships, administrative policies, procedures, systems and feedback about the school building.*		
10	Organisation & Design	Pupils	The school building design enables the policies and processes of the staff to effectively deliver the needs of pupils.	2	Pupils have enough space in the school to meet their needs.
11	Organisation & Design	School Staff	The quality of the school buildings and its systems helps me carry out my tasks.	5	The building works well and supports staff needs
12	Organisation & Design	School Programme & Services	The building provides enough rooms and spaces and I can move easily between classes.	18	The schools design and layout makes it easy for staff to deliver effective programmes, services and teaching.
13	Organisation & Design	Development & Innovation	The school building design encourages innovation and creativity.	23	The school building facilitates the effective delivery of everyday learning.
14	Organisation & Design	School Operations	The school is always clean and ready for us to use.	31	Day-to-day operations of the school building comply with school policies and rules
15	Organisation & Design	School Culture	The building creates a highly effective environment for learning.	59	The school building creates an atmosphere that makes it easy for people to follow school rules, such as neatness, being on time for classes, etc.
	School Programme & Services	How do you feel about the way school programmes and services use the building?	*Schools Programmes & Services refers to processes for and abilities to offer classes, services and resources to our community.*		
16	School Programme & Services	Pupils	The school building has enough space to offer the programmes and services that meet the needs of the pupils	3	Pupils enjoy using the school building for learning

17	School Programme & Services	School Staff	The school building enables our teachers and staff to support the programmes and services offered to pupils properly.	6	The school design enables staff and teachers make effective use of the space and facilities to deliver their programmes and services.
18	School Programme & Services	Organisation & Design	The schools design and layout makes it easy for staff to deliver effective programmes, services and teaching.	12	The building provides enough rooms and spaces and I can move easily between classes.
19	School Programme & Services	Development & Innovation	The school programmes and services make creative use of spaces, facilities and technology available in the building.	24	The school building helps teachers deliver high quality teaching.
20	School Programme & Services	Building Resources	The school has been able to design excellent programmes and services with the resources the building and spaces offer.	38	The school building has enough resources to support good teaching.
21	School Programme & Services	School Culture	The school building helps us have programmes and services that enable an inclusive positive culture.	60	The school building and class rooms help engage pupils in school teaching and learning.
	Development & Innovation	Do you feel the school building is innovative?	*Development & Innovation includes the growth and development of skills, the building of competencies, capabilities, procedures, training, facilities and infrastructure, and innovations that the facility allows for new programmes and services.*		
22	Development & Innovation	School Staff	School building innovations and systems training help create an effective work environment for teachers and staff.	7	Staff and teachers use the school building in creative, energy efficient ways.
23	Development & Innovation	Organisation & Design	The school building facilitates the effective delivery of everyday learning.	13	The school building design encourages innovation and creativity.
24	Development & Innovation	School Programme & Services	The school building helps teachers deliver high quality teaching.	19	The school programmes and services make creative use of spaces, facilities and technology available in the building.
25	Development & Innovation	School Operations	The school enables up to date teaching methods to be used.	32	Day-to-day operations of the school building support the development of new activities.
26	Development & Innovation	Building Resources	School class rooms are light, airy and comforTable.	39	We make creative use of the building.
27	Development & Innovation	Planning	We have a building that allows staff to provide imaginative teaching.	44	Our school buildings work the way we expect
28	Development & Innovation	Communications	The school has developed an effective communications system throughout the school building.	49	We communicate our innovative approach to potential pupils.
29	Development & Innovation	School Culture	The school building has helped us develop activities and events that contribute to a positive school culture.	61	The school building supports both science and creativity.

	School Operations	How do you feel about the day-to-day running of the school building?	*School Operations relates to the efficiency of day-to-day running of the school, including maintenance, technology, supplies and what is necessary to provide programmes and services.*		
30	School Operations	School Staff	Day-to-day operations of the school building help teachers and staff work effectively.	8	The staff find the school building easy to use and operate.
31	School Operations	Organisation & Design	Day-to-day operations of the school building comply with school policies and rules	14	The school is always clean and ready for us to use.
32	School Operations	Development & Innovation	Day-to-day operations of the school building support the development of new activities.	25	The school enables up to date teaching methods to be used.
33	School Operations	Building Resources	The way the school building is used is energy efficient	40	The school is well managed and maintained.
34	School Operations	Planning	The way the school is managed reflect the aims of the school.	45	We know what to do in case of an emergency.
35	School Operations	Exemplary Building	Our School and the way it is run are exemplary.	54	Our school building is a leading example of a effective well-functioning school.
36	School Operations	School Culture	The way the school is operated create a positive impact upon the people who come here.	62	The culture and values of the school are evident in the safe, day-to-day operations of the school building.
	Building Resources	How do you feel about how well we use the school building as a resource?	*Resources includes the materials and money needed to allow the school to operate, including information related to funding, measurement and accountability.*		
37	Building Resources	School Staff	The school building is a great resource for school staff.	9	Staff and teachers make good use of school resources.
38	Building Resources	School Programme & Services	The school building has enough resources to support good teaching.	20	The school has been able to design excellent programmes and services with the resources the building and spaces offer.
39	Building Resources	Development & Innovation	We make creative use of the building.	26	School class rooms are light, airy and comfortable.
40	Building Resources	School Operations	The school is well managed and maintained.	33	The way the school building is used is energy efficient
41	Building Resources	Communications	The school building has a pleasant appearance.	50	The school building's appearance is maintained and cleaned properly.
42	Building Resources	Exemplary Building	The school building has the resources for effective management of the school.	55	Our school building design helps us make effective use of our resources.
43	Building Resources	School Culture	The way we use the school building is having positive results for the school and the pupils.	63	The way we treat the school building shows respect for the school.

	Planning	How do you feel about the school building's procedures?	*Planning refers to the school building plans, milestones, time frames and assumptions used to construct the school facilities. This includes specific missions, programmes, goals or objectives that have been written down or implemented, as well as strategies or plans that have been discussed but not written down.*		
44	Planning	Development & Innovation	Our school buildings work the way we expect	27	We have a building that allows staff to provide imaginative teaching.
45	Planning	School Operations	We know what to do in case of an emergency.	34	The way the school is managed reflect the aims of the school.
46	Planning	Communications	It easy for people to find their way around the school building.	51	The interior design of the building is appealing.
47	Planning	Exemplary Building	People understand what is expected of them while in the school building.	56	Our school building is an example of effective involvement of the school community in planning for future generations.
48	Planning	School Culture	The school and its buildings support our inclusive culture.	64	The school building we have accurately reflects the needs of the pupils and teachers.
	Communications	How do you feel about communications related to the school building?	*Communications is used in its broadest sense to include the clarity with which facts and opinions and messages are shared both internally and externally. This includes electronic as well as other forms of communication, such as interviewing, market research, and public relations, as well as communication with different groups throughout the community.*		
49	Communications	Development & Innovation	We communicate our innovative approach to potential pupils.	28	The school has developed an effective communications system throughout the school building.
50	Communications	Building Resources	The school building's appearance is maintained and cleaned properly.	41	The school building has a pleasant appearance.
51	Communications	Planning	The interior design of the building is appealing.	46	It easy for people to find their way around the school building.
52	Communications	Exemplary Building	The school building appearance shows that we have an excellent building.	57	Our school building enables effective communication amongst staff and pupils alike.
53	Communications	School Culture	The school is proud of its pupils and facilities.	65	The school is held in high regard by its peers, staff and pupils.
	Exemplary Building	How do you feel about the building as an example of a wonderful school?	*Exemplary Building focuses on the way that the vision and wishes people have for the school building are put into action.*		

54	Exemplary Building	School Operations	Our school building is a leading example of an effective well-functioning school.	35	Our School and the way it is run are exemplary.
55	Exemplary Building	Building Resources	Our school building design helps us make effective use of our resources.	42	The school building has the resources for effective management of the school.
56	Exemplary Building	Planning	Our school building is an example of effective involvement of the school community in planning for future generations.	47	People understand what is expected of them while in the school building.
57	Exemplary Building	Communications	Our school building enables effective communication amongst staff and pupils alike.	52	The school building appearance shows that we have an excellent building.
58	Exemplary Building	School Culture	Our school building is a source of pride.	66	The school's importance in the community and values of inclusiveness can be seen in the diverse ways that staff, pupils and the community use the building.
	School Culture	How do you feel about the way the School Building supports school spirit and culture?	*School Culture includes the way the building supports events, school spirit, positive attitudes, values and conduct.*		
59	School Culture	Organisation & Design	The school building creates an atmosphere that makes it easy for people to follow school rules, such as neatness, being on time for classes, etc.	15	The building creates a highly effective environment for learning.
60	School Culture	School Programme & Services	The school building and class rooms help engage pupils in school teaching and learning.	21	The school building helps us have programmes and services that enable an inclusive positive culture.
61	School Culture	Development & Innovation	The school building supports both science and creativity.	29	The school building has helped us develop activities and events that contribute to a positive school culture.
62	School Culture	School Operations	The culture and values of the school are evident in the safe, day-to-day operations of the school building.	36	The way the school is operated create a positive impact upon the people who come here.
63	School Culture	Building Resources	The way we treat the school building shows respect for the school.	43	The way we use the school building is having positive results for the school and the pupils.
64	School Culture	Planning	The school building we have accurately reflects the needs of the pupils and teachers.	48	The school and its buildings support our inclusive culture.
65	School Culture	Communications	The school is held in high regard by its peers, staff and pupils.	53	The school is proud of its pupils and facilities.
66	School Culture	Exemplary Building	The school's importance in the community and values of inclusiveness can be seen in the diverse ways that staff, pupils and the community use the building.	58	Our school building is a source of pride.

S4c - Process Data (Data View Definitions (SOFI Worlds))

The SOFI spheres of influence define the fundamental community areas of interest and influence, but as we see these are in some cases abstract entities which do not immediately align with individual roles and functions. Clearly to understand the data and results it will be necessary for the researcher to view the results from the point of view of any of the respondents or stakeholders involved in the school community. To enable this and to maintain anonymity of response each respondent is asked to check a box or boxes on the questionnaire to group a world point of view. The community of respondents has been designed to be as wide as possible. The nature of the LND community is diverse but well defined and in consultation with the school the following communities have been identified to provide the variables for the SOFI "Worlds".

- Department Heads
- Head Teacher
- First Floor
- Ground Floor
- Parent
- Community Member
- Prefects
- Governor
- Librarian
- FM staff
- Teaching staff
- Administration Staff
- Sixth Form Students
- Female
- Male

S4d - Process Data (Data Gathering through the SOFI Questionnaire)

Gathering data from busy people is a challenge, especially if there is a perception that they cannot effect the change that the survey seeks to challenge or address. There are also a wide range of capabilities and maturity factors when attempting to gather data from such a wide audience. As discussed above these factors we discussed and addressed as part of the question setting exercise and following a disappointing response from the electronic screens, an example of which is shown in Figure 7.25 below, a move was made to provide a paper version of the same questions as shown in Figure 7.26. This methodology provided around two thirds of the final respondent's data. Whilst this is an interesting observation and is further discussed in the further research section of Chapter eight and does offer further insights into the human perceptions of the various communities it does fall outside of the scope of this research.

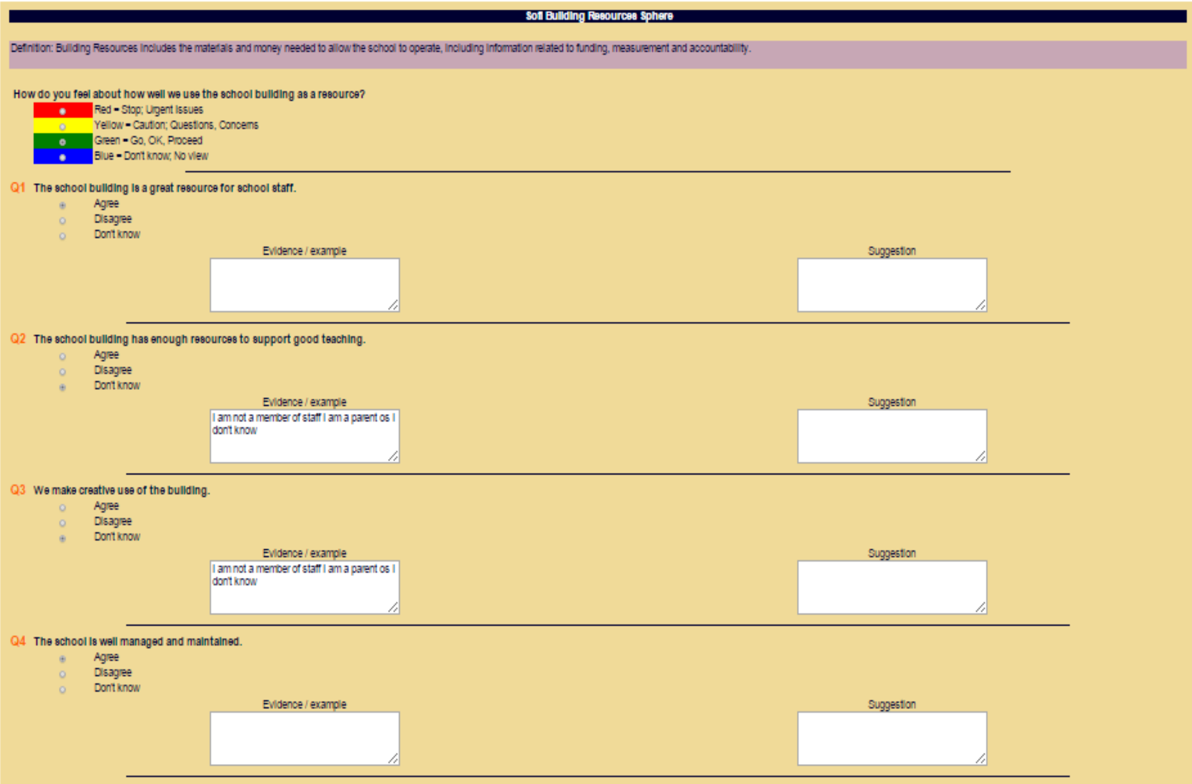
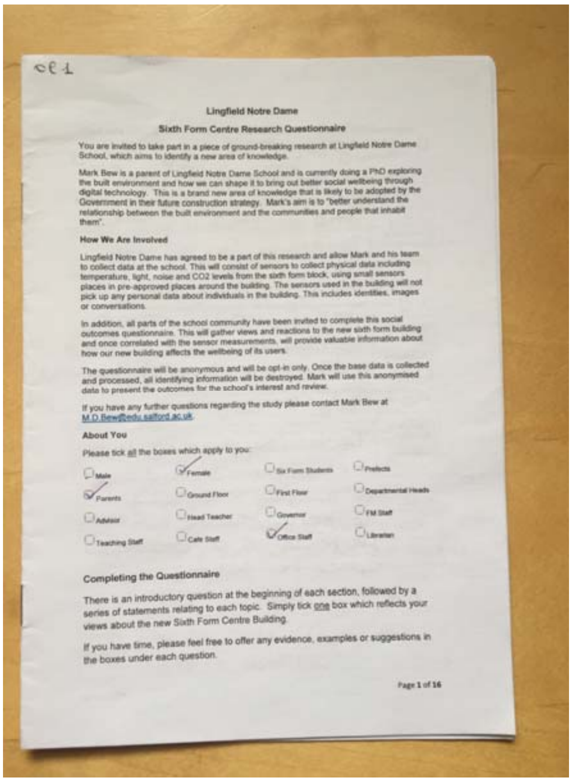


Figure 7.25 - SOFI Online Questionnaire Screen



Lingfield Notre Dame

Sixth Form Centre Research Questionnaire

You are invited to take part in a piece of ground-breaking research at Lingfield Notre Dame School, which aims to identify a new area of knowledge.

Mark Bew is a parent of Lingfield Notre Dame School and is currently doing a PhD exploring the built environment and how we can shape it to bring out better social wellbeing through digital technology. This is a brand new area of knowledge that is likely to be adopted by the Government in their future construction strategy. Mark's aim is to "better understand the relationship between the built environment and the communities and people that inhabit them".

How We Are Involved

Lingfield Notre Dame has agreed to be a part of this research and allow Mark and his team to collect data at the school. This will consist of sensors to collect physical data including temperature, light, noise and CO2 levels from the sixth form block, using small sensors places in pre-approved places around the building. The sensors used in the building will not pick up any personal data about individuals in the building. This includes identities, images or conversations.

In addition, all parts of the school community have been invited to complete this social outcomes questionnaire. This will gather views and reactions to the new sixth form building and once correlated with the sensor measurements, will provide valuable information about how our new building affects the wellbeing of its users.

The questionnaire will be anonymous and will be opt-in only. Once the base data is collected and processed, all identifying information will be destroyed. Mark will use this anonymised data to present the outcomes for the school's interest and review.

If you have any further questions regarding the study please contact Mark Bew at M.D.Bew@edu.salford.ac.uk.

About You

Please tick all the boxes which apply to you:

Male	Female	Six Form Students	Prefects
Parents	Ground Floor	First Floor	Departmental Heads
Advisor	Head Teacher	Governor	FM Staff
Teaching Staff	Cafe Staff	Office Staff	Librarian

Completing the Questionnaire

There is an introductory question at the beginning of each section, followed by a series of statements relating to each topic. Simply tick one box which reflects your views about the new Sixth Form Centre Building.

If you have time, please feel free to offer any evidence, examples or suggestions in the boxes under each question.

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Figure 7.26 - SOFI Paper Questionnaire

The distribution of the questionaries' and the methodology for selection and processing the distribution required careful planning. There were a number of considerations described in Chapter six which had to be considered. Where possible the researcher ensured that there were at least three respondents from each community to offer a statistically useful response. The process had to be secure with effective methods to ensure the commitments made in the ethics statement were upheld, with complete anonymity at all times. Potential respondents were identified with key LND stakeholders, especially the Head teacher. In close consultation a complete coverage of the community and identified worlds was developed, with suitable numbers of respondents and statistically useful data volumes. Respondents were carefully communicated with using the LND school staff to ensure ownership and commitment from both the management team and the respondents. The process for communication was developed and agreed with the school prior to the data gathering phase and key communication documents can be seen in Appendix five.

S4e - Process Data (Analysis Definition and Development Process)

The final part of the "Process Data" section is to perform the final analysis of all the vast quantity of data that has been collected. There are two phases of the analysis, the first is to provide a response to the social perceptive survey and the building physics sensor data in isolation. The second is to amalgamate these results into a single analytic to understand the relationship between the two data sets. This is a complex process and the IDEF0 process model in Figure 7.27 provides a process with which to demonstrate the process performed by the Test Bench.

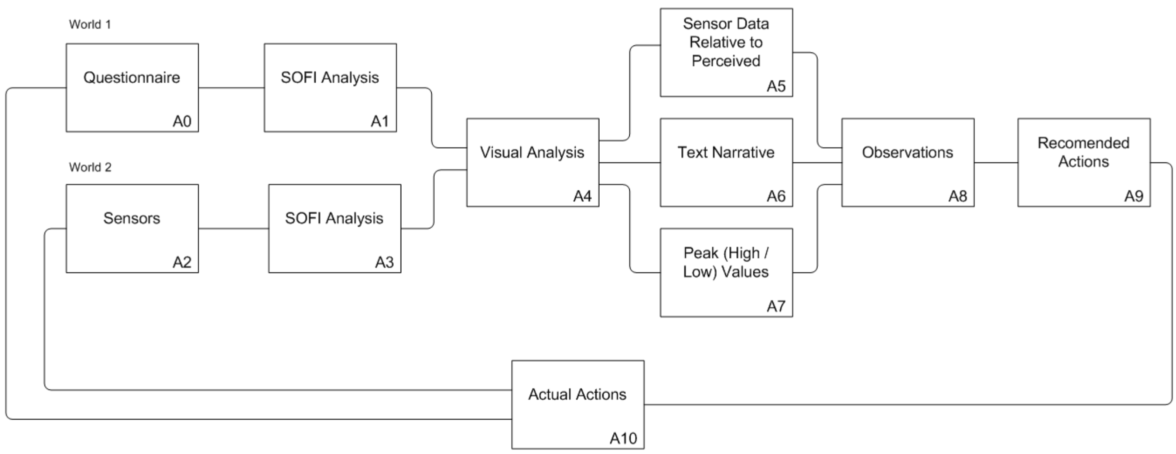


Figure 7.27 - Data Analysis and Development Process

Table 7.10 – Process and Activity Descriptions for Analysis Process

Process Number	Process Name	Description	Comments
A0	Questionnaire	The process of gathering human perceptive data from the various communities which use the school	
A1	SOFI Analysis	The process defined in Chapter 6 where the SOFI tool uses the perceptive data collected in A1 and presents the social and physical relationships in graphical formats	
A2	Sensors	The process of gathering actual building physics data from the various spaces and locations in the school	
A3	SOFI Analysis	The process defined in Chapter 6 where the SOFI tool uses the sensor data collected in A1 and presents the social and physical relationships in graphical formats	

Process Number	Process Name	Description	Comments
A4	Visual Analysis	A process of physical review to identify the potential relationships of the various types and views on the data collected and processed presented in a format to enable further analysis	The results of this analysis produce a large matrix of both social and physical results. The full results appear in Appendix 1, but a worked examples appear in Figure 7.28 and Figure 7.29
A5	Sensor Data Relative to Perceived	A direct visual review of the data presented in A4 specifically analysing the relationships between each world view with respect to the sensor data related to the coincident spaces and rooms of the school	
A6	Text Narrative	The SOFI questionnaire allows for the collections of a narrative and comments from the respondents. This text provided a useful contextual view of the respondent's view and can offer additional insights to the results.	
A7	Peak (High / Low Values)	The data analysed in A5 is based on a rolling eight-hour average, but as we discovered in this Chapter with the example of sensor one there can be significant peaks as rooms are occupied and emptied between classes. This additional context can offer additional insights as to how the spaces are perceived by the users.	
A8	Observations	This process is the documentation following the analysis undertaken in processes A5 - A7. It is by design objective and supported by the evidence presented by the data.	
A9	Recommended Actions	This process offers up to two potential recommendations to be undertaken by the school to improve the perceived and actual performance of the building for the effective delivery of educational services	
A10	Actual Actions	This process is out of scope for this research but would be used to register actual interventions or actions prior to re running the analysis again	

Once the processes A0-A10 have been activated various forms of graphical outputs are generated from the reporting instruments described in Chapter seven. These take the form of tabular reports, shown in Figure 7.28 and Figure 7.29, which describe the perceptive and sensor results based on the community segment, or from the sensor data the scores, the recorded narrative, analysis observations and two sets of potential actions. The full data results for this type of data are analysed in Chapter eight and are listed in full in Appendix one, Table two.

	Parents (6)	Pupils (5)	Advisor (1)	Teaching Staff (8)	Male (7)	Female (16)	Prefect (5)	Governor (2)
Media Suite 1	Very few areas of alignment with the pupil and school staff, organisation or services but otherwise very good. This is counter to all of the other sensor observations which identify a consistent set of records.	In general the pupils thought the room was better than the sensors reported. There are good linkages with the pupil response and poor with the sensor especially with the pupil, staff, organisation and programme spheres. Staff were slightly uncertain as were services. Linkages were much stronger for the perceptive that the measured.	Common ground with yellow results for pupils, staff, organisation and programme. Sensors performed better than perceived in this area. Relations at common levels were poor in both cases and had low alignment between operational and staff	Perceptive records were better for organisation, staff, programme and pupils, in all other areas sensor data was better. There were more relational links at strategic levels than tactical, where they were absent for the sensor relationships	The media suite perceived and recorded datasets were relatively well aligned. The sensors performed slightly worse than perceived at tactical levels and slightly better at strategic and operational. The tactical relationship links were poor	Perceptive results were better for all tactical areas and mostly the remainder except a few don't knows. Similar strategic and operational link relationships . No tactical sensor relationships.	Perceptive results were better for all tactical areas and mostly the remainder except a few don't knows. Similar strategic and operational link relationships . No tactical sensor relationships.	Sensor data has outperformed all strategic and operational areas especially communications. Tactically perceptive values were slightly better. Similar pattern with links

Figure 7.28 - Visual Analysis Results (Perception)

	Peak / Alarm Sensors	Narrative	Summary Observations	Potential Action 1	Potential Action 2
Media Suite 1	Temperatures peaked and fell to values outside of the specified limits at 31.2 - 19 Degrees C. VOC peaked at 3 times the specification at 3676, Humidity dropped 10 10%, 35 % below specification and noise peaked at 80 dB, which was 20 dB above limits, but only for a very short peak in time.	The smalls rooms and media suite are small and stuffy when I visited. The media suite does seem to communicate that technology was an afterthought not centre of thinking during design	Parents observations indicated a lack of understanding of what the Media Suite was for. This was indicated by poor alignment of pupil and staff relationship scores. The pupils liked the space and the linkages between pupils and staff my underlie a better understanding of the potential of technology by pupils that staff. The better perception of the performance of the room may be due to the fact that space is so new to the community and represent such a significant improvement on the past. The peak values for temperature and VOC were recorded in a mild time of year. The performance of the space in more extreme weather conditions may prove to be a significant issue especially as the narrative indicated a stuffy feel to the space already. Female respondents showed the liked the area more than male. This may be because the shape and design of the space encourages a safe and include feel. The Governors were more sceptical and may have external experiences which coloured their view	An improvement in air quality would seem to be the most immediate improvement in this space. The need is evidenced by the peak values and the narrative references to the "stuffy" atmosphere. Potential solutions to this could include both natural and mechanical ventilation.	The number pupils using the media suite was not measured, but may prove to be a useful measure. A larger area would both reduce crowding, air quality and circulation, but may not work commercially. A more innovative approach to the use of technology may provide more options to provide different teaching patterns of areas from media studies activities. Without this option maybe a better more regular spaced area would deliver a better performance.

Figure 7.29 - Visual Analysis Results (Sensors)

The SOFI report generator provides a wide range of reporting output which can be used to interpret the results of the sensor and perceptive feedback. The spheres reports shown in Figure 7.30 to Figure 7.33 are example reports, which are discussed in detail in Chapter eight. Figure 7.30 shows the combined results of the seven first floor sensors and Figure 7.31 indicates the results of the three ground sensors. By way of example these reports indicate a good level of performance at the tactical operational levels (measured elements towards the bottom of the page) and a poor performance towards the top (more strategic elements). Connectivity of relationships also follows the same pattern. It would also appear that the upper floor also performs overall slightly better that the ground floor, both is actual and in terms of relationships. Figure 7.32 shows a very high level of connectivity and perceived satisfaction from the sixth form pupils and Figure 7.33 shows a combined view of all 23 people (male and female) compared to the atrium space. This report indicates a much higher level of human perceived wellbeing that the atrium space actually achieved against the project brief and specification. A full set of these reports are shown in Appendix one, Table five, six & seven.

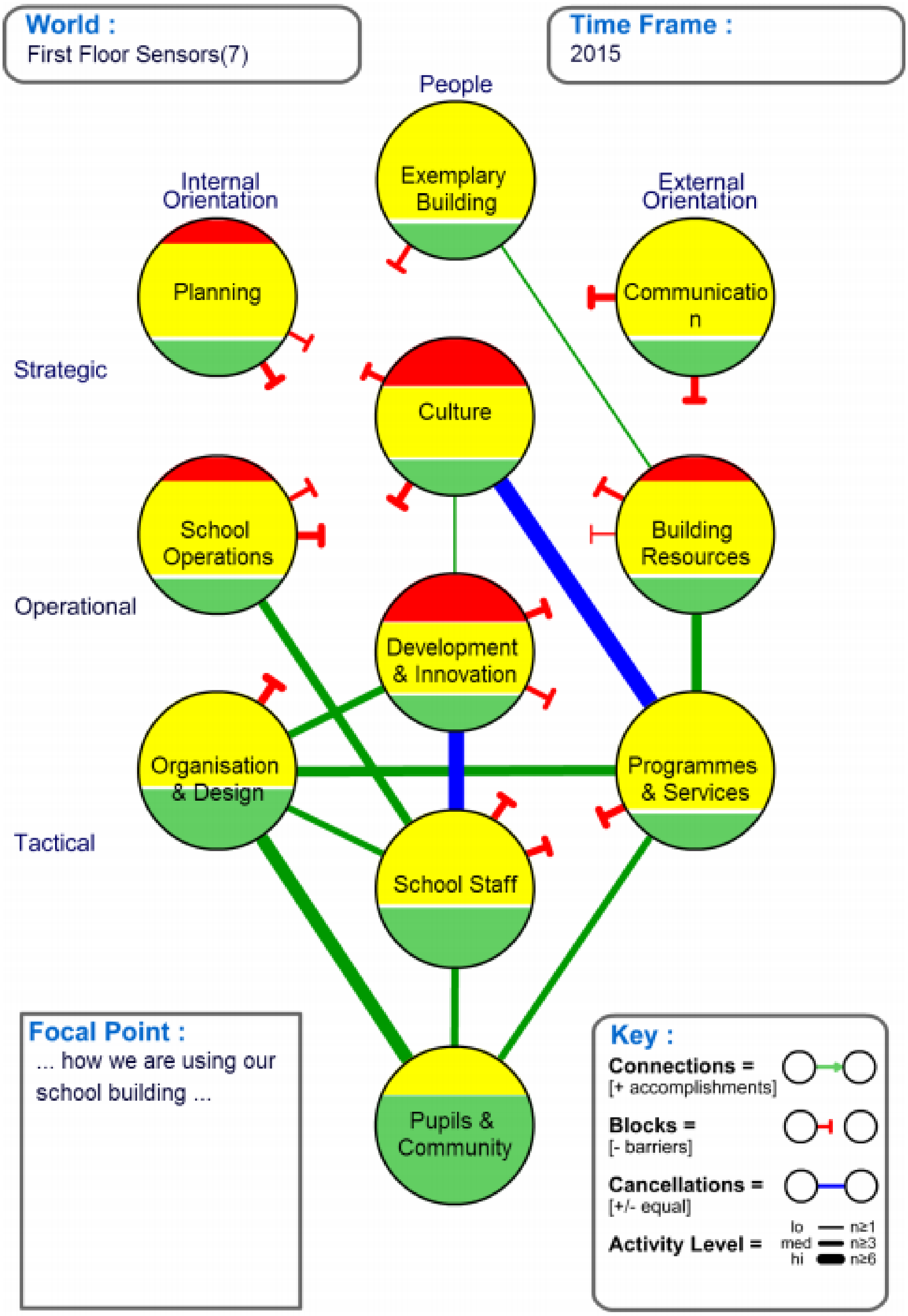


Figure 7.30 - Showing the data from the "world" point of view of all of the sensors on the first floor

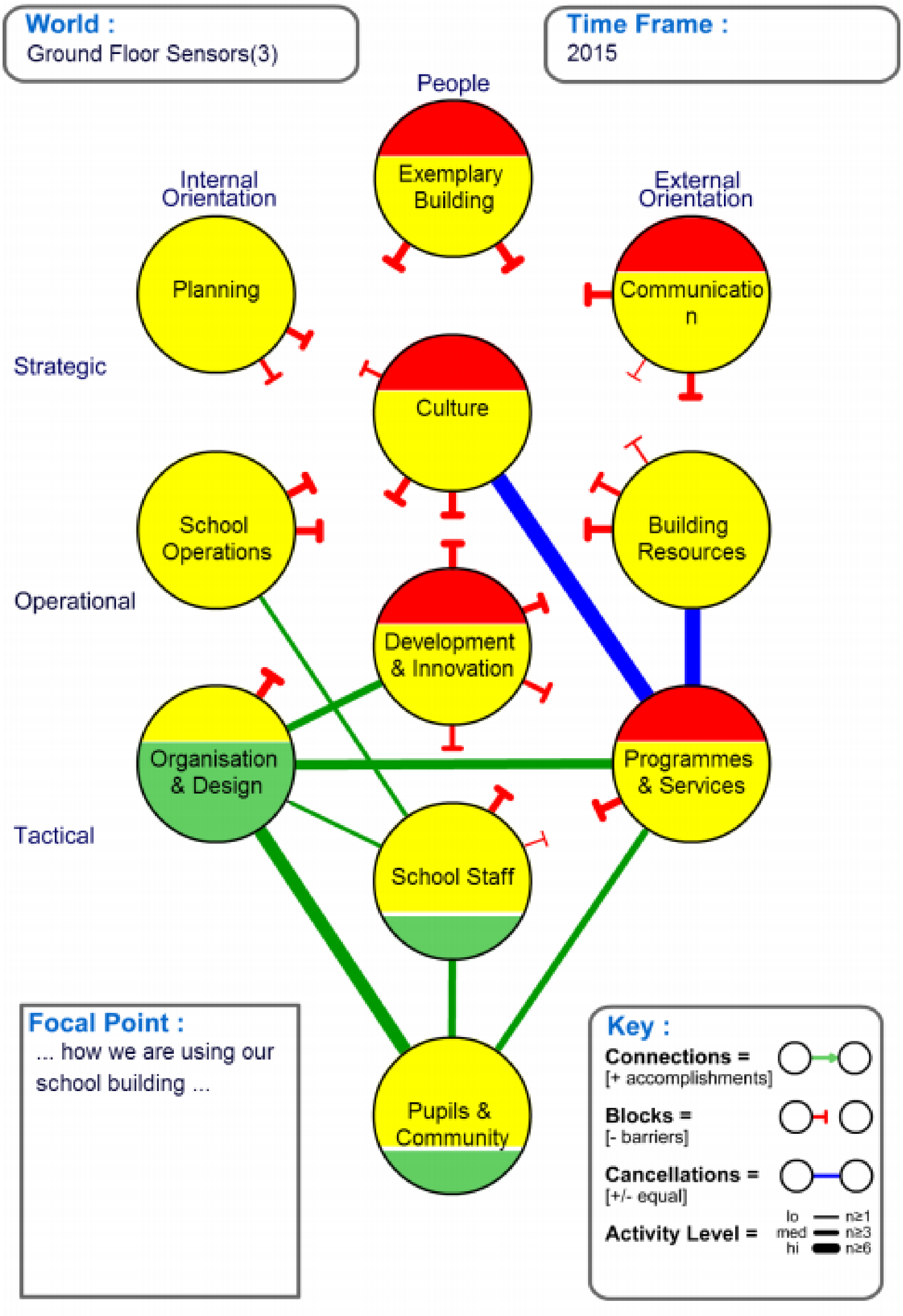


Figure 7.31 - Showing the data from the "world" point of view of all of the sensors on the ground floor

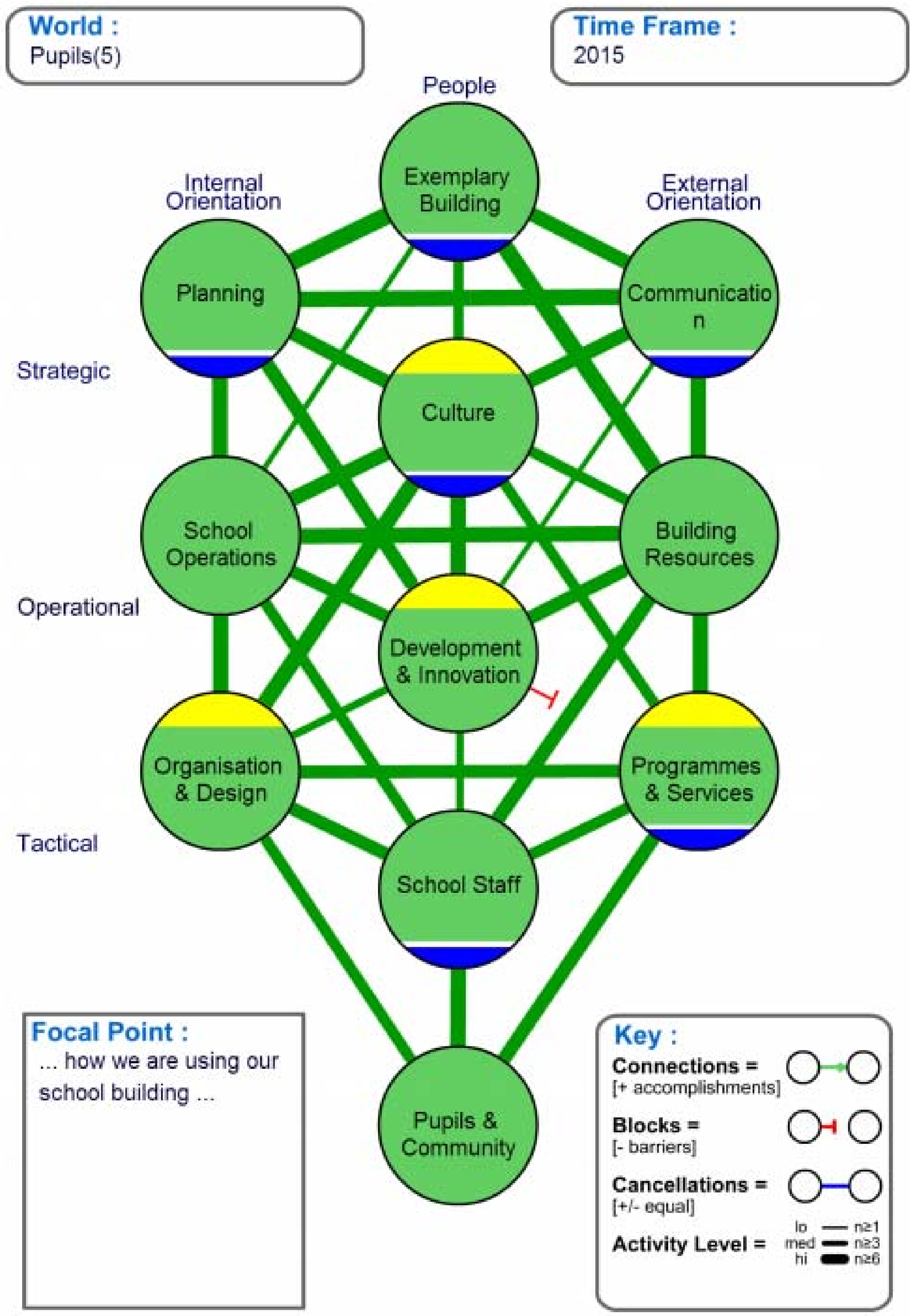


Figure 7.32 - Showing the data from the "world" point of view of the 6th Form pupils

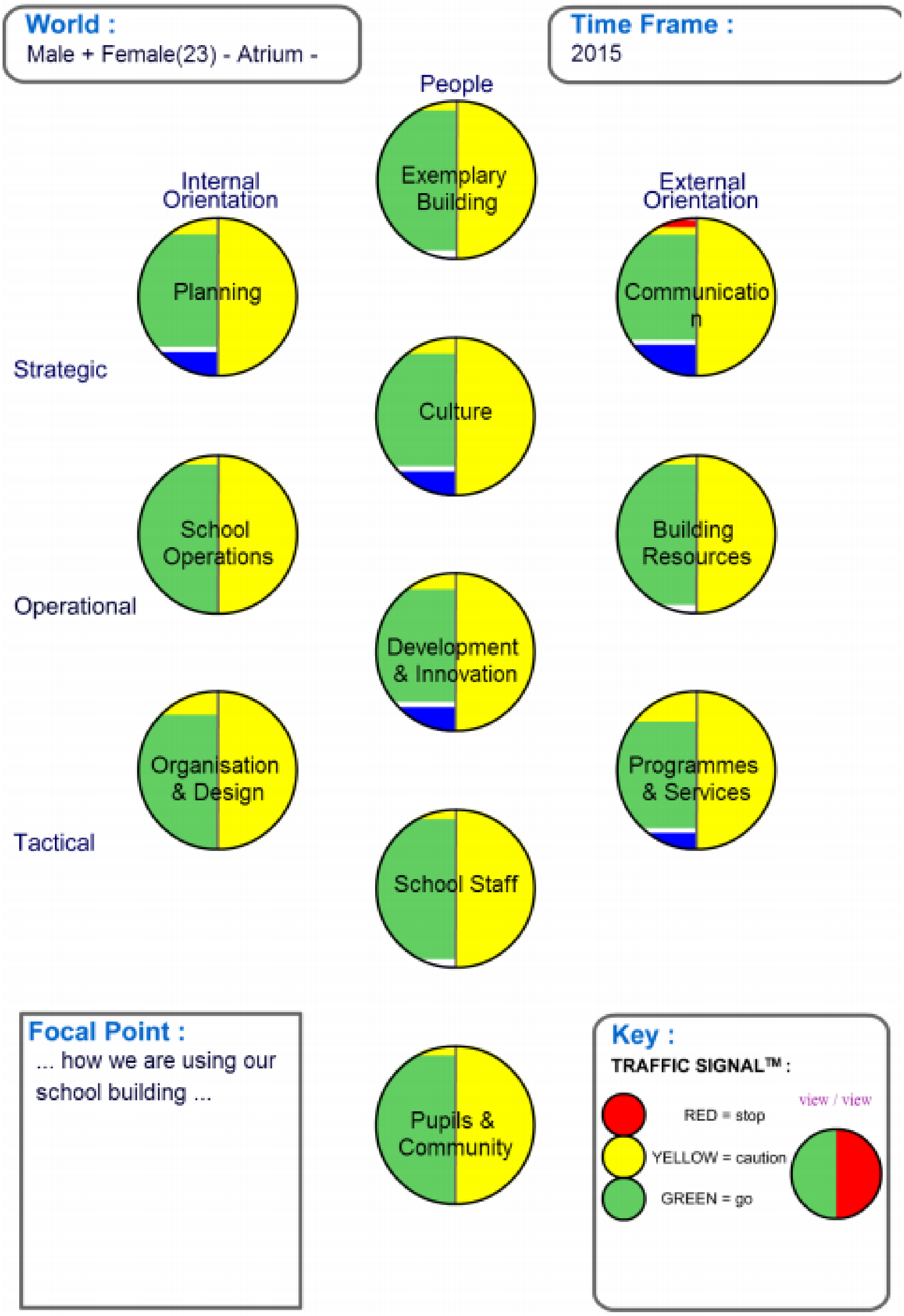


Figure 7.33 - SOFI Hemisphere Map - All vs The Atrium

The process commences with the data gathering process described above from the two worlds of building physics sensor data and human perceptive data (A0 and A2). Once the data is collected it is analysed by the SOFI tools (A1 and A3) and passed to a process which is currently managed manually where the results are presented in a form to allow the formal analysis process in A5-7. Once the final observations have been made a series of recommendations are presented to the school's executive for future consideration and action. Once this cycle has been completed the analysis stage can then recommence as many cycles as is necessary.

7.5 Time Horizon

The time horizon for the project has been selected over the first quarter of 2015. Each set of sensors has been operated for around 16 days to gain a representative sample of performance data. Ideally this would have been undertaken for a much longer period of time covering at least one whole set of annual seasons to establish the impact external influences such a s the weather and the coming and going of new student cohorts.

It would also be valuable to re-run the analytic a number of times over the design life of the asset as new technologies and uses for the buildings develop and the perception of uses on the environment changes both as the asset ages and social perception develops. However, this is not a practical proposition within the scope of this research so the single quarter dataset will be used to draw observations and opportunities for future study.

7.6 Validity

The validity of the data is managed differently in all data set acquisition strategies using appropriate strategies, selected from within the constraints identified in the research and literature review phase of this research. The differing approaches reflect the differing demands and needs of each data type.

- The building physics operational data collected by the sensors has been validated through the use of a checking analytic to ensure data is both present and within sensible limits. This has allowed the researcher to be alerted to occasions when the sensors required repair, resets or were located in positions where there were environmental impacts which were influencing the results.

- The perception records made use of the SOFI tool, which has its own validation approach and uses design strategies to simplify data record checking, for example using a "yes-no-don’t know" multiple choice to minimise the interface time with the user.
- The free text "context" gathering properties are not validated as it was always anticipated that within the scope of this research this task would be undertaken manually
- The as built and briefing information was tested against the output specifications or demand matrices developed using the BIM Toolkit.

As part of the additional research response it would certainly be of value to provide a more competent data validation approach that was technically more able to be applied across all of the data types. This would certainly be necessary to provide any success if the Test Bench were required to use in a production environment.

7.7 Ease of Use

Ease of use is a whole research topic in its own right and a lot of lessons learnt in this area are well known issues. However, there have been a number of areas which have challenged the researcher, these include:

The definition of information to be delivered in the BIM by the design and construction teams is a very new area of work in the construction market. The industry has been accustomed to the production of schedules, reports and drawings, but new approaches including the Test Bench require structured high quality data and this must be validated. The tools and the required content has not been used on enough projects yet to be fully tested for completeness and validity, thus requiring a lot of manual intervention to ensure a valid data set.

The "Internet of Things" is still anything but and devices using proprietary protocols and methods still abound across the market. The Building Management tools also remain in the most proprietary black boxes not allowing users and operators to make use of the data within them. The positioning and calibration of sensors is a research topic on its own and for the purposes of this research a source of power, access to a wireless router and security were the main concerns. The use of the Cube Sensors provided insights into the building physics of the school that were unavailable through any other means. However, the robustness of such devices in a school has to be questioned if used as here on a short term temporary basis. Future research should address these detailed issues.

On the collection of perception and people related information the key issues which have arisen are the need for the users to have access to email and the internet and to be prepared to spend enough time answering as many questions as are required for the Test Bench. There was also some feedback that the reciprocal questions were repeats of similar ground that had already been covered which would be addressed in a future iteration, with clearer more precise general questions. The fact that some users failed to populate the comments sections indicates the challenge of developing questions and user interfaces that are easy to use and gather maximum information. Future developments will include considerations with respect to other more advanced techniques in collecting information such as wearables and other smart technologies.

7.8 Other Observations

In the process of the detailed application of the Test Bench into a building and a community the level of planning, awareness and communication must not be under estimated. The LND School was the third such institution approached and for a variety of reasons the only one that was able to see the process through to a successful conclusion.

7.9 Summary

Chapter seven has described the detailed application of the Test Bench to a live working school with real people going about their daily business. The Test Bench has taken a number of disparate data sources as identified in the research phase and delivered a research tool which has provided the ability to validate the research aims of this research. Some of the techniques are new, such as applying double loop techniques with both perceptive and physical data sources and would require development before they could be used in a production environment. Key to this was the usability of the perceptive data collection tools and the volume of data produced by this single experiment was large. Also some of the analysis was undertaken manually, for an experiment on a larger community and building more of the data processing would need to be automated.

Chapter eight describes the processing of the data collected and the final analysis to discover how the building performed with respect to the brief and how the community perceived this in their daily activities. Also the identification of actionable improvement items.

Chapter 8

Analysis and Findings

8.1 Introduction

Chapter seven described how the Test Bench was implemented at LND school and how data was gathered and stored. It further showed how the data could be presented for analysis having been pre-processed by the SOFI analytic tools. The following data was produced

a. The building information model provided geometric and tabular data (COBie) about location, shape, specification, adjacency and quantities which describe the physical school asset as briefed.
b. The building information model provided geometric and tabular data about location, shape, specification, adjacency and quantities which describe the physical school asset as built.
c. The SOFI questionnaire (electronic and paper) provided semi structured data recording the community's perception of itself and each other.
d. The SOFI questionnaire (electronic and paper) provided unstructured text containing a useful context setting narrative and comments.
e. The Cube sensors took data samples every minute to record the physical performance of the building and its spaces to measure the performance of the building as operated.
f. The SOFI reporting tools analysed the above data and provided the sphere reports

All of the results gathered from the data sources above have been placed in Appendix one - Data Results. Chapter eight provides an analysis, narrative and reflection on the data gathered which provides the evidence for the research findings.

8.2 Data Analysis Process

There are a number of approaches applied to each stage of the Test Bench process. The process as discussed is complex in the time sequence stages and the nature of the data being processed, being of quantitative and qualitative form. The process defined in the IDEF0 shown in Figure 8.1.

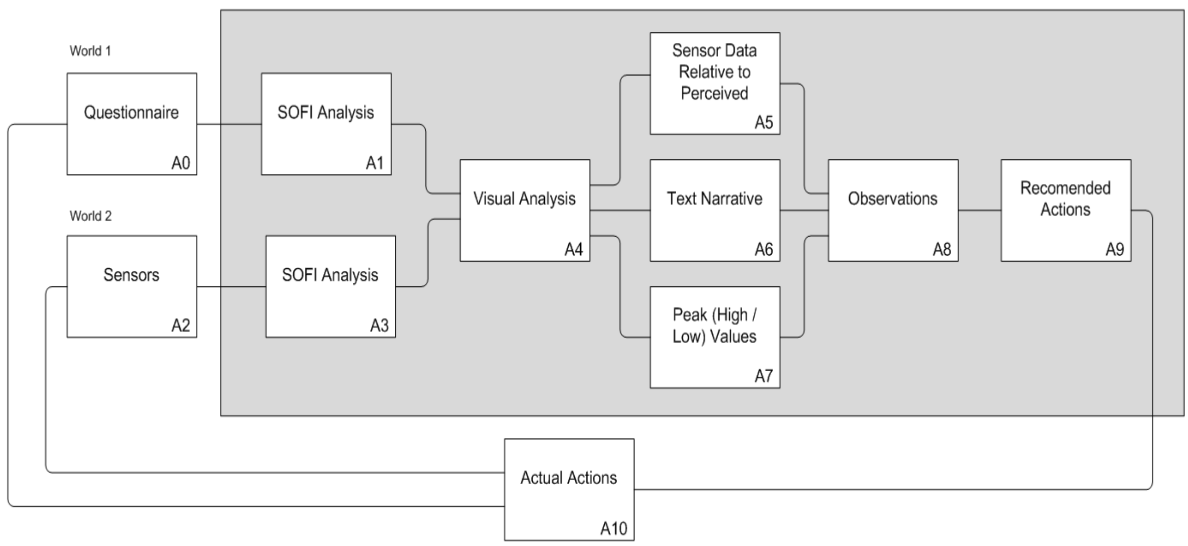


Figure 8.1 - Data Analysis and Development Process (Shaded area of interest)

Here the stages and sequence of processing provide a useful structure to provide the results narrative, observations and conclusions. The first stage uses the SOFI analysis tools to convert the qualitative data into a format that can be processed and combined with the physical values from the values coming from the sensors. This type of processing and analysis is necessary to enable the researcher to have the ability of comparing the two different types of data. Once this data has been processed it is output in the form of the SOFI reports seen in Figure 7.30 through Figure 7.33. These are stylised graphics which allow the researcher (or user) to view the perceptive results in the context of how the respondent views their community environment and how they view others. The ability to change data "views" or "worlds" enables the data to be sliced in as many directions as there are possible combinations. Once this is then combined with the sensor derived data results a matrix of 11*11 potential community combinations and 16*16 potential combinations between communities and the sensors. This is further increased to 18*16 as we include the peak sensor values and the text narrative offered by the users, giving a total number of potential results observations of 288 sample points. This matrix can be seen in Appendix 1, Table 2. The following sections describe in detail each stage of the analysis process.

8.2.1 SOFI Perception Analysis (A1)

The launch of the perceptive analysis phase was launched in early 2015. The end of winter and early spring was mild, with no significant extreme weather events. The Sixth form pupils were commencing their second full term in the new building and the FM staff were working hard to ensure the performance of the building was tuned to the weather and usage demands of both the new sixth form pupils and the building.

The electronic version of the questionnaire was presented first and following a disappointing response, through dialogue with the school a paper version followed. The split between paper and electronic respondents was one third electronic and two thirds paper. The respondents came from the following communities.

- Parents (6)
- Pupils (5)
- Advisors (1)
- Teaching Staff (8)
- Governors (2)
- Departmental Head (1)
- Head Teacher (1)
- Café Staff (1)
- Office Staff (3)
- Librarian (1)

The full results of the questionnaire are in Appendix one, Table one. They show the raw data and text results from the process. The report in Table one is the native output of the SOFI tool, which gives a result showing the way the respondent feels about their own community and space and the perception of the respondent on other neighbourhoods and finally the reciprocal score from other parts of the community.

These values are then processed by the SOFI report writer and produce the sphere's reports, including the perception influence map. Figure 7.32 is an example of the report generated for the pupil's world or point of view. The remainder of the reports are shown in Appendix 1, Table six.

In the Figure 7.32 example of the pupil's world map the pupil's relationships with all other community members was very good except that between development and communication, operations and the school building and development and programme and services. It is not clear why this would be other than the relationship between the school support staff and the pupils is a secondary relationship to that between themselves and the teaching staff. The relationship between development and programme is particularly poor. The value of these internal community relationships and world perceptions is used to form a wider view to the relationships of the organisation as a whole and as well as providing overall context does provide an element of experiment control by enabling the analyst to exclude results where particularly poor community relationships may affect the perception of the asset.

8.2.2 SOFI Sensor Analysis (A3)

The sensors were positioned in the school building and data was collected as described in Chapter seven. The data in its raw form was validated for lost or rouge values. To make the data usable a level of aggregation was necessary, this was developed as part of the Test Bench toolkit. The first view shown in full for all sensors in Appendix one, Table three has been made to enable a daily view of high, low, and average values for the eight hours of school operation.

A fragment from the report is shown below where the five variables the sensor collects, together with an external data feed from another public data source giving the local weather information. As can be seen the daily high and low values are recorded with the averages values for overall and working weekday (eight hours) are calculated. On the right hand side, the averages and peak values are indicated. Please note that these values are for the full time that the sensor was in use not the two days indicated here. For the full dataset and the remaining ten sensors please see Appendix one, Table three.

Sensor	S1						
Location	Media Suite	S	M				
Date		01/03/2015	02/03/2015	Average Overall	Average Weekday	Peak High	Peak Low
	Temperature (Sensor)						
	High	26	25.2			31.2	
	Low	19	20.1				19
	Average	23	22.3	23.9	24.2		
	Temperature (Outside)						
	High	5.1	6			13	
	Low	3.2	3				4
	Average	4.5	4	6.6	6.2		
	VOC						
	High	802	791			3676	
	Low	512	453				400
	Average	670	650	626.4	632.4		
	Light						
	High	101	99			2410	
	Low	5	2				0
	Average	51	50	309.8	359.9		
	Noise						
	High	44	47			80	
	Low	43	45				41
	Average	43	46	44.8	45.5		
	Humidity						
	High	40	45			45	
	Low	36	32				10
	Average	37	36	32.1	31.6		
	Pressure						
	High	1011	1018			1028	
	Low	1006	1010				1006
	Average	1010	1012	1019.5	1019.5		

Figure 8.2 - Data Results for Sensor 1 “Media Suite” Aggregated data results for two days showing average and peak values

On first inspection of the values there were some interesting observations with a large rise and fall in the values for VOC. However, with the knowledge that we are comparing values for a Sunday and a Monday, it is perhaps surprising that some of the values were so high on a non-occupation day. However, even with this small amount of information, the time aspect makes the information much more accessible when plotted over time.

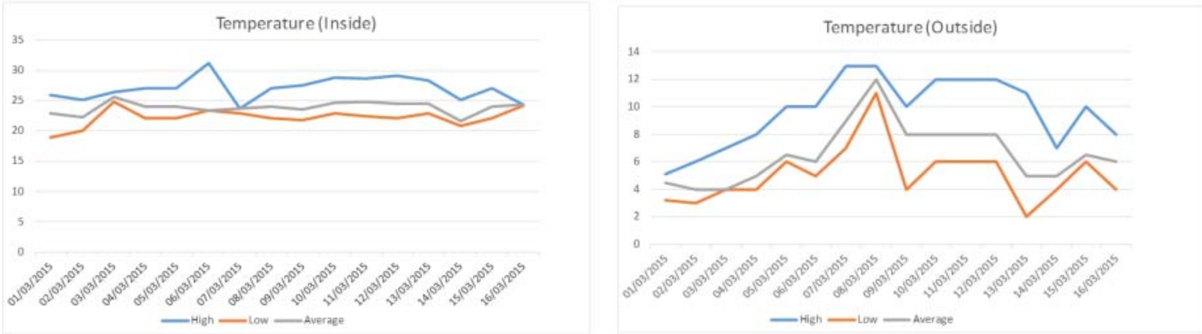


Figure 8.3 - Data Results for Sensor 1 "Media Suite" Plotted by Time by Peak High & Low & Average for Internal and External Temperature

The first two graphical plots are for the internal and external temperatures. The outside temperature appears fairly typical for the time of year ranging between 2 degrees Celsius and up to 12. The swing in temperature is relatively high placing additional load on the LND school buildings systems to maintain a common temperature inside the spaces. The inside plot is much closer, with a peak deviation of around 7 degrees. The values recorded on the 8/3/15 indicate the large impact a high outside temperature has on reducing heat loss on the building. One of the interesting features not considered in this analysis but of interest for future research was the rate of heat loss once the heating system had shut down - the effectiveness of the building insulation and the impact of the outside temperature being highly relevant for the effective sustainable operation of the building, especially in terms of reducing carbon emissions.

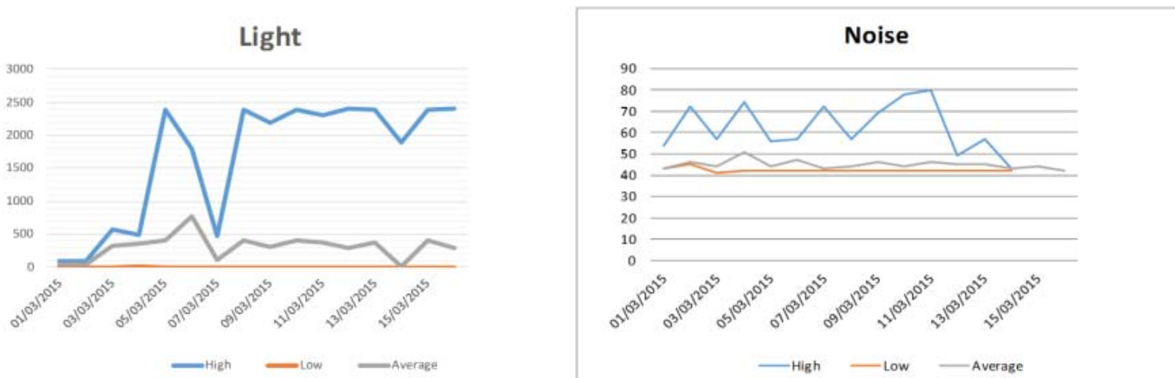
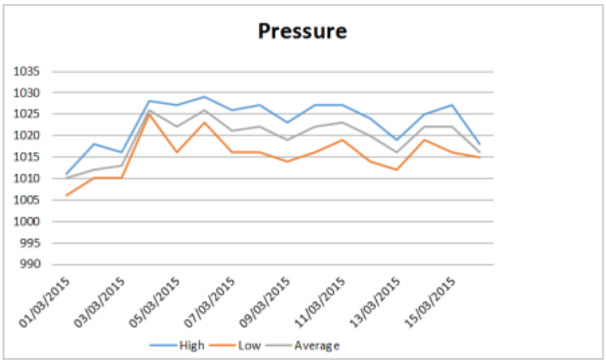


Figure 8.4 - Data Results for Sensor 1 "Media Suite" Plotted by Time by Peak High & Low & Average for Light & Noise

The light values are mostly as expected with a peak daytime value and a very low (around zero) lux level at night indicating that the lights were turned off out of hours. There are dips around the 1st, 7th and 14th which are likely to be related to weekends and the rooms not being used. It is possible that the weather also had an influence on these values, with a colder temperature being recorded outside which could have been linked with poor weather and light conditions outside. The average humidity also has a relatively volatile set of readings, with a significant dip on the 4th which was a Wednesday. There is no obvious reason why this peak should have occurred from the data gathered.

The noise profile is of interest, clearly there are good reasons for the noise to be lower at the weekends and the average value is kept low as the room will spend some periods empty, but the sustained high values indicate that this is a noisy place to spend time, which may not be conducive to individual study.



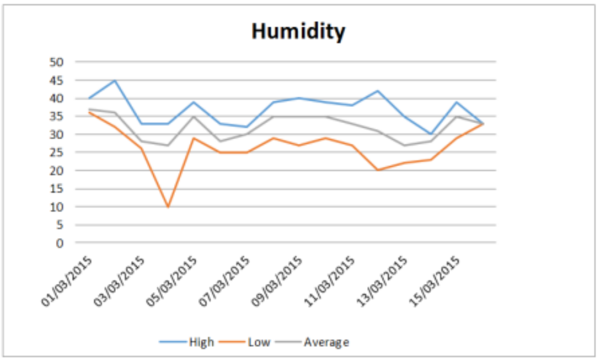


Figure 8.5 - Data Results for Sensor 1 “Media Suite” Plotted by Time by Peak High & Low & Average for Pressure & Humidity

Other than the rise in pressure over the first few days, the atmospheric pressure was relatively constant, other than predicting future weather trends this information was of little use.

The humidity readings on average were fairly flat at around 30%, which is considered very low for an environment such as a school, where such low values make the transmission of bugs and virus's common, it is not clear from these results what the drop on the 4th may have been, but it could be its coincidence with a bright warm day heated the air in the room with the windows closed and caused the dip.

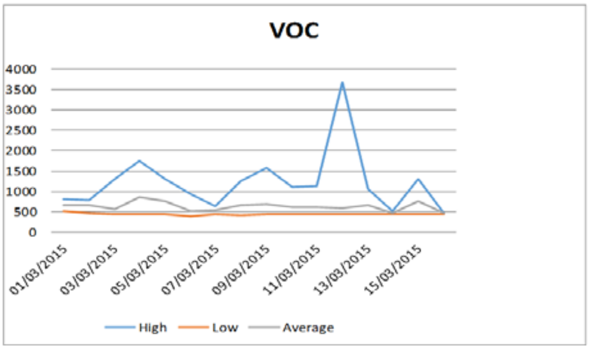


Figure 8.6 - Data Results for Sensor 1 “Media Suite” Plotted by Time by Peak High & Low & Average for Volatile Organic Compounds

The VOC values support the theory of the 4th but a large peak on the 12th is harder to pinpoint. The average values remained static at around 620 through the period of sampling.

The purpose of the analysis shown above is to demonstrate the ability of the building to maintain a performance that meets the requirements of the specification and brief. This check takes the time evented data shown above and plots the rolling average and peak values into a checking process that provides a Red / Amber / Green (RAG) score to the result. The example shown below is for sensor one. Here the values have been tested against the specification and the resultant RAG provided. This serves a number of purposes for further research: the first is it is a very simple clear indicator to a lay user looking at the result to see if their building is performing as required, secondly is gives us an ipsative value to enable the researcher to answer SOFI questions. The full results for this process can be seen in Appendix one, Table four.

S1								
Media Suite	**Actual**				**Specification**			
	Average Overall	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**	**Ave**
Temperature (Sensor)								
High			31.2		26			
Low				19.0		23		
Average	23.9	24.2						
Temperature (Outside)								
High			13.0					
Low				4.0				
Average	6.6	6.2						
VOC								
High			3676.0		1000			
Low				400.0		450		
Average	626.4	632.4						
Light								
High			2410.0		8000			
Low				0.0		300		
Average	309.8	359.9						
Noise								
High			80.0		60			
Low				41.0		40		
Average	44.8	45.5						
Humidity								
High			45.0		55			
Low				10.0		45		
Average	32.1	31.6						
Pressure								
High			1028.0					
Low				1006.0				
Average	1019.5	1019.5						

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Overall Rating based on weekday average

Figure 8.7 - Data Results for Sensor 1 "Media Suite" Processed results for entire sample period showing average and peak values and RAG performance against Specification

Having processed the sensor data into a format that can be used by the SOFI analytic tool. The configuration for this process is described in Chapter 7 with the digital queries shown in Figure 7.24. Once the data is applied to the SOFI analytic the results provide the Ipsative values in the form of the Red / Amber / Green values. Once processed this provided the output values shown in Table 7.8 for sensor 1 and in full in Appendix one, Table four for all other sensors. Once these results were uploaded into the SOFI analytic tool as a separate world but with the same palate matrix configuration the relationship between the worlds and the community spheres of influence was formed to create the composite view of perception and actual physical performance needed to create a common platform to observe the relationships between the two data types.

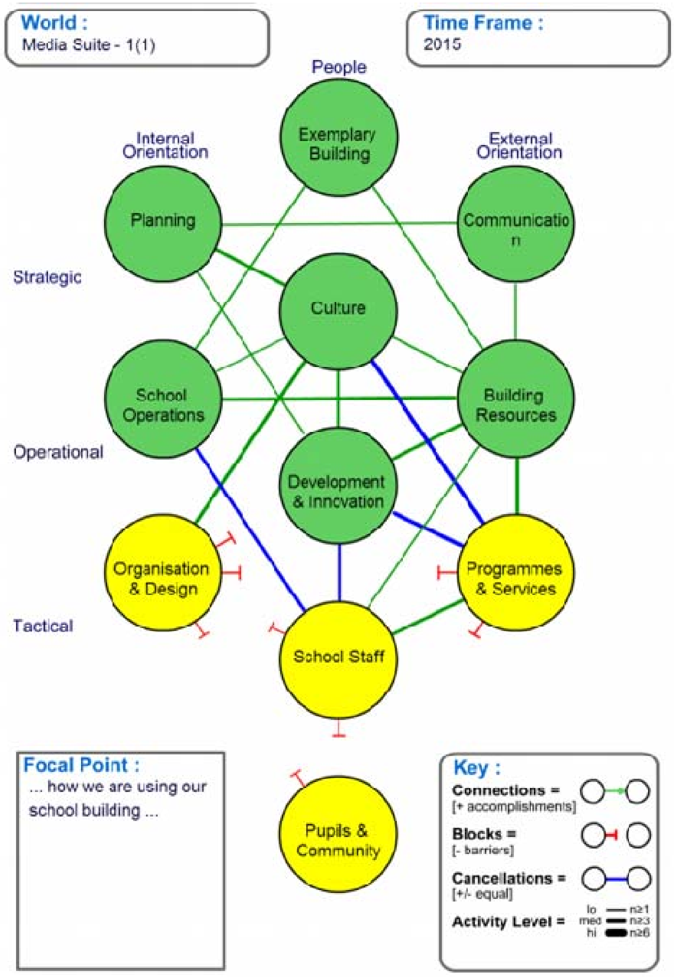


Figure 8.8 - Perception Results for Space 1 "Media Suite" Processed results from SOFI analysis

Once the SOFI analytic reports are run a series of reports as shown in Figure 8.8 are produced showing the results in the same influence type model info graphic in the perceived results. These are the results for the sensor 1 positioned in the media suite. As can be seen the results in general and certainly with respect to many of the other sensors seen in the other parts of the building performs well at the higher strategic and operational levels, but performed less well at the tactical, immediate levels. This was due to the relatively poor performance of the space with respect to humidity.

The full combined and processed set of results for each sensor can be seen on the following pages. They have been summarised into a single dashboard report to provide a lay users information set to inform other decisions. The plain language queries and code logic is displayed to indicate how the results feed from these sensor analytics to the SOFI tool palates.

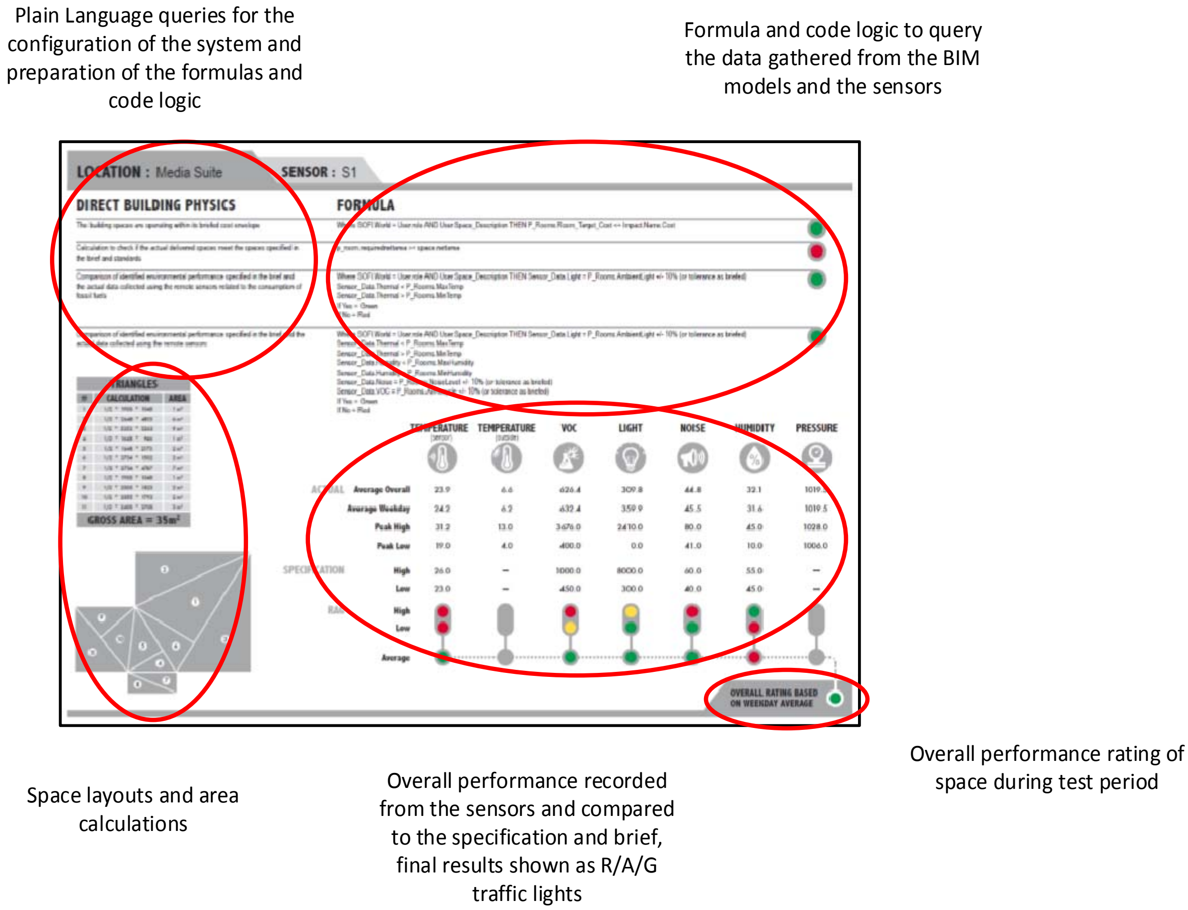


Figure 8.9 - Space Sensor Results Dashboard

In the following eleven figures, each of the sensors is shown in its own dashboard. The figures to sensor and areas are mapped as shown in Table 8.1.

Table 8.1 - Sensor/Space Dashboard – Figure References

Figure Number	Sensor	Space Name
8.10	S1	Media Suite
8.11	D3	Quiet Study Area
8.12	B2	UCAS Office
8.13	D3	Atrium
8.14	BR2	Room 30
8.15	S1	Common Room
8.16	K4	Kitchen
8.17	S1	Room 7 Downstairs
8.18	BR2	ICT B Downstairs
8.19	D3	Lecture Theatre
8.20	K	H E Class Room

The result indicate that only two areas managed to perform to a green rating over the period of an average weekday usage pattern. Six areas managed amber ratings and the remaining three were scored red.

Nearly all areas scored red on humidity and VOC and this could have been due to the newness of the building with the new materials releasing VOC from the manufacturing process. However, this view can be challenged as if the detailed results are examined that rate of VOC growth is dramatic as soon as the rooms are occupied. Whatever the cause of the VOC an improved air circulation strategy would be identified as an urgent need to improve both values.

The occurrence of peak values in most spaces is also of concern with particular focus on peak noise in the atrium and Room 30 approaching or actually achieving 90dB at peaks. These dashboard reports are of use to help inform the analysis process but the key task to provide the raw data to feed the SOFI analytic tools described in section A 4-7 below.

LOCATION : Media Suite   **SENSOR :** S1

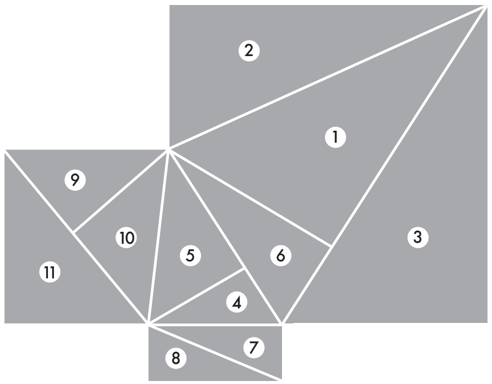
DIRECT BUILDING PHYSICS / FORMULA

DIRECT BUILDING PHYSICS	FORMULA	RAG
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	Green
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	Green
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	Green

TRIANGLES

#	CALCULATION	AREA
1	1/2 * 1900 * 1048	1 m²
2	1/2 * 2648 * 4815	6 m²
3	1/2 * 5353 * 3263	9 m²
4	1/2 * 1648 * 946	1 m²
5	1/2 * 1648 * 2173	2 m²
6	1/2 * 2734 * 1502	2 m²
7	1/2 * 2734 * 4767	7 m²
8	1/2 * 1900 * 1048	1 m²
9	1/2 * 2055 * 1823	2 m²
10	1/2 * 2055 * 1793	2 m²
11	1/2 * 2400 * 2705	3 m²

GROSS AREA = 35m²



		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	23.9	6.6	626.4	309.8	44.8	32.1	1019.5
	Average Weekday	24.2	6.2	632.4	359.9	45.5	31.6	1019.5
	Peak High	31.2	13.0	3676.0	2410.0	80.0	45.0	1028.0
	Peak Low	19.0	4.0	400.0	0.0	41.0	10.0	1006.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–
RAG	High	Red	Grey	Red	Yellow	Red	Green	Grey
	Low	Red	Grey	Yellow	Green	Green	Red	Grey
	Average	Green	Grey	Green	Green	Green	Red	Grey

OVERALL RATING BASED ON WEEKDAY AVERAGE: Green

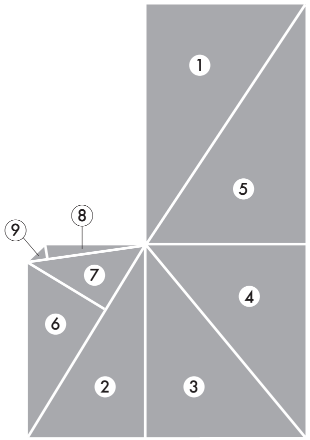
LOCATION : Quiet Study Area   SENSOR : D3

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

TRIANGLES

#	CALCULATION	AREA
1	1/2 * 4400 * 2153	5 m²
2	1/2 * 3873 * 1718	3 m²
3	1/2 * 3873 * 2153	4 m²
4	1/2 * 2153 * 3873	4 m²
5	1/2 * 2153 * 4400	5 m²
6	1/2 * 1457 * 3285	2 m²
7	1/2 * 1457 * 951	1 m²
8	1/2 * 244 * 237	0 m²
9	1/2 * 244 * 1503	0 m²

GROSS AREA = 24m²



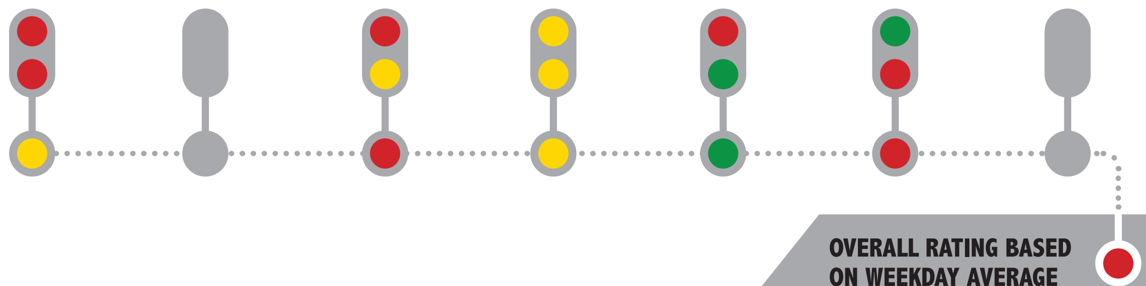
		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	22.7	6.6	1298.2	263.0	45.3	34.8	1020.6
	Average Weekday	22.7	6.2	1463.0	280.8	45.7	35.0	1021.1
	Peak High	27.6	13.0	6898.0	2047.0	82.0	51.0	1035.0
	Peak Low	19.0	3.2	450.0	0.0	42.0	25.0	1006.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG

High

Low

Average

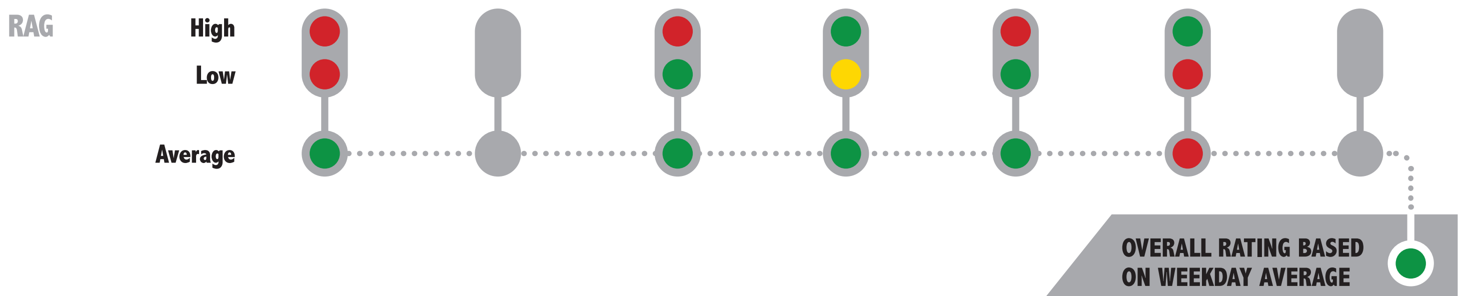


OVERALL RATING BASED ON WEEKDAY AVERAGE

LOCATION : UCAS Office **SENSOR :** B2

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	23.1	6.6	581.6	396.3	43.0	28.4	1023.6
	Average Weekday	23.6	6.2	579.3	377.5	43.0	28.4	1023.9
	Peak High	38.8	12.0	1596.0	2779.0	73.0	38.0	1034.0
	Peak Low	17.0	5.1	450.0	0.0	41.0	15.0	1013.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–



LOCATION : Atrium

SENSOR : D3

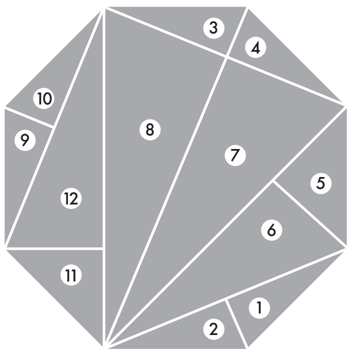
DIRECT BUILDING PHYSICS / FORMULA

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

TRIANGLES

#	CALCULATION	AREA
1	1/2 * 1858 * 4473	4 m²
2	1/2 * 1858 * 4500	4 m²
3	1/2 * 1868 * 4552	4 m²
4	1/2 * 1868 * 4468	4 m²
5	1/2 * 3512 * 3571	6 m²
6	1/2 * 3512 * 8256	14 m²
7	1/2 * 10950 * 4470	24 m²
8	1/2 * 10950 * 4550	25 m²
9	1/2 * 1848 * 4186	4 m²
10	1/2 * 1848 * 4767	4 m²
11	1/2 * 3651 * 3683	7 m²
12	1/2 * 3651 * 8175	15 m²

GROSS AREA = 35m²



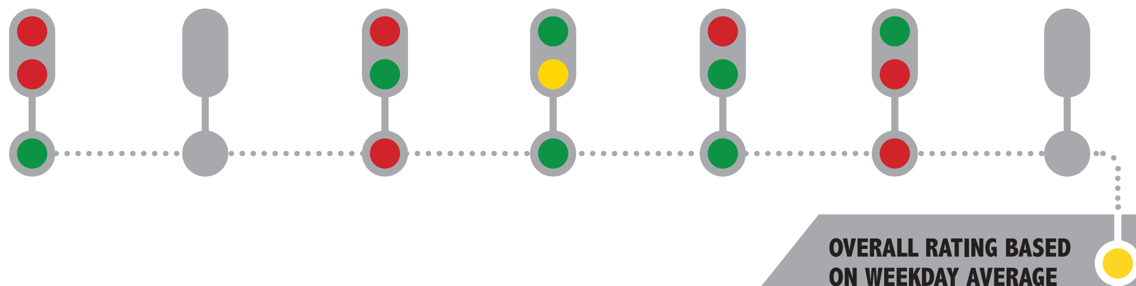
		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	22.0	7.9	1821.9	898.5	48.7	36.5	1008.1
	Average Weekday	22.4	7.9	1829.2	1041.6	49.9	36.1	1007.0
	Peak High	31.2	13.0	9474.0	5863.0	87.0	47.0	1024.0
	Peak Low	19.4	4.0	450.0	1.0	43.0	21.0	990.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG

High

Low

Average



OVERALL RATING BASED ON WEEKDAY AVERAGE

LOCATION : Room 30 **SENSOR :** BR2

DIRECT BUILDING PHYSICS

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

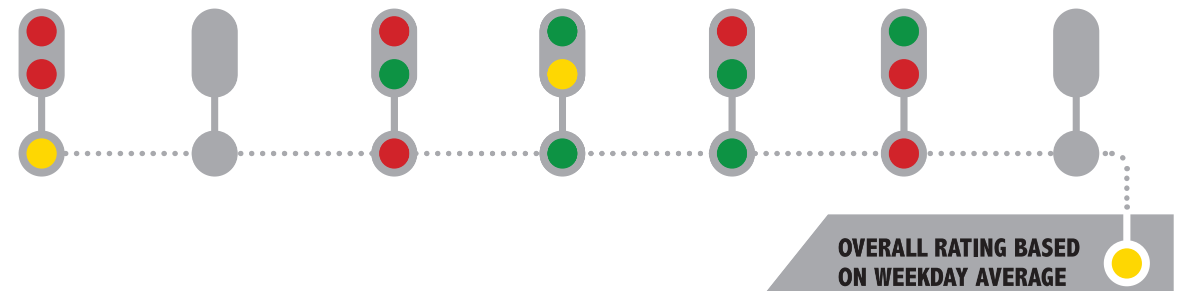
		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	23.6	7.9	1020.7	168.9	43.7	29.9	1008.7
	Average Weekday	23.8	7.9	1044.7	227.6	44.2	29.9	1007.7
	Peak High	29.1	13.0	3839.0	2452.0	90.0	39.0	1024.0
	Peak Low	19.6	5.0	450.0	0.0	41.0	21.0	992.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG

High

Low

Average



OVERALL RATING BASED ON WEEKDAY AVERAGE

LOCATION : Common Room **SENSOR :** S1

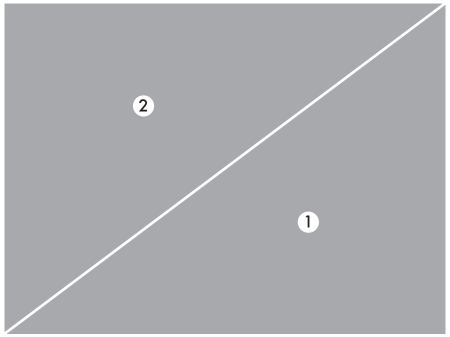
DIRECT BUILDING PHYSICS / FORMULA

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

TRIANGLES

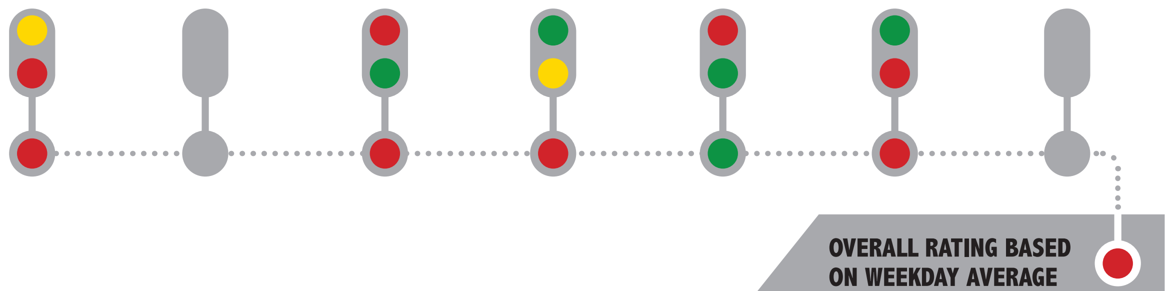
#	CALCULATION	AREA
1	1/2 * 6248 * 8208	26 m^2
2	1/2 * 6248 * 8208	26 m^2

GROSS AREA = 51m^2



		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	16.5	6.4	940.3	99.0	36.8	31.1	819.3
	Average Weekday	20.5	7.9	1377.4	165.2	45.7	38.4	1007.3
	Peak High	26.5	13.0	13647.0	2390.0	89.0	36.0	1024.0
	Peak Low	17.3	5.0	450.0	1.0	42.0	28.0	990.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG High / Low / Average



LOCATION : Kitchen

SENSOR : K4

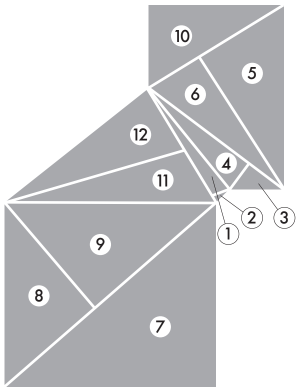
DIRECT BUILDING PHYSICS / FORMULA

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

TRIANGLES

#	CALCULATION	AREA
1	1/2 * 328 * 3257	1 m²
2	1/2 * 328 * 261	0 m²
3	1/2 * 1100 * 986	1 m²
4	1/2 * 1100 * 3083	2 m²
5	1/2 * 3897 * 1829	4 m²
6	1/2 * 3897 * 1171	2 m²
7	1/2 * 3624 * 4113	7 m²
8	1/2 * 2913 * 2567	4 m²
9	1/2 * 2913 * 2915	4 m²
10	1/2 * 1275 * 2716	2 m²
11	1/2 * 3871 * 1415	3 m²
12	1/2 * 3871 * 2104	4 m²

GROSS AREA = 33m²



		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	23.1	7.9	1919.4	150.0	49.3	33.4	1008.8
	Average Weekday	23.4	7.9	1836.9	209.1	50.3	33.2	1008.0
	Peak High	27.2	13.0	13647.0	1793.0	48.0	50.0	1025.0
	Peak Low	19.3	3.0	450.0	4.0	46.0	23.0	993.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–
RAG	High							
	Low							
	Average							

OVERALL RATING BASED ON WEEKDAY AVERAGE

LOCATION : Room 7 Downstairs **SENSOR :** S1

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

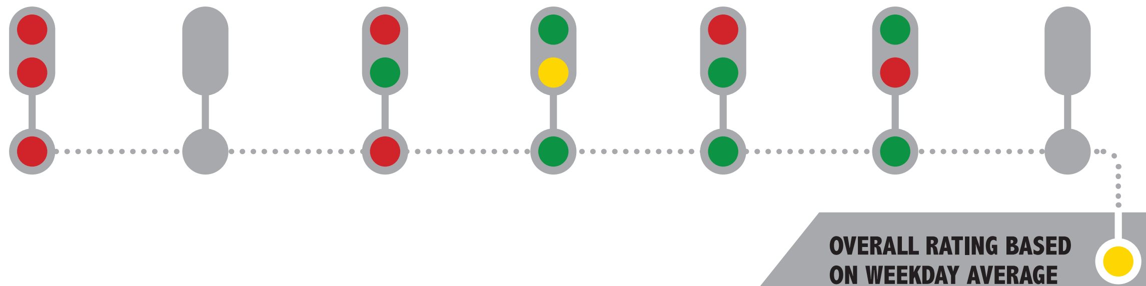
		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	20.5	9.5	1577.2	429.0	46.4	40.1	1005.4
	Average Weekday	21.0	10.2	1537.3	471.2	46.3	40.6	1005.2
	Peak High	35.1	17.0	13647.0	8286.0	90.0	56.0	1018.0
	Peak Low	18.0	5.0	450.0	0.0	42.0	24.0	993.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG

High

Low

Average



OVERALL RATING BASED ON WEEKDAY AVERAGE

LOCATION : ICT B - Downstairs   **SENSOR :** BR2

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

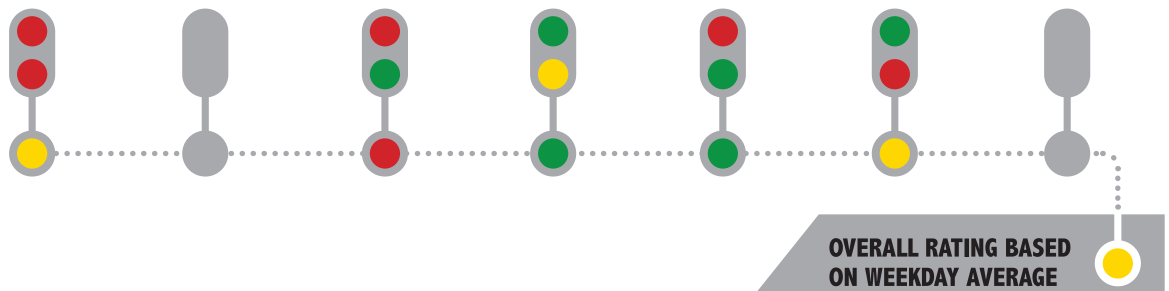
		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	22.8	9.1	1183.8	236.5	45.5	32.6	1012.2
	Average Weekday	22.8	9.3	1312.3	255.8	45.3	32.7	1010.4
	Peak High	29.1	20.0	13647.0	2779.0	90.0	29.0	1026.0
	Peak Low	19.1	3.0	450.0	0.0	41.0	22.0	993.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG

High

Low

Average

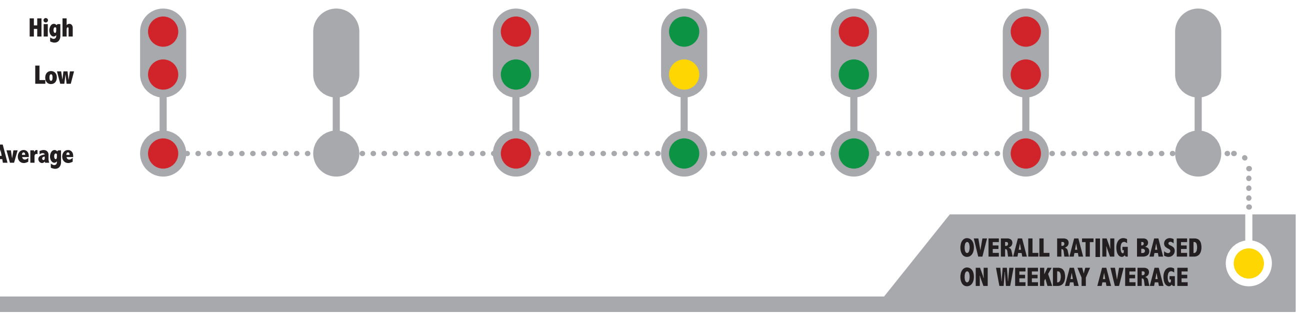


LOCATION : Lecture Theatre **SENSOR :** D3

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	22.6	7.7	1305.9	211.3	45.1	36.3	1013.3
	Average Weekday	20.1	7.3	1277.0	235.8	40.3	32.4	902.2
	Peak High	27.8	20.0	4763.0	2047.0	80.0	47.0	1035.0
	Peak Low	19.0	3.0	450.0	0.0	42.0	25.0	993.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG



LOCATION : HE Room **SENSOR :** K

DIRECT BUILDING PHYSICS	FORMULA
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remote sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity < P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

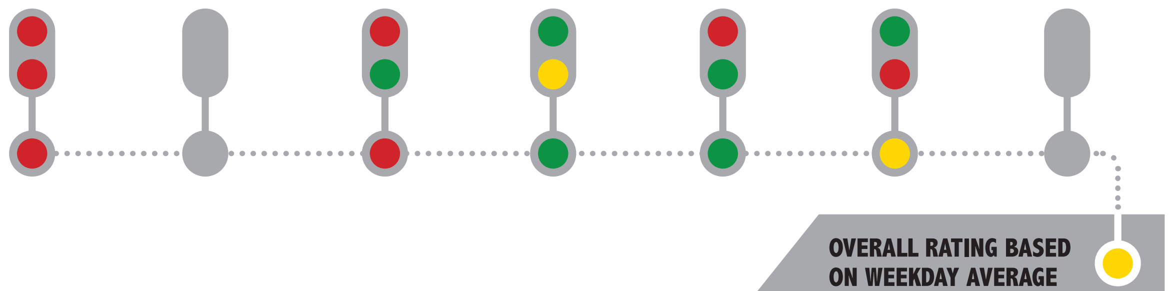
		TEMPERATURE (sensor)	TEMPERATURE (outside)	VOC	LIGHT	NOISE	HUMIDITY	PRESSURE
ACTUAL	Average Overall	24.5	11.4	2197.8	382.0	45.6	34.2	1008.0
	Average Weekday	24.5	11.4	2197.8	382.0	45.6	34.2	1008.0
	Peak High	27.6	11.0	13647.0	2060.0	85.0	50.0	1018.0
	Peak Low	20.5	4.0	450.0	0.0	41.0	25.0	994.0
SPECIFICATION	High	26.0	–	1000.0	8000.0	60.0	55.0	–
	Low	23.0	–	450.0	300.0	40.0	45.0	–

RAG

High

Low

Average



OVERALL RATING BASED ON WEEKDAY AVERAGE

8.2.3 Visual Analysis (A4)

The visual analysis of the data takes place iteratively with each layer of evidence being progressively applied to create a narrative a lay user can interpret and make use of. The first stage of observations has been undertaken for every combination of node connections between community and sensor to create a large results matrix. The observations are created through manual inspection and are by design all based on facts derived from the results presented. This is developed with the researcher bias (Leedy and Ormrod 2001) research in mind. To counter the bias, the observation results have been independently assessed by the SOFI consulting team and in a very small number of cases observations were reviewed and updated. This approach is also derived from the ipsative approach which is a descriptor used in psychology to describe a specific type of comparison, where two desirable options are compared to identify the most desirable. The Table shown in 8.2 is a section of the full Results Matrix, indicating a narrative explanation of the relationship between the communities and the spaces being compared; in this case once again the communities with respect to the media suite data collected by sensor 1. Key analysis considerations which have been considered in this process are listed below:

- Connections between analysis and observations
- Understand the provenance and implications of results at the strategic, operational and tactical levels
- Note that some participants of the questionnaire are members of multiple communities. Examples of this include all participants being members of either male of female or their home community e.g. pupils.
- To avoid any observation or cognitive bias at least three respondents were encouraged in each area, however some communities this is not possible eg Head teacher. Specific care is needed when analysing these results.
- Are there recorded interactions between communities?
- Remain aware that this is a living changing community being measured at a time slice of the life of the community and asset, further and potentially different results will derive from a longitudinal study over a number of seasons and years.
- The SOFI perception model uses Ipsative measure which forces the participant to select the one that is most preferred, rather than a Likert model where the

respondents chose the score (e.g. 1-10) which best represents the amount that agree or disagree with a point of view. This gives a binary result, which makes integration with the sensor data possible, rather than the Likert model measuring only statistical variance across the results and throwing away outliers. The SOFI approach alternatively includes all members of the social system as providing necessary input, assuring they have a voice in the process. This inclusive approach is necessary for enabling ownership and buy in to social change actions to be implemented successfully in the organisation. The full Results Matrix can be seen in Appendix one, Table two.

Table 8.2 - Example of Analysis Results for Perceptive Results for the Media Suite

Parents	Pupils	Advisor	Teaching Staff	Male	Female	Prefect	Governor (2)
Very few areas of alignment with the pupil and school staff, organisation or services but otherwise very good. This is counter to all of the other sensor observations which identify a consistent set of records.	In general, the pupils thought the room was better than the sensors reported. There are good linkages with the pupil response and poor with the sensor especially with the pupil, staff, organisation and programme spheres. Staff were slightly uncertain as were services. Linkages were much stronger for the perceptive that the measured.	Common ground with yellow results for pupils, staff, organisation and programme. Sensors performed better than perceived in this area. Relations at common levels were poor in both cases and had low alignment between operational and staff	Perceptive records were better for organisation, staff, programme and pupils, in all other areas sensor data was better. There were more relational links at strategic levels than tactical, where they were absent for the sensor relationships	The media suite perceived and recorded datasets were relatively well aligned. The sensors performed slightly worse than perceived at tactical levels and slightly better at strategic and operational. The tactical relationship links were poor	Perceptive results were better for all tactical areas and mostly the remainder except a few don’t knows. Similar strategic and operational link relationships. No tactical sensor relationships.	Perceptive results were better for all tactical areas and mostly the remainder except a few don’t knows. Similar strategic and operational link relationships. No tactical sensor relationships.	Sensor data has outperformed all strategic and operational areas especially communications. Tactically perceptive values were slightly better. Similar pattern with links

8.2.4 Sensor Data Relative to Perceived (A5)

The initial view of the individual datasets is a valuable check of the dataset and enables the researcher to identify odd results that should have been excluded in the validation process and to gain an initial understanding of the shape of the results and where further questioning may be required in the future to establish a clear understanding. The next stage is to start and add to the descriptive narrative describing the results from the two worlds of sensors and perception. To aid this process the data seen here has been passed thorough to the SOFI report generator which takes the results and presents them in a more useful format to interpret examples of which are shown below, with the full pack in Table six of Appendix one. The info graphic format shown in these figures and results is designed to make the interpretation of the results quicker and easier, which is designed to compare different worlds as in the example below.

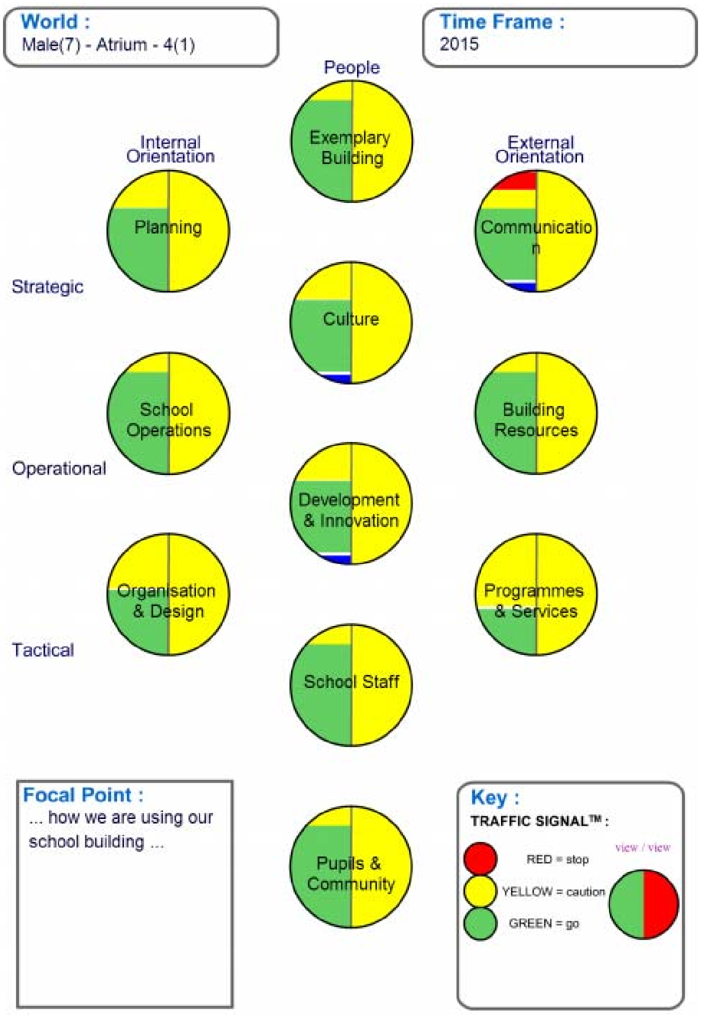


Figure 8.10 - Perception Results for Male Social Perception in the Atrium

It can be seen in the example shown in Figure 8.10 the comparison of scores between the male community (left hand side of the spheres) who use the atrium and the atrium area of the building derived from the building physics sensor results (on the right hand side). We can see the male response is much better (greener) than that of the sensor results which were predominantly lower scores with yellow spheres.

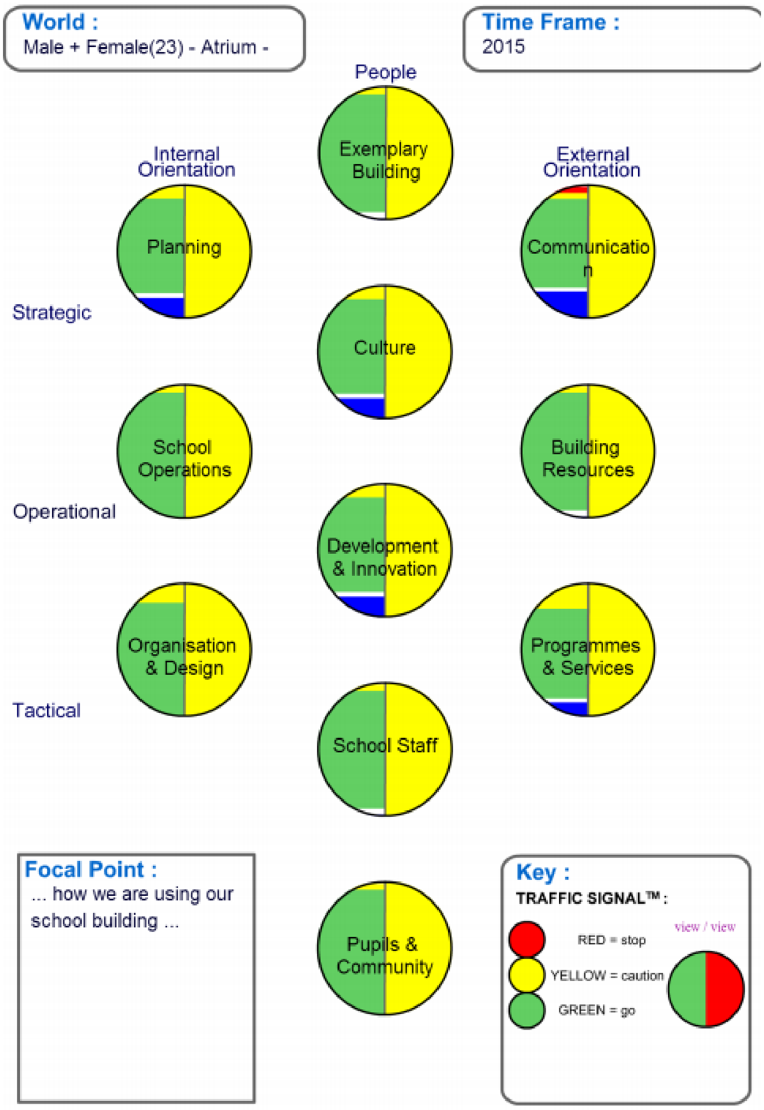


Figure 8.11 - Perception Results for Male & Female Social Perception in the Atrium

If this is then compared with the female (left hand side) to atrium (right hand side) we see an even more positive perception of the female community to the space when compared to male and the building physics results. The Results Matrix in Appendix one, Table two is updated with this new information.

8.2.5 Text Narrative (A6)

The next piece of intelligence is the written narrative supplied by the respondents to the survey. The free form text allows the respondents to provide comments and offer solutions or opinions in any way they wish. In the example shown in Figure 8.12 for the Media Suite refers to the impression that the room was rather "stuffy", in a description of the perceived quality of the air. This may have coincided with the high VOC value discussed above, however it is not possible from these datasets to offer a view on this as the narrative has no timing meta data. The unsolicited offer of the fact that the room may not have been designed with technology as a first consideration offers interesting insights to other aspects of the overall design including air quality and space. It may also point to other technology needs such as charging facilities, Wi-Fi and storage. The Results Matrix in Appendix one, Table two is updated with this new information.

	Narrative
Media Suite 1	The smalls rooms and media suite are small and stuffy when I visited. The media suite does seem to communicate that technology was an after thought not centre of thinking during design

Figure 8.12 - Text comments received for the Media Suite

8.2.6 Peak (High / Low) Values (A7)

The final input is the data derived from the sensors which show the peak high and low values for each sensor show in Appendix one, Table four. These are useful to consider if the space or room is suffering significant peaks in performance. These peaks were deliberately excluded from the SOFI analysis process for this research but a future experiment could include some of the critical values to establish or enable a benchmarking exercise to take place from which future projects could be calibrated. However, included in this process was the opportunity to look at the peak results and to provide a narrative view on the data generated. The example of the sensor 1 in the media suite shown in Figure 8.13 shown below is designed to be a factual unbiased view of the data provided. The Results Matrix in Appendix one, Table two is updated with this new information.

In the example of the Media suite, the peak values are interesting as it can be seen that this space spent some time working outside its specification. The peaks are large in terms of their proportions and it is hard to imagine that this will not have an impact on the users. Indeed, this is confirmed by the contextual information provided by the written feedback shown in Figure 8.12, where the reference to stuffiness is identified.

	Peak / Alarm Sensors
Media Suite 1	Temperatures peaked and fell to values outside of the specified limits at 31.2 - 19 Degrees C. VOC peaked at 3 times the specification at 3676, Humidity dropped 10 10%, 35 % below specification and noise peaked at 80 dB, which was 20 dB above limits, but only for a very short peak in time.

Figure 8.134 – Observations of Sensor Peak Values for Media Suite

8.3 Potential Actions or Interventions Identified from Results

8.3.1 – Recommended Actions

The final process in the scope of this experiment is to provide some recommended “actions". This stage would normally be undertaken by the design and operations professionals employed to look after the asset. It is expected that these actions would be identified with the normal professional skills and capabilities as well as a good understanding of the existing asset and its systems, as well as and understanding of the latest building regulations, best practice and new innovations.

Table 8.3 presents the results of the action planning phase of the project. It is taken from that full matrix shown in Appendix one, Table two. In the example shown below for potential actions for the media suite, there are two actions identified; one looking at the physical opportunities to change the air circulation strategy for the space and the second being more invasive looking at pupil numbers and the methods of educational delivery. These potential actions now identified will need to pass to the implement actual actions process A10 for management and fiscal approval before the action can be made and the process re-measured, thus completing the double loop process cycle.

The whole purpose of the double loop process and its selection for this type of analysis is to gather and process a whole portfolio of data to arrive at a strategy that supports an action to improve the performance of the asset and in turn the perception and social outcomes of the people inhabiting the spaces. The results shown above, especially when considered with the aid of the narrative provides the necessary input to identify a range of potential actions which could be implemented. These actions if implemented could be re-evaluated in the future through a longitudinal study to see how the asset and its users improved over time. Table 8.3 identifies the potential actions which are the final delivery within the scope of this research.

Table 8.3 - Identified Actions to support "Action Planning"

	Potential Action 1	Potential Action 2
Media Suite 1	An improvement in air quality would seem to be the most immediate improvement in this space. The need is evidenced by the peak values and the narrative references to the "stuffy" atmosphere. Potential solutions to this could include both natural and mechanical ventilation.	The number pupils using the media suite was not measured, but may prove to be a useful measure. A larger area would both reduce crowding, air quality and circulation, but may not work commercially. A more innovative approach to the use of technology may provide more options to provide different teaching patterns of areas from media studies activities. Without this option maybe a better more regular spaced area would deliver a better performance.
Quiet Study Area 2	An improvement in air quality would seem to be the most immediate improvement in this space, peak values of over 6 times indicate a significant issue. This could include both natural and mechanical ventilation.	There are clearly concerns around the number of spaces for quiet study. The utilisation was not recorded but would be a useful observation. A larger area would both reduce crowding, air quality and circulation and potentially reduce noise which is clearly an issue for this type of space.
UCAS Office 3	None	None
Atrium 4	Solar shading and insulation on atrium glazing could alleviate some of the peak readings being seen by the sensors in terms of temperature. Thus is likely to be driving up the VOC readings as well and in more extreme seasons this is likely to become a larger issue.	An improvement in air quality would seem to be the most immediate improvement in this space. This could include both natural and mechanical ventilation, or if funds and planning allowed a more attractive solution may include the consideration of an oast to provide greater natural ventilation.
Room 30 5	The high levels of VOC would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation.	The high levels of noise may make a review of the spaces density desirable. The short term overcrowding may be OK in the short term but may signal a problem for the future. If density isn't the issue a review of acoustic damping may be an appropriate next step.
Common Room 6	The high levels of VOC would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation.	The high levels of noise may make a review of the spaces density desirable. The short term overcrowding may be OK in the short term but may signal a problem for the future. If density isn't the issue a review of acoustic damping may be an appropriate next step.
Café Kitchen 7	Check that extraction systems are operating as effectively as designed. High VOC and humidity may be a sign of poorly specified or operating extraction plant	Re-run the SOFI data collection process and be more specific about the segregation of location e.g. kitchen operative or café user. This may provide a deeper insight in to the performance of the facility.

	Potential Action 1	Potential Action 2
Room 7 8	Review the potential for the installation or use of existing blinds to reduce solar gain	Check if the space is used by unsupervised students as 90db is a very noisy environment and whilst the peak values were sporadic they did occur regularly.
ICT B 9	An improvement in air quality would seem to be the most immediate improvement in this space, peak values of over 13 times indicate a significant issue. This could include both natural and mechanical ventilation.	The lack of space will be adding to the high temperatures bad VOC as well as noise. Provision od more space allocate to the ICT activates or identification of other methods of delivering such a pervasive technology may be a more appropriate way forward.
Lecture Theatre 10	Check that the air conditioning and change rates are working as specified to try and reduce the peak VOC values	Single action space
HE Room 11	The high levels of VOC would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation.	Single action space

8.4 Findings from the Analysis

The findings from the analysis phase are summarised by the findings narrative shown in the following section. The experiment was based on the concept of using the building physics data as a control and the participant's perceptive data as the experimental group. This strategy has worked as it is possible to see both the control data and evaluate its validity as well as the perceived data as referenced to the control. This emergent delta value is the level of satisfaction and social capital that was or was not being achieved by the participant's use of the space.

8.4.1 Comments on Findings

8.4.1.1 Media Suite

Observation Results

Parent's observations may have indicated a lack of understanding of what the Media Suite was for. This was indicated by poor alignment of pupil and staff relationship scores. The pupils liked the space and the linkages between pupils and staff may underlie a better understanding of the potential of technology by pupils that staff. The better perception of the performance of the room may be due to the fact that space is so new to the community and represents such a significant improvement on the past (see Figure 8.14). The peak values for temperature and VOC were recorded in a mild time of year. The performance of the space in more extreme weather conditions may prove to be a significant issue especially as the narrative indicated a “stuffy” feel to the space already. Female respondents showed they liked the area better than male respondents. This may be because the shape and design of the space encourages a safe and inclusive feel. The Governors were more sceptical as to the room’s performance and may have external experiences which influenced their opinion.

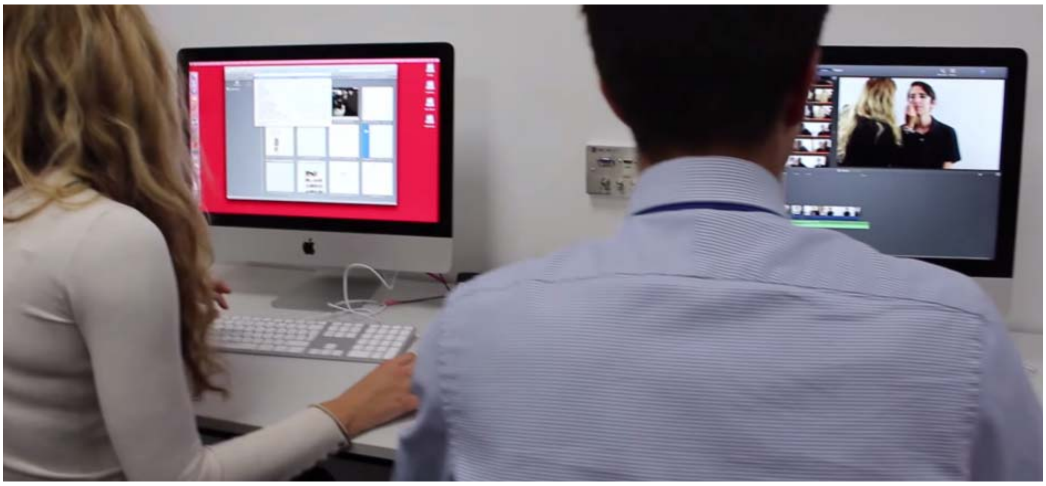


Figure 8.14 - Inside the Media Suite

Comments & Actions on Findings

Parents observations indicated a lack of understanding of what the Media Suite was for. This was indicated by poor alignment of pupil and staff relationship scores. The pupils liked the space and the linkages between pupils and staff may be identifying a better understanding of the potential of technology by pupils that staff. The better perception of the performance of the room may be due to the fact that the space is so new to the community and represents such a significant improvement on the past. The peak values for temperature and VOC were recorded in a mild time of year. The performance of the space in more extreme weather conditions may prove to be a significant issue especially as the narrative indicated a stuffy feel to the space in the data collected. Female respondents showed the liked the area more than male. This may be because the shape and design of the space encourages a safe and include feel. The Governors were more sceptical and may have external experiences which influenced their view. The concept of teaching media studies as a separate discipline is now considered as part of the normal teaching process of all subjects with multimedia being an integral part of the study. This approach may place less pressure on the performance of specialist spaces such as the Media Suite.

In terms of actions an improvement in air quality would seem to be the most immediate improvement in this space. The need is evidenced by the peak values and the narrative references to the "stuffy" atmosphere. Potential solutions to this could include both natural and mechanical ventilation. Secondary actions should consider the number pupils using the media suite as this was not measured, but may prove to be a useful indicator as some of the poor air quality could be due to overcrowding, identification of a larger area would both improve air quality and circulation, but may not work commercially. A more innovative approach to the use of technology may provide more options to provide different teaching patterns of areas from media studies activities.

8.4.1.2 Quiet Study Area

Observation Results

The parents are not direct users of this area so it was not surprising that there was little evidence of user level alignment. However, the strategic view of having a quiet study area was well thought of. The pupils like the quiet study area and the results show they had a lower connection with the staff in here. The teachers thought the quiet study area performed much better than the sensors actually recorded. This was borne out by the SOFI processed data and the peak performance data where at busy periods the noise rating reached 82 dB, which is about the average noise of traffic from inside a car. This in unlikely to cause and harm but is rather more noise than a teacher may expect from a quiet study area. There was not a major difference in the results for male or female participants, both scored their use of the space better than the sensors predicted. The narrative mentions that there were insufficient spaces for quiet study and that they were often over crowded, this would account for the high VOC readings from the sensors. The alignment of pupil perceptions may indicate an improvement in the old buildings facilities and their use of the space as a communal congregation rather than for quiet study. This would be supported by the very high VOC and noise levels. The low humidity and high VOC would not provide a healthy environment, with evidence of high bug transmission in these conditions.

Comments & Actions on Findings

The relationship connections and disconnections provide a useful benchmark to the overall results, with good levels of alignment as to what may be expected, i.e. lower levels of connection between parents and teachers to staff. However, there were interesting results regarding the noise and air quality with respect to the very high and sustained peaks. There was clearly a high demand on these spaces and future designs and potential modifications should consider changes to the specific design of these facilities.

Actions to consider for improvement are led by a need to make an improvement in air quality. Peak values of over six times indicate a significant issue which should be addressed potentially using both natural and mechanical ventilation methods. There are clearly concerns around the number and availability of spaces for quiet study. The utilisation was not recorded but would be a useful observation as it would appear anecdotally that it was very high at peak periods. A larger area would both reduce crowding, improve air quality and circulation and potentially reduce noise which was clearly an issue, especially for a space designed to be for quiet study.

8.4.1.3 UCAS Office

Observation Results

This area provided a set of results which was very complimentary, the physical results were all green, with good levels of connection and the social results were similar. In the hemispherical relationship report almost all areas were green. There were a few small areas of concern with the external community, but as this is a location which is unlikely to be occupied by this community it is unlikely to be of concern. There appear to be no significant issues.

Comments & Actions on Findings

The data presented from both the sensors and the users was very well aligned. This apart from being a very good result for both the users and the facilities team, provides a useful control data set to show that the Test Bench can provide an aligned set of results for a well operating space. There were no actions for immediate improvement detectable from the data.

8.4.1.4 Atrium

Observation Results

The atrium is clearly a massive improvement on any existing space in the school. It is light, open and modern, it is in the centre of the sixth from working space and acts as a very effective congregation and relaxation space. Not surprisingly the area gets very noisy but this may be an indication of success with people enjoying the facility. The feeling of a mini university environment with a cafe and soft furnishings is a vast improvement on past facilities and may indicate a reason for the high perceived results. The area may suffer from heat and cold in seasonal extremes, this could be confirmed in a longitudinal study.

Figure 8.15 - Inside the Atrium

Comments on Findings

This area needs to be reviewed in the light of a longitudinal study to see how it performs over time and across seasons. It is a critical social space and undoubtedly is a great asset to the school. As can be seen in Figure 8.15 there is a large area of glazing and the performance of this from an anti-glare and insulation point of view will be critical to the performance of the space throughout the year.

Areas for action identified solar shading and insulation on the atrium glazing could alleviate some of the peak readings being seen by the sensors in terms of temperature. This is likely to be driving up the VOC readings in peak occupation times and will become more extreme in the summer and winter seasons. This concern was identified in the second action which identified an" improvement in air quality make a large improvement in this space". This could include both natural and mechanical ventilation, or if funds and planning allowed a more attractive solution may include the consideration of an oast to provide greater natural ventilation functionality.

8.4.1.5 Room 30

Observation Results

This space seems to be on the surface providing an area that people like to be in. They have responded positively in all areas except communication. The sensor values also back this up at a tactical level with a matching green status. However the level of divergence increases as the questions become more strategic. If this is read in conjunctions with the peak sensor values this could indicate an area which is functioning well but is beginning to already reach its practical capacity. This is supported by the high VOC values and the high level of noise which is evident at busy times. It is not possible to verify any of these observations as there was not specific narrative provided for this area to provide deeper insights.

Comments & Actions on Findings

This room is also a quiet study area and while the current results are satisfactory the facility seems to be at its capacity. This may be an issue that could be managed through the school management processes whereby other spaces could be made available for study to reduce load and potentially enable levels of study interaction. Actions identified for improvements included a need to reduce the high levels of VOC. This indicates a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation, so perhaps a mechanical solution would perform better. Also the high levels of noise may make a review of the spaces density desirable. The overcrowding indicated by the peak VOC values may be satisfactory in the short term but may signal a problem for the future. If density is not a significant issue, a review of acoustic damping may be an appropriate area to investigate further.

8.4.1.6 Common Room

Observation Results

This room is clearly well thought of by staff and pupils but is operating at the boundaries of its design parameters, there is some interesting narrative which eludes to some operational issues, with the room being seen as a "bit of a distraction" and a "source of conflict". This maybe how the room is supervised or its agreed usage. The high VOC and low humidity could be due to the large amount of soft furnishings, but this does not explain the very peaky nature of the results which on closer analysis of the data may identify coincidence with high occupancy periods such as lunch time, breaks and study periods.

Comments & Actions on Findings

This is a new and different facility to any the school has provided in the past. A longitudinal study would provide a very interesting insight to this area, including future design criteria. Areas for improvement and actions were identified as once again as high levels of VOC would could indicate a lack of adequate ventilation or the fabric and paint products releasing VOC gasses. The fact that the peaks in values were coincident with the times people regularly congregate would however indicate a deeper design problem. Once again the high levels of noise may make a review of the spaces use and supervision necessary.

8.4.1.7 Café Kitchen

Observation Results

These results will be contaminated by the fact that much of the community would have answered from the point of view of a café customer not a member of the kitchen staff. The narrative comments provided and the perceived results indicate there is a high level of satisfaction, however the cafe staff were less convinced with lots of "don't knows" in their responses. The shape for the kitchen is rather odd and the optimum layouts for use may have been challenging to achieve. The high levels of VOC and humidity are not much of a surprise given the way the rest of the building has performed, but the low humidity may provide challenges for future cleanliness of the facility.

Figure 8.16 - The Café in the Atrium

Comments & Actions on Findings

The picture shown in Figure 8.16 is of the café from the atrium side (pupil/customer) looking into the kitchen, unfortunately this doesn’t show the challenging shape the architectural layouts have presented the kitchen staff. Clearly ventilation and high VOC are not desirable, but the "don’t know" views provided by the staff would require further investigation in the future, potentially with a longitudinal study providing new insights.

Actions identified should include an inspection of the extraction systems to ensure they are operating as effectively as designed. High VOC and humidity may be a sign of poorly specified or operating extraction plant, which should also be inspected. Also it may be beneficial to re-run the SOFI data collection process and be more specific in the questioning regarding the segregation of location eg kitchen operative or café user. This may provide a deeper insight in to the performance of the facility.

8.4.1.8 Room 7

Observation Results

This room is clearly challenged by temperature peaks and troughs which is confirmed by its south facing aspect and high potential for solar temperature gain. A vary rapid drop in temperature shown in the detailed sensor data indicates a high thermal loss through large areas of glazing and/or a lack of appropriate high performance insulation. The solar gain may also account for the high peak VOC values. The high peak noise levels may indicate there are periods of unsupervised student activity here.

Comments & Actions on Findings

Clearly some issues identified here require attention. The specification of the insulation and glazing should be checked as well as how the space is supervised and used. Identified actions documented a need to review the potential for the installation or use of existing blinds to reduce solar gain. There was also a need to check if the space is used by unsupervised students as noise peals of 90db is a very noisy environment and whilst the peak values were sporadic they did occur regularly.

8.4.1.9 ICT B

Observation Results

The significant peaks of thermal performance could indicate a lack of effective insulation, large areas of glazing (as described above) and / or significant peak loads through occupation and the use of computer equipment. The VOC readings also support this view with a thirteen times peak during heavy occupation periods. Noise is an issue which could be managed through supervision or the addition of acoustic damping. The positive perception ratings measured may be influenced by the honeymoon effect of the facility being a much better facility than was available before, but also indicate that the future capability of the space to meet future demands may be compromised. This is further evidenced by the narrative comments which identify a lack of capacity. This would also indicate very heavy utilisation and hence the peaks in VOC and temperature.

Comments & Actions on Findings

This room appears to be overloaded and very small for the type of work expected of it. It is possible with developments in low CO_2 technology heat dissipation will continue to reduce but the rate of VOC growth during use indicates a greater issue that would be solved by this approach alone. Actions identified an improvement in air quality as being the most immediate improvement for this space with peak values of over 13 times indicating a significant issue. This could include both natural and mechanical ventilation solutions.

8.4.1.10 Lecture Theatre

Observation Results

The provision of this type of lecture theatre is relatively rare in this type of school. It is a nice space as can be seen in Figure 8.17. It has mechanical ventilation and air conditioning and this is reflected in the air quality and comfort results. The acoustics work well and the comments gathered are positive.

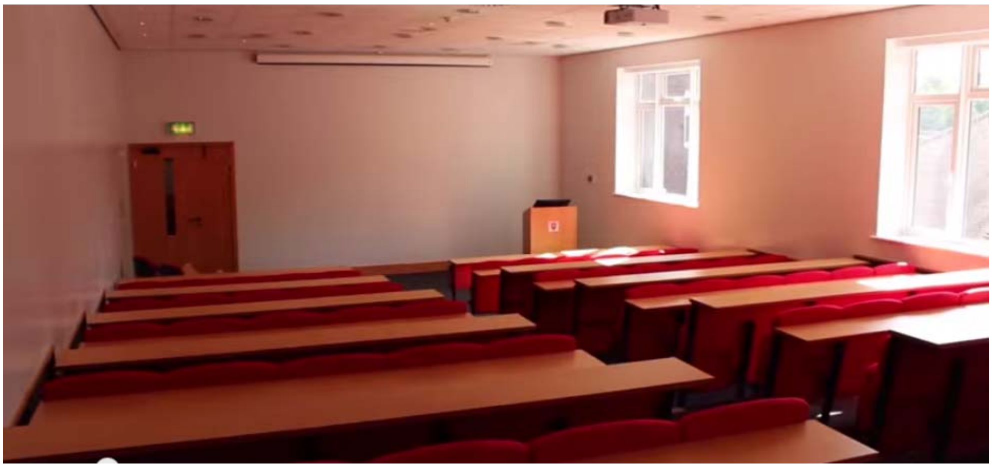


Figure 8.17 - The Lecture Theatre

Comments & Actions on Findings

This appears to be a well-liked and well performing part of the asset. The lessons of good air circulation and management should be learnt from here and applied in other areas of the school that fail to achieve these standards. The only action identified was to check that the air conditioning and air change rates are working as specified to try and reduce the peak VOC values during periods of heavy load.

8.4.1.11 HE Room

Observation Results

Both VOC and noise featured high on the list of potential physical recorded concerns in the HE Room. This was not related back into the perceived results particularly, this may be because the room is only occupied for relatively short periods of time and so the impact is not perceived readily. The noise peaks may be due to the collaborative and community activities undertaken in the space.

Comments & Actions on Findings

This space would need further investigation as its sensor data does not support its use descriptor which would indicate more senior students doing individual quiet study. However, the high VOC, noise and temperature values indicate a potentially higher utilisation. The action for this space should start with a review of the high levels of VOC which would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation as designed.

8.4.1.12 First Floor Sensors

Observation Results

The human perception of the new sixth form block is very good at all levels. The buildings physical performance with respect to brief is generally good with some extreme peaks and lows which whilst are OK with current loads may present challenges in maintaining high levels of performance in the future. The first floor performed better than the ground floor, there a number of potential reasons for this; including that fact that the area is new and is enjoying a "honey moon" effect. The data collected so far is for one non-extreme season so peaks and troughs in building performance may become more pronounced. The first floor has the "fun" areas including the cafe atrium and common room both of which are very well perceived.

Comments on Findings

The data supported a view that the new sixth form floor was well perceived by its users, to the extent that the deficiencies in its physical performance and its execution went mostly unnoticed by the users. This raises challenges to the long term performance of the asset, which could be better understood by a follow up longitudinal study and the effectiveness of the EfA briefing guidance which could indicate the brief and specification for similar assets could be reviewed. This may have the impact of enabling better performing school accommodation to be provided at a reduced cost, thus enabling more improvements to become fundable in the future.

8.4.1.13 South Sensors

Observation Results

This side of the building is warmer than the north side, this is likely to be through the greater light levels on the south side and greater general heat gains through solar gain making the south side generally warmer. This view is supported by anecdotal information gathered whilst walking around the building with staff on the north side more likely to be asking for the heating to be turned up.

Comments on Findings

Solar gain and shadow calculations should be run to test the effectiveness of the design against the actual values. Checks on the specification of the insulation and glazing should also be undertaken.

8.4.1.14 North Sensors

Observation Results

It is likely to be through the greater light levels on the south side and greater general heat gains making the south side generally warmer. This view is supported by anecdotal information gathered whilst walking around the building with staff on the north side more likely to be asking for the heating to be turned up.

Comments on Findings

Greater insulation and a review of heating system zones may be potential solutions to improving the performance and the perception of the north side of the building. Further strategies may include a review of lighting and use of colour in these rooms and spaces.

8.4.1.15 All Sensors

Observation Results

The sensors recorded generally good results at current tactical levels. However, the more strategic readings however indicate a number of areas such as longer term culture and development which may require some of the actions identified to be executed to provide long term effectiveness.

Comments on Findings

The school fails to meet the basic physical performance guidelines set out in the EfA literature described in Chapter seven. There are a number of likely reasons for this, including the need to build to a strict cost plan and the use of EfA guidelines in a private sector environment. The lack of available performance comparison data means that further research will be necessary over a longer term longitudinal aspect to evaluate these aspects.

8.4.1.16 Parents

Observation Results

Parents are not generally users of the school or its spaces, but they play a very significant part in key decisions for the wellbeing of the school, including a large part in the initial selection process for their children. There perceptive views are all very good as are the relationships between all parts of the community. There is a small issue of external communication which is an interesting score and may be influenced by some low scores in this area by some parents.

Comments on Findings

Good links support anecdotal evidence of good relationships. However, further analysis would be required to fully understand the aspects relating to certain low scores from some parents. It is possible a larger sample would help here.

8.4.1.17 Pupils

Observation Results

Pupils overall perceived the school in a very positive way, with a few uncertainties in the more strategic areas at the top of the SOFI model reports. Generally, the relationships between all parts of the community are good, with the exception of the relationship between programme and development. This may support the view that the school has an asset that suits its current needs but is already nearing its capacity to deliver future services. It is also interesting to see the pupils questioning the relationship between development and programme, which could indicate a disconnection between the application of modern technology and the delivery of educational services.

Comments on Findings

Good links support anecdotal evidence of good relationships within all of the community. The comments were positive and the pupils enjoy learning in their new facility.

8.4.1.18 Advisor

Observation Results

The perception of the advisor was difficult to interpret, it is not clear who this advisor is and what the role may mean in terms of perception. There are very few relationships between community and this may be due to the low sample level of that the advisor had not been in post long enough to establish relationships. The SOFI Map defaults state is to show all eleven spheres in a yellow, caution state. The first two actions are mapped as green links.

Comments on Findings

This result warrants further investigation as part of a follow up study. The sample of one was too low to draw specific conclusions and the exact nature of the advisor's activities and involvement are unknown.

8.4.1.19 Teaching Staff

Observation Results

The school community is well perceived by the staff. It is not as positive as that seen by the pupils but has a number of similarities. The key area of uncertainty is the development and innovation areas. This is possible due to the school being at an early stage of settling in with a number of new concepts such as the common room, atrium, lecture theatre and computer suites and these values will improve with time.

Comments on Findings

Good links support anecdotal evidence of good relationships, but as mentioned above a period of settling with a longitudinal study may provide new insights,

8.4.1.20 Male Respondents

Observation Results

Male respondents all have a generally positive response to the school. There was an issue at the external communication which was in the main from a response from a Governor. The general perception was measurably less positive than the females.

Comments on Findings

Good links support anecdotal evidence of good relationships. A longitudinal review may elicit greater insights over time.

8.4.1.21 Female Respondents

Observation Results

Female perception was very positive, but there were some areas of tactical uncertainty picked up by the perception measurements, these ae indicated by a larger area of blue in the maps when compared with the male respondents.

Comments on Findings

It was interesting that these results came to light, as they challenge the perception of male and female tolerance to comfort and temperature. These results do offer the opportunity to challenge the physical brief and how it could be adjusted to provide similar perceptive performance and enable lower cost of provision. It is also likely that a longitudinal study to this aspect could further understand this phenomenon.

8.4.1.22 Prefects

Observation Results

Prefects overall perceived the school in a very positive way, with a few uncertainties in the more strategic areas. Generally, the relationships between all parts of the community are good, with the exception of the relationship between programme and development. This may support the view that the school has an asset that suits its current needs but is already nearing its capacity to deliver future services. The prefect community did not appear to enjoy a significantly better relationship with the staff or other key relationships, however this could have been due to the high number of prefects in the pupil respondent sample.

Comments on Findings

Good links support anecdotal evidence of good relationships, with no further observations not already made about pupils generally.

8.4.1.23 Governors

Observation Results

The governors are infrequent casual users of the school buildings, but should be expected to have an excellent understanding of the dynamics of the school. The results are not as positive as other communities with a number of more tactical perceptions being amongst the lower scores. The communication perception was partially red, which may indicate a level of poor understanding or communication between the school and the governors, or this may be reflective of the amount of time governors can spend with the school. There were good linkages perceived by the governors but there was a missing link between school operations and school staff; this should be further investigated. The links between development, operations, planning and exemplary building were also poor. This is likely again to be through a lack of understanding between governors and the operations of the school.

Comments on Findings

Interesting results providing evidence of good relationships but a healthy external challenge, could benefit from further research, including longitudinal.

8.4.1.24 Departmental Heads

Observation Results

There was only one respondent in this area and this was a very positive view of the school at all areas. All links were in place and positive.

Comments on Findings

Good links support text context of anecdotal evidence of good relationships. It would have been useful to have a larger sample of data to provide greater insights to this important community.

8.4.1.25 Head Teacher

Observation Results

The head teacher was very positive in all areas and all links were in place. There was one area of uncertainty, which was in the area of development and innovation. This is probably due to the head teacher wanting to let the building settle into its operational cycle before looking for interventions to optimise and improve the service going forward. It was interesting to see the lack of confidence in the relationship between the organisation and design and the school staff, which would reinforce this point of view.

Comments on Findings

Good links support anecdotal evidence of good relationships. If the observations made around wanting to see the new asset settle into daily use the implementation of a longitudinal study would be of great value to explore how this has manifested over time.

8.4.1.26 Café Staff

Observation Results

There was only one café staff record and the feedback was generally positive, but suffered a lot of areas where there was uncertainty. There was also a lot of missing links between the various parts of the community. The most important was the lack of a relationship between the staff and building resources, indicating an opportunity to improve the kitchen area.

Comments on Findings

This relationship would indicate a number of issues which require further analysis and potentially immediate actions.

8.4.1.27 Office Staff

Observation Results

Office staff were very positive about life in the school. Key areas of uncertainty were programme, resources, planning and communication. There was a weak relationship between pupils and services.

Comments on Findings

Generally good links support anecdotal evidence of good relationships but the weak relationship between pupils and services could benefit from further investigation.

8.4.1.28 Librarian

Observation Results

There was only one respondent in this area and there was an excellent level of satisfaction at all tactical levels, but much confusion at operational amend strategic levels. There is also an uncertain link between organisation and staff. There was no link between exemplary building and building resources. This was supported by the narrative which indicated a need to have more library facilities.

Comments on Findings

Good links support anecdotal evidence of good relationships, with a predictable view on library provision in the current scenario. There are many opportunities to study how the library and media form an integral part of the learning process in the future.

First Floor Observers

Observation Results

The perception of the observers on the first floor was very good with positive links between all areas. The relationship between exemplary building and resources was very positive. This part of the building is all new and may benefit from the honeymoon effect.

Figure 8.18 - 1st Floor Corridor Space

Comments on Findings

Good links support anecdotal evidence of good relationships; a longitudinal study will provide further insights as the asset develops in use.

8.4.1.30 Ground Floor Observers

Observation Results

The perception of the ground floor was more uncertain with all strategic and operational areas having a high level of uncertainty. There is no relationship between exemplary building and building resources. This part of the building is much the same as the existing building but has benefitted from a refurbishment in the style of the new upper floor.

Comments on Findings

The ground floor space has attracted lower scores than the first floor, but due to the fact it is an existing space and does not have the attractions of the first floor such as the café and atrium (Figure 8.19) it is not surprising.

Figure 8.19 - Outside the building, with new atrium visible

8.5 Overall Findings

Each of the reports and observations delivered by the Test Bench and the SOFI system has enabled a complex set of data inputs to be analysed and used to provide direct repeatable measurements. The narrative above has been drawn for the full analysis shown in Appendix one. Table two. The analysis tools have allowed a direct relationship to be formed between social perceptive data and building physics data to give an insight as to how the two entities perform not only in isolation but together. These insights have allowed a manual inspection stage to identify opportunities for actions to further improve perceptive outcomes.

The results gathered have identified that the school building spaces performed poorly, the sensor data indicates that the spaces spend a significant part of the time, especially when loaded operating out of specification. However, this is counter to the results shown from the perceptive analysis, whereby the overwhelming view, especially from females is the school is a very satisfactory place to work and learn.

8.6 Summary

Chapter eight has demonstrated that the Test Bench can be implemented into a live working environment and effectively interact with both the physical and perceptive environment. Further to this the data collected through these activities can be processed to provide useful insights to how the asset and the community interacts and performs. This information can then be used to provide feedback and identify actions to improve the performance of the asset either physically or perceptively.

To establish if these actions do indeed improve the outcomes a further longitudinal study would need to be carried out, which is out of scope for this research. However, this and other future opportunities are discussed in Chapter nine, which also identifies research conclusions and other future research.

Chapter 9

Conclusions, Scientific Contributions & Suggested Future Research

9.1 Introduction

Chapter eight took the data provided by implementing the Test Bench described in Chapter seven and defined a data analysis and development process illustrated in Figure 8.1. The results of this process led to a set of recommended actions which could be implemented at the LND school to help improve the operation and the community's social perception of the school in operational use.

Chapter nine will reflect on these results and look across the research drawing conclusions and identifying areas of future research which could provide further insights and improvements in asset performance.

9.2 Holistic Reflection

This work has been focused on understanding the context and domain of the built environment that most effects the social wellbeing and behaviours of its users, measured through their perceptions of their surroundings. These have been measured and analysed with respect to the performance data gathered from the sensors inside the actual spaces and rooms where the participants work and live. The literature and industry review has provided a clear purpose and research questions to be formed and an experiment has been run to investigate in a real and live environment to provide data to support the research questions. The experiment has been undertaken by the development of a Test Bench to gather primary data through an experiment at the LND School, as well as being able to reflect on the available secondary data from the Education Funding Agency and other agencies offering advice on the design and specification of educational assets. The Test Bench using the SOFI analysis and double loop principles has provided a diagnostic tool to understand how the principles of requirements management described by Kiviniemi (2005), the BIM data development processes and existing data standards can be brought together and matched with user perceptive post occupancy data in an integrated way to identify actions to improve social outcomes and in the case of the experiment a more effective school. The process of reviewing the literature focused findings into a number of key themes which comprised the following list:

- Data related issues
- Process related issues
- Social Measurement or perception issues
- Tools and methods needed to bring the differing types of data together
- Types of analysis
- Time slice strategies

The impact of these themes are discussed here in the context of the Test Bench experiment. Complex data and data that are hidden in document or proprietary formats that are hard to process or understand are a characteristic of information in the construction industry. The fragmentation, the vast gulf of intellectual capability and distributed nature of the industry therefore set the context for poor data quality, low expectation and poor performing assets. The Government has set programmes of work to improve the standardisation and validation of data, but with the repetitive nature of reports from (Latham 1994), (Egan 1998) and (Wolstenholme 2002) the evidence of progress should be considered disappointing with respect to other industries.

The research question set out in Chapter one identified key areas of research required to establish a full understanding of the relationship between the physical and perceptive qualities of a built asset.

This was articulated by the aim of being able:

"To develop a methodology which analyses data from the briefing, delivery and operational phases of a built assets lifecycle and combines the user's perceptions of the assets performance to provide insights that can assist in the identification of actions that can improve existing and future assets to encourage a positive impact on people's lives"

To achieve these outcomes a set of research objectives were set to guide the subsequent research. These results of the research undertaken to deliver these objectives forms the basis upon which the following conclusions are based:

1. To establish the nature and structure of data processed throughout an asset's lifecycle. This work involved the research, documentation and analysis of the data management process for design, build and operations of physical assets, specifically relation to the elements which effect social aspects, specifically briefing. Analysis of the data entities and attributes through the literature review has shown relationships of design, delivery and operation attributes as well as onto future plans for the wider Smart City/Grid functionality. There is variance in approach and taxonomy, but the principle of designers identifying spaces and allocating systems to those spaces, delivery businesses defining the details of these systems and their operational parameters, followed by operational or facilities management businesses providing operational information holds good across the entire industry. This is evidenced by the work carried out by the UK BIM Task Group on COBie for infrastructure which has been integrated into BS1192:4:2014 (2014). COBie was selected to be the data schema for the Test Bench and was found to be adequate for the task of describing the physical and performance elements of the experiment, but required additional data entities to be established for the management of briefing and sensor data collection.

2. To establish the availability, nature and characteristics of human perception and methods for collecting data to record the perceptions. This work involved research, documentation and analysis of the data management process of social perception

aspects during the "in-use" phase of an assets lifecycle specifically those related to the user community and building space's. Social measures were found to be not well documented in the literature, very complex and provided little evidence of widespread implementation. The discovery that there are no current standards either domestically or internationally and that there are very few methods of gathering social or composite sustainability data indicates the state of the market and current thinking remains immature. Methodologies which were found, were exclusively drawn from sectors outside the built environment. This necessitated the development of methodologies to associate communities with spaces and zones. The number of methodologies which provided a holistic community view of the majority population using the space was limited to the SOFI system. This approach used double loop techniques to help normalise the perceptive data.

3. To identify methods which allow social perceptions and built asset physical performance data can be usefully analysed. This work involved identification of methods which could provide measurable comparisons between physical and social data to provide "actionable" opportunities to improve outcomes. The literature on how social wellbeing, perception measurement and outcomes can be observed and measured was very limited. For an area identified as being so critical to the benefit of society and places such a demand on public resources, the lack of critical understanding remains low. The human mind is very complex and is clearly beyond the scope of this research, but the effect of the built environment has a clear influence on how people live their lives and the quality of those lives. As described above the ability to measure these variables is far more challenging than the traditional measures of cost, temperature, CO^2 or floor space. However, based on the literature the following findings are supported. Poor building design and environment is linked to poor social wellbeing and performance. The work done by Shelter (2004 & 2007) demonstrates this very clearly. They also cite mental illness as a key reason for tenancy breakdown. Compared with the general population, people with mental health problems are twice as likely to be unhappy with their housing and four times as likely to say that it makes their health worse and James (2011) identified these relationships in his report on poor academic performance.

The ability to use space location and community relationship using the BIM and SOFI tools was a breakthrough. The links formed through location, space and relationship provided clear relationships which were used to provide feedback and actions to improve the performance of the asset or the impact of the building on its users to improve their outcomes not just at the level of the community but also the spaces each part of the community inhabited.

4. To develop a methodology that can be used to systematically process physical asset data and social perceptions. Discovering a data comparison between social and physical data schemas provided a basis for understanding how data needs to be processed (created, collected, used and presented) to provide useful insights and actionable interventions. The key concept here was the ability to provide a feedback loop (and double loop) to allow changes to be made and the data cycle repeated to re-evaluate the new criteria. The proposed processes we documented in the IDEF0 format and formed the basis for the design of the Test Bench. The Test Bench instantiated these designs when applied to the LND school scenario.

5. To determine how the outputs of such an approach can provide feedback that can be presented in an actionable format that can be used to improve existing asset performance and future briefing. The Test Bench as described above provided a range of analytical reports and data presentations which enabled a very full picture of the performance of the asset and the community perception in their various spaces. There were several reports and analytics which were demonstrated in the experimental instantiation. These include tabular observations and the coloured sphere icon reports, which provide a useful composite view of perception and physical record in a single page. These formats were of an appropriate nature to provide recommendations for actions in the form used.

   The usefulness of the data would have been made richer if the manual process was automated (as more iterations would have been possible) and if a longitudinal data set had been made available.

9.3 Scientific Contributions

In setting out to propose a new methodology for assessing how well built assets support effective social outcomes, it became clear that the current method of asset procurement does not incentivise the delivery of assets to provide adequate social outcomes. The behaviours encouraged by pursuing the least cost (capital) route lead to low sector investment and assets which fail to meet fiscal, functional or social needs. The slow take up of new approaches is partly due to the long-term nature of outcomes manifestation and the lack of agreed approaches or evidence to support more effective methods. During the process of research and the development of the Test Bench the following areas provided scientific contributions:

- Identification of physical and social data integration methods
- Development of a methodology to analyse physical and social data to enable feedback for improvement action
- Instantiation of the identified method

9.3.1 Identification of Physical and Social Data Integration Methods

The repeatable integration of quantitative and qualitative data is essential to the successful analysis of physical and perceptive data. Further to this, the relativity of the integration to space (area or zone within the asset) is necessary to identify specific functional performance. The lack of evidence for this integration in the built environment has encouraged practice that continues to support the delivery of poorly performing assets through the selection of suppliers on the least capital cost route and it was identified that any evidence elicited from a new approach would rely on a methodology which was reliable and repeatable.

It was found that data collected by sensors; collecting light, sound, VOC, humidity and pressure which were spatially referenced by a BIM model, could be used to compare performance against both the designed (briefed) design intent and the measured (perceived) reaction of the asset users and occupants. It was also found that user perception data collected using the SOFI analytics provided a data set that recorded the perception of the users within their own communities and those adjacent and related communities that go to make up the wider community of communities. It was found that the spatial location of these communities provided a common link to integrate the data sets to enable observations as to the performance of the asset.

The analysis of this data enabled information to be used to provide feedback as to how the asset was being used and potential improvements that could be made to the asset to improve its performance for future users.

9.3.2 Development of a Methodology to Analyse Physical and Social Data to Enable Feedback for Improvement Action

The identification of methods and its theoretical implications required the development of an application methodology. The development process of asset design, construction, handover, is well established. The process of asset briefing and measurement are less well implemented, if at all and the systematic linking with the occupants and users has no agreed or useable current methodology. These limitations create an environment unsuitable for the enabling of feedback and learning.

The methodology proposed identifies the shortcomings in the existing practice and identifies new approaches to achieve the desired approach. Key to this is the analysis of the integrated physical and social data into a presentation that can inform the asset owner and service provider and to enable a feedback process to provide enough context to be meaningful, using the double loop learning approach. The design of the methodology was developed into a working model in the form of the "Test Bench", which was used to instantiate the approach.

9.3.3 Instantiation of the Identified Method

The principles identified regarding data schema definition, integration methods and feedback enabled the development of a Test Bench. The Test Bench is a set of tools designed to implement a full-scale lifecycle test project simulation (experiment) undertaken in a live operational environment. This experiment was designed to facilitate understanding as to how the physical and social data can be processed, reviewed and used as feedback to identify actions.

The results once analysed indicated how the asset and its community performed with respect to each other in a series of identified spaces within the asset. This data was presented in a manner that could be interpreted by an asset user or operator. The experiment instantiated the approach, provided effective actionable items and provided definitive limitations to provide new opportunities for research.

The ability to be able to provide social community perspective data associated with spaces and zones enabled the possibility of investigating the nature of the impact on the asset and space on each part of the community in detail. The way in which people impact the asset and what they feel about it provided a repeatable score, which with further longitudinal studies will enable better and deeper insights and improvement strategies. The process of the instantiation activity identified that there are opportunities for the automation of many of the data collection and analysis processes.

9.4 Limitations of the Research

The results described above have shown that it is possible to bring quantitative and qualitative data together in the Test Bench and derive a useful and accurate analytic which supports many views of the literature in a repeatable and useful manner. However, there are several practical application issues that would require further consideration and development as part of further research or production development. Key to this would be a re-run of the experiment for a number of longitudinal studies to enable a deeper and more long term dynamic view of the data as the building performs through each season and the cohorts change with the academic years. This would give a control regarding the sensor data and would start to provide an insight to the "honeymoon" effect that could be influencing the first academic year of pupils currently using the asset who provided a perceptive result that is somewhat more optimistic than the building physics results may have predicted.

Other areas to be considered in the application of the Test Bench are:

The management and definition of the questionnaire; due to limited support resources and the experimental nature of the research, there were several issues encountered in the delivery and management of the perception gathering process using the SOFI system. The

SOFI model requires a procedure to test thirty-three reciprocal relationships. Further experience in the design of the questionnaire would accelerate the implementation process. This would maintain the reliability of the questions and the reciprocal nature of the double loop function while eliminating questions that could appear to be repeats. In a developed form, there are several potential improvements that could have been added to the implementation process, including the use of handheld technology and analytics to improve the specification of questions or the potential use of wearables to sense data. The commercial version of the SOFI system features the possibility of gathering input data in different ways using a longitudinal questioning approach over a much longer period and by using data acquisition technologies in the school itself. This approach would have the benefit of gathering data even closer to its source and targeting inputs for the different spheres of activity to targeted audiences and data sources, so selected participants would be responding to a small number of questions at a given time.

Selection and provision of sensors; the selection of the Cube Sensors for this research was reflective of the low availability and reliability of building management and operational systems. To insulate this from the research the stand-alone sensors offered an effective alternative strategy, however this strategy is only effective if the data is used as a comparator rather than an absolute value. The complexities of calibration and sensor sighting are well documented but remain out of scope of this research.

The analysis is multi phased and has a lot of manual functions; this would be a barrier to wider adoption. It also relies on the analyst having a relatively high level of capability and understanding of the asset and its detailed design and the design process. Much of this could be automated to provide better productivity, it would also potentially be better from a bias point of view, with any bias embedded across all data samples to offer a level of continuity.

The life span of a built asset can vary from 30 to 130 years depending upon the nature of the structure and services expected of it. Indeed, many structures are many years older than this and still provide useful accommodation. The use of assets to meet the need of the users also changes. In the experiment the changes in teaching, particularly through the use of technology have had a dramatic impact on how students are taught and where they can derive useful information. No longer is the library the font of all knowledge the internet and multimedia services provide a much wider scope and this effects the design and usage of the buildings. This was evidenced by the results of the Media Suite being over used and crowded and highlighted the need for providing such services across the entire building.

The Test Bench showed how data could be used to provide a set of potential actions. If the Test Bench was run again periodically it would over time show trends and impacts of the actions identified over time. Further it would provide a record of the changes over time allowing the management team to plot changes and inform future strategy, or apply similar actions to other parts of the school. The overall methodology would benefit enormously from a longitudinal process, enabling the Test Bench to have a direct record of the impact of the actions.

9.5 Recommendations and Further Research

The research instantiated here by the Test Bench has identified key areas of learning, contribution and limitations. The following areas were identified as being key to providing the next key areas of understanding:

- Improving the collection of community perceptive performance information
- Providing effective data for physical measures
- Definition as to how the analysis process can be automated
- Implementing a longitudinal approach

9.5.1 Improving the Collection of Social Perceptive Performance Information

The methodology for collecting the social perception performance was collected using a paper and electronic questionnaire, based on a cross sectional strategy. This provided two challenges, the first was the cross-sectional strategy was compromised by the time needed to collect the data, which could have allowed events to contaminate the data. This would have been exacerbated by the relatively low sample of respondents. An increase in numbers would have allowed a higher level of certainty.

The experience of getting the community to fill in the questionnaires either on paper or on line was more challenging than may have been expected especially from an educational community. There were a lot of questions and because of the double loop nature of the questions many seemed similar. These may become better with experience and more research, but a useful extension would be the identification of other methods of gathering this information through alternative methods. These could include data harvested from mobile phones, cars and wearable technologies. This approach would also open opportunities for ongoing longitudinal studies which could go much wider than the performance of single assets, by allowing deeper understanding of the performance of businesses and networks of assets and services.

9.5.2 Providing Effective Data for Physical Measures

The acquisition of consistent reliable data to record the performance of the physical attributes of a built asset remains challenging. The availability of standards relating to data formats, calibration and sensor location provides many opportunities for poor interpretation from low quality data. The use of the Smart cube sensors provided sufficient data to provide the Test Bench instantiation but the lack of calibration and evidence for repeatability would limit the usefulness of this data. The challenge of sensor location especially in an open public space also makes direct detailed comparisons difficult without a normalisation strategy.

9.5.3 Definition as to How the Analysis Process can be Automated

The task of data processing in the Test Bench was only partially automated. This was inevitable as the Test Bench was only conceived as a tool for the purposes of instantiating this research. There are however several opportunities to improve the processing of data and management, these are summarised as:

- Data collection
- Data storage
- Data analysis
- Information presentation

Data collection used three instruments; BIM, Sensors and SOFI. These instruments were used to create and manage data. The BIM outputs were standards based, the remainder were converted from proprietary sources. The lack of standards, or low maturity in standards for data exchange provides an uncertain environment for reliable data exchange. The validity, provenance and security of the data all require future research and application before being viable in the open market.

Data storage identified a number of issues using a relational database technology and the lack of flexibility and would likely provide a situation where scaling up may provide some issues. The storage of the social perception was maintained in the SOFI database, with the results passed to the impacts entity of the COBie schema. The volumes of the cube sensor data in common with other IoT applications was vast and if an asset was fully instrumented a viable data management strategy would need to be developed.

The data analysis was provided in three ways; report queries from the Test Bench database, SOFI reports and manual inspection and review. The automated reports made it easy to analyse and repurpose the data, however the manual inspection especially once the two data types have been integrated is time consuming and difficult to provide on a repeatable basis. The approach requires technical knowledge and will be effected by the analyst's experience and capability. The approach also in effect creates another subjective dataset which is open to interpretation, the exact position we seek to remove. (Argyris 2002) identified a team of trained scorers were needed to analyse the data, he argued that this approach would maintain the scientific integrity, validity and reliability of the analysis. However, if the process could be automated using an inference engine or other artificial intelligence technique the repeatability and rate at which assets could be analysed could increase enormously.

There are also different types of analysis that could be applied to the data once it is gathered. One such approach could be the application of Space Syntax type analysis. This approach offers an interesting insight to the potential of converging the two approaches, with a further double loop being calculated showing dependencies and potential optimal performance models. The dependencies could indicate insights about which variables have stronger ties with all other variables. This will help us know what to prioritise in the data and relationship model. A smart network variable could also be added to the network to see how they relate to existing infrastructure, adjacencies or crowding. This is an interesting opportunity which should be researched further. To illustrate this in Figure 9.1 shows a Zeroth Order Pearson's Correlation Matrix to produce an undirected network. The method was used previously in a paper by De La Fuente et al (2004) and used to develop a paper co-authored by the author and Al Sayed et al (2015).

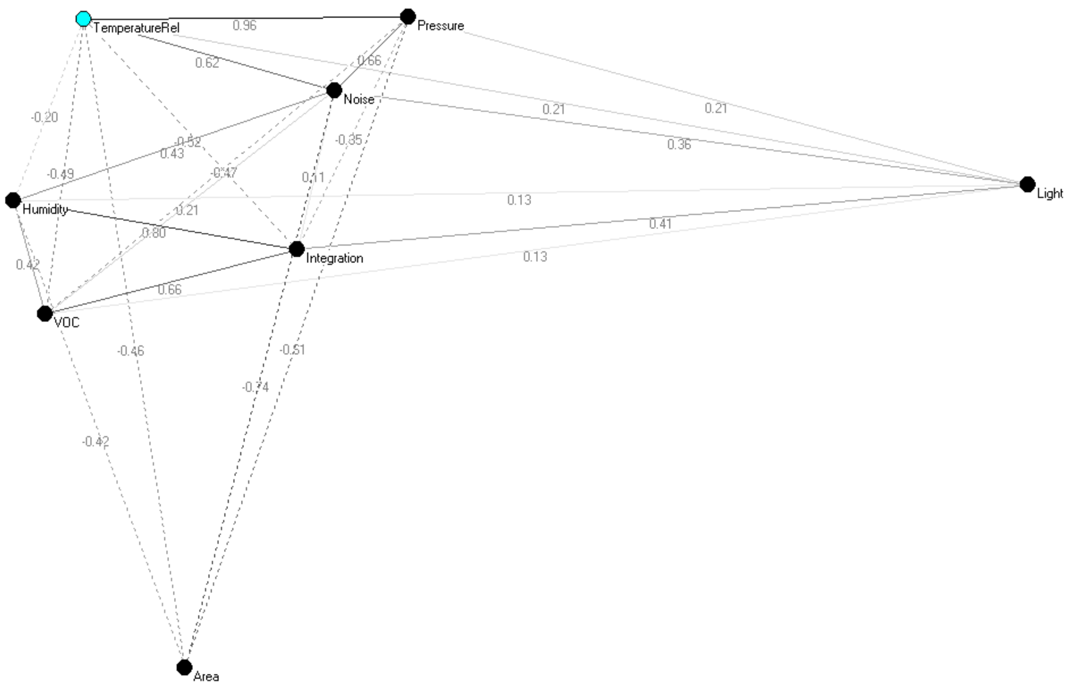


Figure 9.1 - Performance Dependency Network

9.5.4 Implementing a Longitudinal Approach

The establishment of a physical and perceptive dataset and the ability for that dataset to be used and informed by the double loop process has elicited a very rich and powerful information source. However, the limitations of a cross sectional dataset of a vibrant community occupying an asset with a design life of maybe fifty years is clearly going to have limitations. These limitations could be usefully addressed by the implementation of a longitudinal element to the research. The Test Bench and the SOFI system are both capable of this approach and it is a clear recommendation that this should be undertaken. The changing needs of users and the performance degradation over time of the asset are all key to providing a long terms sustainable environment for wellbeing and good social outcomes.

9.6 Conclusion

The purpose of this research was to develop and instantiate a methodology which processes data from the delivery and operational phases of a built asset and with the aid of understanding the user community's perceptions and create intelligence that can optimise the asset's performance for the benefit of its users. The scope of the instantiation was limited to that of an educational asset, however I believe that many of the principles would be applicable to any type of asset.

The main scientific contributions of this research are the identification of a set of methods which provide valuable and effective relationships between physical and social data to provide "actionable" interventions for performance improvement and the instantiation of this discovery through the development and application of the "Test Bench".
The major implications of this research has been to develop a testable relationship between social outcomes and physical assets, which with further development could provide a valid challenge to the least cost build option that is taken by the vast number of asset owners. The cost of staff and resources outweighs the cost of an assets very rapidly and the effective motivation and productivity the right environment can provide or inhibit will challenge the capital focus on cost. The integration of the process into the BIM and briefing activities enables the approach to be adopted in an incremental basis making adoption more achievable.

This research has opened up a wide range of potential future research activities. There is a need to apply a longitudinal test to the approach and to apply the process to a range of different assets, to provide a more diverse and adequate statistical sample of data. The tasks undertaken through manual inspection also require automation into the double loop process, which could provide a fully automated feedback and digital briefing process.

The use of building and community models will change the tasks and processes used in designing and developing assets in the future. The Test Bench is a working example of this model based approach.

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Appendix 1 - Data Results

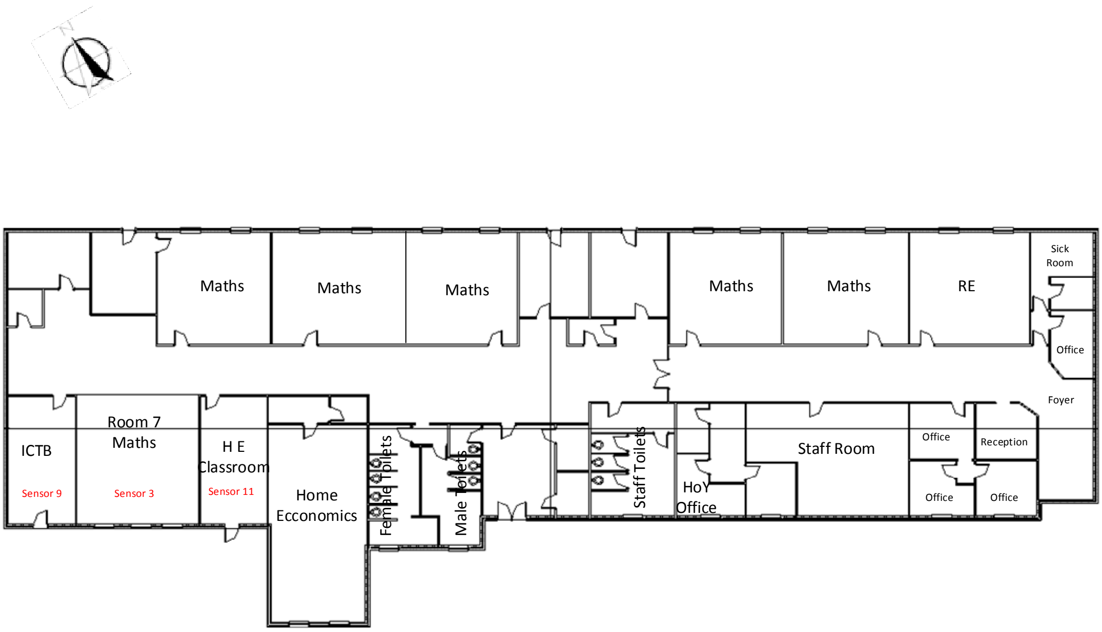
The information collected from both the physical and social data collection tools creates a vast data set held in the Test Bench database. For the analysis and conclusions this data was processed and presented in formats that allowed the user of the system to interpret effectively. Due to the quantum of data only representative samples are presented here in this Appendix. In each respective section there is a narrative that explains the data, its formats and where access has been provided for the full datasets. Clearly the social data has security and ethical constraints which are considered. Schedule of Information and Data

1. Physical data
2. Social Data
3. Analysis

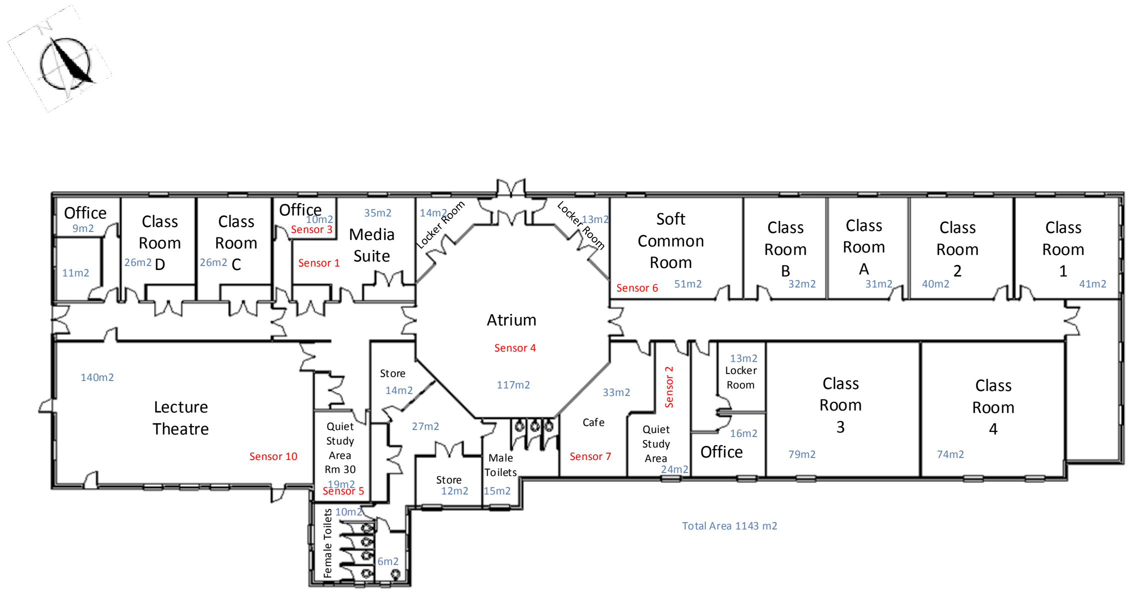
1. Physical Data

Building Physics data has been gathered over a representative period in a range of locations to sample the range of performance the building is capable of. The sensors have been located in the spaces indicated at normal desk height out of direct sources such as windows and radiators to provide consistent results. Sensor locations are as indicated below.

Ground Floor Layout



First Floor



The data produced by the sensors is held in delimited string transactions created one a minute. These are summarised and presented as a period record as can be seen is Table 3. These Tables show by day each transducer reading from each sensor in terms of high, low and average values. This peaks values are also shown for working hours only as well as peaks high and low. In each case the same data is plotted against time.

Table 4 takes the peak values for each sensor and with the actual as built space data is used to answer the physical SOFI queries. These are displayed as the RAG values which are transposed into the SOFI tool, there is a page for each sensor and set of questions.

2 Social Data

The social data is gathered through the SOFI questionnaire process and is held in the SOFI database. The records are available but will not be circulated as they contain data which would enable the identification of the individuals who submitted the data. At the end of the research process this low level primary data will be destroyed in line with the commitments made both with the school and the University ethics strategy.

Table one shows the aggregated scores from all respondents of the survey process. The data shown incudes the score themselves and the text narrative that provides valuable evidence to support and validate the conclusions.

a. Analysis

The information in Table two is all of the visual analysis of the results. Every nodal intersection of a physical or social interaction has a comment and observation. The result of this information provides material for identifying "actions". There are two actions suggested per physical space.

The next three sets of results Tables contain the outputs from the SOFI analysis process. Table four contains the "Sensor Influence Maps" which are the results derived from the calculations in Table thee. Table five presents the same report but with the information from the social dataset, showing the "Perception Influence Maps".

Finally, Table six shows the "Combined Hemisphere Maps" which compares the social and physical data on one sheet per intersection.

Copies of all datasets are available as part of a digital archive described in Appendix four.

Table 1

Aggregated survey data results report from SOFI report generator.

How do you feel about the way that your school building serves you and your local community?

Red = 0 (0%) Yellow = 1 (4%) Green = 22 (96%) Blue = 0 (0%)

The school building encourages good access and relations between pupils and staff. - impacts (School Staff)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"The new school building provides a great environment for the pupils"
"The grounds are beautiful. We have great facilities. The buildings are well-maintained and fit for purpose."
"Staff room accessible for all pupils."
"The teacher's offices are interspersed among the classrooms and therefore easily accessible."
"School offices are located at the entrance to the 6th form centre."
"The atrium cafe is always buzzing with staff and pupils chatting and mingling"
"The atrium is a good space for socialising"
"Atrium cafe"
"With teachers in one place students have ground access"
"Plenty of space, modern"
"Not used by my subject or myself much"
"Staff offices are light and clean"
"Lovely wide cafe area for 6th form"

Suggestions:

"The question is a strange combination. By access do you mean entry? Or making use of the buildings? Either way I am not sure how "access" is related to staff/pupil relations"
"The PE department is a fair distance away from the rest of the school and with the time demanding nature of a PE teacher's role this means there is not always much interaction between PE members of staff and other academic staff members. This also has implications on teaching time for PE lesson both academic and practical."
"Doors left open"

Pupils have enough space in the school to meet their needs. - impacts (Organisation & Design)

Agree	17 (74%)
Disagree	4 (17%)
Don't Know	2 (9%)

Evidence / example:

"There are many more class rooms than in the old building"
"This is more related to the lack of actual silent study that isn't cramped/noisy etc"
"I have sought feedback from pupils directly who have given positive responses to the amount of space in the building."

"The classrooms are large and airy and there are plenty of 'breakout' spaces."
"Not Always. Study Room does not accommodate enough students. Some go and work elsewhere which is hard to supervise."
"Lack of lunchtime space"
"Space for socialising and working"
"Some class rooms very small"
"6th form is overcrowded."

Suggestions:

"I agree, except on one point - I don't think there's enough IT space"
"Common room areas"
"Additional study areas have to be found"
"we need a career room and a much larger library"

Pupils enjoy using the school building for learning. - impacts (Programmes & Services)

Agree	17 (74%)
Disagree	0 (0%)
Don't Know	6 (26%)

Evidence / example:

"People seem very happy at LND"
"The Sixth Form centre is enjoyed by all its users"
"The number of pupils staying at LND for the sixth form is the highest proportion yet."
"The facilities are excellent, the environment conducive to teaching and learning. The lecture theatre in particular is an excellent space for learning"
"Sixth form students studying after school"
"the library is always busy"

Suggestions:

"although again there is not enough IT provision"
"Some are happy some are not"

How do you feel about the school Staff's use of the building?

Red = 0 (0%) Yellow = 1 (4%) Green = 20 (87%) Blue = 2 (9%)

The school building design helps teachers and staff meet the needs of the pupils - impacts (Pupils & Community)

Agree	20 (87%)
Disagree	0 (0%)
Don't Know	3 (13%)

Evidence / example:

"It's a great feeling environment"
"The building was purpose built so considerations must have been made in this respect"
*"*Didn't tick any box* "*
"Plenty of space for both"
"Specific 6th teaching space. Sense of 'space'"
"Light, airy, modern classrooms built for purpose"
"Big airy classrooms: Art Room is

beautiful and inspires creativity"

Suggestions:

"Another exception would be Library provision. If funding had been available, a Sixth Form Library would have been ideal. The current Library in Le Clerc is particularly badly designed"
"Plans for music room"

The school design enables staff and teachers make effective use of the space and facilities to deliver their programmes and services. - impacts (Organisation & Design)

Agree	20 (87%)
Disagree	0 (0%)
Don't Know	3 (13%)

Evidence / example:

"The new school appears much better"
"The quality of the classrooms and the lecture theatre including equipment are excellent."
"Each subject has different needs"
"Some of the layout of the 6th form room is not efficient"
"As a growing school we could always do with more space but existing site is lovely"

Suggestions:

"Again there's an IT requirement which is not fully met."
"More science labs"

Staff and teachers use the school building in creative, energy efficient ways. - impacts (Programmes & Services)

Agree	7 (30%)
Disagree	3 (13%)
Don't Know	13 (57%)

Evidence / example:

"It is cold on the north side sometimes i understand and it is not clear how much use is made of renewables and what the further potential could be"
"TimeTable drives usage"
"Certainly creative but unsure of energy efficiency"
*"*Has ticked [AGREE] and [DISAGREE]* "*
"Student could close doors to outside areas"
"Teaching happens in classroom. I don't think this is creative."
"The new 6th work overheats...and staff leave PCs and projectors on.."
"Agree but many areas are still 'white' walls."

Suggestions:

"They could have student work/art on them"

The staff find the school building easy to use and operate. - impacts (Development & Innovation)

Agree	16 (70%)
Disagree	0 (0%)
Don't Know	7 (30%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"I presume so"
"Easy to move around and an area accessible from a central atrium"
"Built for purpose"

Suggestions:

None

The building works well and supports staff needs. - impacts (School Operations)

Agree	16 (70%)
Disagree	0 (0%)
Don't Know	7 (30%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"The cafe certainly was a welcome addition"
*"Overall yes, with the odd niggle (as above *question 7 on paper*)"*
"Spacious offices"
"Open spaces, large airy classroom, etc."

Suggestions:

"Except I cannot really speak for the needs of other staff, particularly science specific or PE"
"A photocopier, colour printer and a number of computers for pupils in the PE building would be a huge help."

Staff and teachers make good use of school resources. - impacts (Building Resources)

Agree	18 (78%)
Disagree	0 (0%)
Don't Know	5 (22%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"Cafeteria. "
"Auditorium in the Sixth Form."
"Everything is used much of the time - few wasted resources"

Suggestions:

"Set of iPads underutilised due to lack of training, although this is being addressed"

How do you feel about the quality of the school building design?

Red = 0 (0%) Yellow = 3 (13%) Green = 19 (83%) Blue = 1 (4%)

The school building design enables the policies and processes of the staff to effectively deliver the needs of pupils. - impacts (Pupils & Community)

Agree	13 (57%)
Disagree	0 (0%)
Don't Know	10 (43%)

Evidence / example:

"I am not a member of staff I am a

parent so I don't know"
"Supports curriculum delivery"
"Broadly good, with somethings that could be better"
"Easy access to whole school"

Suggestions:

"I don't mean to be rude but the question doesn't make sense to me!"
"Bigger whiteboards and position of TVs"

The quality of the school building and its systems helps me carry out my tasks. - impacts (School Staff)

Agree	16 (70%)
Disagree	3 (13%)
Don't Know	4 (17%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"There are points where I agree and points where I disagree."
"As a parent I can see the quality of the facilities which helps me decide whether I want my children to attend 6th Form at LND. As a Governor I can demonstrate the quality of the facilities to guests."
"N/A"
"It is a pleasure to teach in new 6th form"
*"N/A *Did not tick any box*"*
"Use of facilities"

Suggestions:

"The design of the Library is such that it can never be effectively designated as an area for quiet learning and study."
"Lack of a single teaching room per teacher is a pain"
"Printer issues as well as wifi is networks"
"Atrium and Lecture Theatre"

The building provides enough rooms and spaces and I can move easily between classes. - impacts (Programmes & Services)

Agree	16 (70%)
Disagree	4 (17%)
Don't Know	3 (13%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know but class size seems ok, with the exception of the rooms which have been sub-divided"
"More related to the fact that lower years stand in the middle of narrow corridors when waiting for lessons"
"In terms of the whole building I agree."
"The circulation space is fine."
"In the future, additional classrooms may be required"
"N/A"
"Some rooms are cramped"
"but I think the 6th Form suffer from overcrowding and lack of

study areas"

Suggestions:

"However, the Library is too small; it cannot house what it should be able to"
"There should be more quiet spaces which are a little tucked away so we can have a place where if quiet is needed, there is a place you can go."
"More classrooms would be ideal though unlikely"
"Schedule smaller classes in those rooms if possible"

The school building design encourages innovation and creativity. - impacts (Development & Innovation)

Agree	10 (43%)
Disagree	3 (13%)
Don't Know	10 (43%)

Evidence / example:

"I wouldn't say it either encourages or discourages"
"I have seen the pupils appear inspired by the new surroundings, in particular the lecture theatre in which they give presentations of their ideas - and they want to do well."
"It is better but can still improve"
"New facilities encourage new methods but also require flexibility (push +pull)"

Suggestions:

"We could do with an exhibition area"

The school is always clean and ready for us to use. - impacts (School Operations)

Agree	21 (91%)
Disagree	1 (4%)
Don't Know	1 (4%)

Evidence / example:

"The school always appears well kept and clean"
"Again, more related to lower years crushing cake onto the carpet at lunch - it's always cleaned up though"
"It has always been very well presented whenever I have been there."
"Grounds are well maintained"
"It is kept beautifully clean by the relevant teams"
"Excellent cleaners and maintenance staff"
"Cleaners do a wonderful job"
"Maintenance do a wonderful job and catering"
"Standard of cleanliness is very high, both inside and out"

Suggestions:

None

The building creates a highly effective environment for learning. - impacts (Culture)

Agree	17 (74%)
Disagree	2 (9%)
Don't Know	4 (17%)

Evidence / example:

"The results seem to be good"
"The classrooms are good."
"Noise and temperature an issue"
"Not always, dead for quite study if study room is full"
"6th form promotes a studious attitude, although common room is a hit of distraction"
"built for purpose"
"It's peaceful, in a beautiful setting and a lovely place to work"

Suggestions:

"In the summer the classrooms we were in were very warm so I wonder how the temperature is regulated on hot days to ensure the pupils are not uncomfortably hot."

How do you feel about the way school programmes and services use the building?

Red = 0 (0%) Yellow = 4 (17%) Green = 15 (65%) Blue = 4 (17%)

The school building has enough space to offer the programmes and services that meet the needs of the pupils. - impacts (Pupils & Community)

Agree	15 (65%)
Disagree	4 (17%)
Don't Know	4 (17%)

Evidence / example:

"The rooms that have been sub divided seem too small"
"Huge range of extra-curricular activities available"
"The building meets the need of the current intake."
"Auditorium sound is poor"
"Agrees on the whole. Exam time spaces are very busy and there's not always a space to hold an assembly. Not a massive issue though."
"Broadly, there is enough space. Some rooms struggle to accommodate classes"
"6th form issue again"

Suggestions:

"A smaller PE room for A level classes with computers. As currently if there is 2 academic PE classes running at the same time we use a non-specialist room."
"By programmes I am presuming you mean lessons, extra-curricular activities, sporting opportunities. We don't have a swimming pool. We would never be able to provide boarding facilities which caps fees and thus the funds available to the school"
"Significant expansion to meet higher demand for places would not be possible."
"We could do with a larger library

and a careers room"

The school building enables our teachers and staff to support the programmes and services offered to pupils properly. - impacts (School Staff)

Agree	17 (74%)
Disagree	0 (0%)
Don't Know	6 (26%)

Evidence / example:

"Evaluate future needs"
"The light, airy environment in 6th form is good for teaching and learning"
"modern, spacious classrooms"
"I think library/careers room really needs considerations"

Suggestions:

None

The schools design and layout makes it easy for staff to deliver effective programmes, services and teaching. - impacts (Organisation & Design)

Agree	17 (74%)
Disagree	1 (4%)
Don't Know	5 (22%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"Having related lessons near each other in some block is good for promptness and preparation"

Suggestions:

"More classroom space in rooms helps"

The school programmes and services make creative use of spaces, facilities and technology available in the building. - impacts (Development & Innovation)

Agree	15 (65%)
Disagree	1 (4%)
Don't Know	7 (30%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"Sometimes driven by circumstance"

Suggestions:

"Moving towards Apple TV in rooms helps"

The school has been able to design excellent programmes and services with the resources the building and spaces offer. - impacts (Building Resources)

Agree	17 (74%)
Disagree	1 (4%)
Don't Know	5 (22%)

Evidence / example:

"The range of A Levels offered is excellent."
"Maths is excellent"
"The school is developing not sure if the buildings fit the programme or if it is the other way round"

Suggestions:

None

The school building helps us have programmes and services that enable an inclusive positive culture. - impacts (Culture)

Agree	17 (74%)
Disagree	2 (9%)
Don't Know	4 (17%)

Evidence / example:

"They seem to"
"The quality of the facilities have had a very positive impact - demonstrated by the high demand for places in the 6th form from internal and external candidates. The building is DDA compliant."
"Location and grounds help"
"Atrium particularly attractive as a gathering area. Very popular."
"The various common areas are used extensively"
"It's easy to look into classrooms and see what's going on around the school"

Suggestions:

"I think we promote respect for others and recognition of diversity but I have no idea how this is relevant to the building"
"Media club due to more space, more inclusive"

Do you feel the school building is innovative?

Red = 0 (0%) Yellow = 2 (9%) Green = 16 (70%) Blue = 5 (22%)

School building innovations and systems training help create an effective work environment for teachers and staff. - impacts (School Staff)

Agree	12 (52%)
Disagree	0 (0%)
Don't Know	11 (48%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"Needs research"
"It's a nice building to work in."
"Open, clean and airy"

Suggestions:

"I am unaware of training on school building systems. "
"I am also unaware of ground-breaking innovations utilised by this school building"

The school building facilitates the effective delivery of everyday learning. - impacts (Organisation & Design)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"The natural light and interior design is inspiring for students."
"For the present"
"Light and airy, clean and modern"
"Overall a good atmosphere has been created"

Suggestions:

None

The school building helps teachers deliver high quality teaching. - impacts (Programmes & Services)

Agree	16 (70%)
Disagree	3 (13%)
Don't Know	4 (17%)

Evidence / example:

"Teachers are excellent"
"If the lectures are comfortable, I assume this facilitate high quality teaching"
"The space is good for teaching, apart from large classes in smaller rooms"

Suggestions:

None

The school building enables up to date teaching methods to be used. - impacts (School Operations)

Agree	18 (78%)
Disagree	1 (4%)
Don't Know	4 (17%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"The equipment supports teaching methods."
"e-learning will increase"
"Apple TV allowing an increase of iPad use"
"What is an 'up to date' teaching model? IT is certainly used"

Suggestions:

"Wifi can be reduced in areas away from the main school building."

School class rooms are light, airy and comfortable. - impacts (Building Resources)

Agree	20 (87%)
Disagree	1 (4%)
Don't Know	2 (9%)

Evidence / example:

"The small rooms and media suite are small and stuffy when I visited"
"Some are"
"Absolutely"

Suggestions:

"The Library is always cold!"
"Good overall, need more ventilation in heat of summer"

We have a building that allows staff to provide imaginative teaching. - impacts (Planning)

Agree	13 (57%)
Disagree	0 (0%)
Don't Know	10 (43%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"I think a teacher can be imaginative if they taught in the open air"
"Can use a range of delivery methods"

Suggestions:

"(It's imaginative)"
"This isn't down to the building but the space is fine"

The school has developed an effective communications system throughout the school building. - impacts (Communication)

Agree	14 (61%)
Disagree	3 (13%)
Don't Know	6 (26%)

Evidence / example:

"This has nothing to do with the building though"
"Not sure what this is asking - we can hear the fire alarm?"
"Yes - it is very good and the TV screens in hall are excellent"

Suggestions:

None

The school building design has helped us develop activities and events that contribute to a positive school culture. - impacts (Culture)

Agree	20 (87%)
Disagree	1 (4%)
Don't Know	2 (9%)

Evidence / example:

"Sixth Form Centre"
"The opening ceremony and lecture was a good example."
"However concerts, plays etc need a better space"
"Lunchtime talks in the lecture theatre"
"The move to new buildings, fresh decoration etc, has been good"
"Sense of 'special' for lower classes to be taught in 6th block. Lecture/theatre allows more formal/university type lecture atmosphere"
"Lovely hallway with posters, bunting, etc."

Suggestions:

"Dump Mental Health Awareness Week"

How do you feel about the day-to-day running of the school building?

Red = 0 (0%) Yellow = 1 (4%) Green = 22 (96%) Blue = 0 (0%)

Day-to-day operations of the school building help teachers and staff work effectively. - impacts (School Staff)

Agree	19 (83%)
Disagree	1 (4%)
Don't Know	3 (13%)

Evidence / example:

"I am a parent not a member of staff so I do not know"
"Noise, heat and split campus do not help"
"Overall agree but some 'rules' are flexible"

Suggestions:

None

Day-to-day operations of the school building comply with school policies and rules. - impacts (Organisation & Design)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"I am a parent not a member of staff so do not know"
"Overall policies are followed"
"I would assume so"

Suggestions:

None

Day-to-day operations of the school building support the development of new activities. - impacts (Development & Innovation)

Agree	17 (74%)
Disagree	1 (4%)
Don't Know	5 (22%)

Evidence / example:

"I am a parent not a member of staff so do not know"
"Already Full"
"Good spaces for a variety of uses"

Suggestions:

None

The way the school building is used is energy efficient. - impacts (Building Resources)

Agree	8 (35%)
Disagree	2 (9%)
Don't Know	13 (57%)

Evidence / example:

"No evidence of this but don't know"
"Modern building - double glazing etc."

Suggestions:

"But I doubt it!"
"Some way of enforcing equipment shut-down would be good"

The way the school is managed reflects the aims of the school. - impacts (Planning)

Agree	20 (87%)
Disagree	1 (4%)
Don't Know	2 (9%)

Evidence / example:

"Is this connected with the building?"
"Engaging more people would help"
"The school is seeking to develop, and this is made clear"

Suggestions:

None

Our School and the way it is run are exemplary. - impacts (Exemplary Building)

Agree	14 (61%)
Disagree	3 (13%)
Don't Know	6 (26%)

Evidence / example:

"I am a parent not a member of staff so do not know, but seems good"
"Ditto?"
"It is good, but not exemplary. There are certain things the school could prove on, but no school is ever perfect."
"I base this on a combination of exam results, seeing happy balanced children at the school and the lack of serious issues we are faced with as Governors to deal with."
"It is efficient with obstacles"

Suggestions:

None

The way the school is operated creates a positive impact upon the people who come here. - impacts (Culture)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"The overall ambience is excellent."
"Mostly"
"Most students are happy and engaged, most staff enjoy work"

Suggestions:

None

How do you feel about how well we use the school building as a resource?

Red = 0 (0%) Yellow = 1 (4%) Green = 20 (87%) Blue = 2 (9%)

The school building is a great resource for school staff. - impacts (School Staff)

Agree	17 (74%)
Disagree	0 (0%)
Don't Know	6 (26%)

Evidence / example:

"To have classrooms and a lecture theatre of this quality can only be a good thing for staff."
"Some use it well"
*"*Didn't tick any box*"*
*"*didn't tick any colour box*"*
"Modern and comfortable"

Suggestions:

"We could use it more and hire out our own facilities"

The school building has enough resources to support good teaching. - impacts (Programmes & Services)

Agree	19 (83%)
Disagree	0 (0%)

Evidence / example:

Don't Know	4 (17%)

"I am not a member of staff I am a parent so I don't know"
"Using additional teaching methods"
"Apart from a few small rooms, overall a very good space"
"but have heard there are not enough PC/laptops for 6th form"

Suggestions:

None

We make creative use of the building. - impacts (Development & Innovation)

Agree	12 (52%)
Disagree	4 (17%)
Don't Know	7 (30%)

Evidence / example:

"I am not a member of staff I am a parent so I don't know"
"Agrees but could be more displays. stairwell walls are very bare"

Suggestions:

None

The school is well managed and maintained. - impacts (School Operations)

Agree	23 (100%)
Disagree	0 (0%)
Don't Know	0 (0%)

Evidence / example:

"The school or the buildings?"
"The facilities management service is excellent."
"The maintenance programme is visible and efficient"
"Agrees although outside the Auditorium on the road side is messy"

Suggestions:

None

The school building has a pleasant appearance. - impacts (Communication)

Agree	21 (91%)
Disagree	1 (4%)
Don't Know	1 (4%)

Evidence / example:

"Where did this question come from?"
"A good environment is obvious"
"very neat grounds"

Suggestions:

None

The school building has the resources for effective management of the school. - impacts (Exemplary Building)

Agree	19 (83%)
Disagree	0 (0%)
Don't Know	4 (17%)

Evidence / example:

"Pleasant offices facilitate this + look professional when meetings are being held"

Suggestions:

None

The way we use the school building is having positive results for the school and the pupils. - impacts (Culture)

Agree	18 (78%)
Disagree	0 (0%)
Don't Know	5 (22%)

Evidence / example:

"The intake numbers reflect this."
"every opportunity to learn"

Suggestions:

None

How do you feel about how well we do at planning for use of the school building (design plans, evacuation plans, community use plans, etc).?

Red = 0 (0%) Yellow = 2 (9%) Green = 16 (70%) Blue = 5 (22%)

Our school building works the way we expect. - impacts (Development & Innovation)

Agree	20 (87%)
Disagree	2 (9%)
Don't Know	1 (4%)

Evidence / example:

"I don't think enough engagement of users was undertaken to believe this can be true "
"This is evidenced through the lack of thought around technology and heat removal due to technology"
"No planning involvement"
*"*Didn't tick any box* "*
"Overall very pleased with space I teach in. Few concerns"
*"*did not tick colour box*"*
*"*Did not tick colour box*"*

Suggestions:

"Learn from mistakes on this building and plan for the future on this basis. Heat from technology can be reused for other purposes and planned well can reduce cost not increase"

We know what to do in case of an emergency. - impacts (School Operations)

Agree	21 (91%)
Disagree	1 (4%)
Don't Know	1 (4%)

Evidence / example:

"No training or awareness, will have to hope so until this changes"
"Fire drills are successful"
"No training"
"This is regularly practised"
"Fire drills - improving"
"Practice helps"

Suggestions:

"Briefing note on back of visitor's label and a 10 second briefing from hosts to compliment signage"

It easy for people to find their way around the school building. - impacts (Communication)

Agree	21 (91%)
Disagree	1 (4%)
Don't Know	1 (4%)

Evidence / example:

"It is a very simple building and in this respect works well"
"There is clear signage"
"After a few weeks"

Suggestions:

None

People understand what is expected of them while in the school building. - impacts (Exemplary Building)

Agree	21 (91%)
Disagree	1 (4%)
Don't Know	1 (4%)

Evidence / example:

"No evidence"
"Clear rules, not always followed"

Suggestions:

None

The school and its building supports our inclusive culture. - impacts (Culture)

Agree	20 (87%)
Disagree	1 (4%)
Don't Know	2 (9%)

Evidence / example:

"People seem very happy at LND"
"Lifts to Sixth Form Centre for disabled"
"Duty rotas encourage staff to be seen and to intervene"
"6th for building physically separates 6th form which I think is a positive. Others have controlled (but not free) access so is that inclusive?"
"I agree but we could do more"

Suggestions:

None

How do you feel about communications related to the school building?

Red = 1 (4%) Yellow = 1 (4%) Green = 15 (65%) Blue = 6 (26%)

We communicate our innovative approach to potential pupils. - impacts (Development & Innovation)

Agree	16 (70%)
Disagree	1 (4%)
Don't Know	6 (26%)

Evidence / example:

"The school is full so the message must be about right (or the fees are too low?)"
"This is done well both internally and externally."
"I don't think our approach is innovative but it is"
*"*Did not tick the colour box*"*
*"*Did not tick the colour box nor the first question box* It's a warm open school that is well maintained and champions pupils' work (via AA work/TV screen photos, etc.)"*

Suggestions:

"Communicates well"

The school building's appearance is maintained and cleaned properly. - impacts (Building Resources)

Agree	23 (100%)
Disagree	0 (0%)
Don't Know	0 (0%)

Evidence / example:

"Well-kept in and out"
"Cleaners do excellent job"

Suggestions:

"Maintenance sorts issues fast"

The interior design of the building is appealing. - impacts (Planning)

Agree	22 (96%)
Disagree	1 (4%)
Don't Know	0 (0%)

Evidence / example:

"Well-kept in and out"
"Looks like a hospital in places, + white paint marks easily"
"Since the redecoration in 2014!"

Suggestions:

None

The school building appearance shows that we have an excellent building. - impacts (Exemplary Building)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"Well kept in and out"
"The grounds are well maintained"

Suggestions:

None

The school is proud of its pupils and facilities. - impacts (Culture)

Agree	23 (100%)
Disagree	0 (0%)
Don't Know	0 (0%)

Evidence / example:

"Seems to.."
"The teachers ex toll the achievements"

Suggestions:

None

What Traffic Signal colour best indicates the overall state of activities in the Leadership Sphere?

Red = 0 (0%) Yellow = 1 (4%) Green = 20 (87%) Blue = 2 (9%)

Our school building is a leading example of a effective well-functioning school. - impacts (School Operations)

Agree	20 (87%)
Disagree	2 (9%)
Don't Know	1 (4%)

Evidence / example:

"Lack of evidence that there was adequate user engagement or "soft

landings""

Suggestions:

None

Our school building design helps us make effective use of our resources. - impacts (Building Resources)

Agree	16 (70%)
Disagree	0 (0%)
Don't Know	7 (30%)

Evidence / example:

"In the short term yes"
"The atmosphere has improved since 6th form centre opened"

Suggestions:

"Need to look at the impact of e-learning and other technology impacts including the use if Tablet technology in class"

Our school building is an example of effective involvement of the school community in planning for future generations. - impacts (Planning)

Agree	11 (48%)
Disagree	2 (9%)
Don't Know	10 (43%)

Evidence / example:

"Lack of evidence that there was adequate user engagement or "soft landings""
"Little engagement of users"
"What if numbers increase?"

Suggestions:

"I am not aware of how involved the school community is in planning. I would think this is the remit of management"

Our school building enables effective communication amongst staff and pupils alike. - impacts (Communication)

Agree	19 (83%)
Disagree	1 (4%)
Don't Know	3 (13%)

Evidence / example:

"Hard to say, the media suite does seem to communicate that technology was an afterthought not the centre of thinking during design"
"Communication is good"
"The lecture theatre is very useful for this"

Suggestions:

"We have effective communication but this is not enabled by the building per se"

Our school building is a source of pride. - impacts (Culture)

Agree	21 (91%)
Disagree	0 (0%)

Evidence / example:

Don't Know	2 (9%)

"I think the building is a massive step forward and will shape thoughts and actions for the next developments"
"I enjoy showing it off to Caterham staff and pupils"

Suggestions:

None

How do you feel about the way the School Building supports school spirit and cultural activities?

Red = 0 (0%) Yellow = 2 (9%) Green = 16 (70%) Blue = 5 (22%)

The school building creates an environment that makes it easy for people to follow school rules. - impacts (Organisation & Design)

Agree	19 (83%)
Disagree	1 (4%)
Don't Know	3 (13%)

Evidence / example:

"I am a parent not a member of staff so do not know"
"The common room has been a source of conflict"
*"*Did not tick the colour box*"*
"Yes - plenty of rubbish bins, windows in classroom doors, etc."

Suggestions:

"But I think this has much more to do with other factors"

The school building and classrooms help engage pupils in school teaching and learning. - impacts (Programmes & Services)

Agree	19 (83%)
Disagree	0 (0%)
Don't Know	4 (17%)

Evidence / example:

None

Suggestions:

None

The school building supports both science and creativity. - impacts (Development & Innovation)

Agree	20 (87%)
Disagree	1 (4%)
Don't Know	2 (9%)

Evidence / example:

" Science is studied in dedicated labs elsewhere"

Suggestions:

None

The culture and values of the school are evident in the safe, day-to-day operations of the school building. - impacts (School Operations)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"I am a parent not a member of staff so do not know"
"There is always a staff pressure and

students are encouraged to respect the resource"

Suggestions:

"Could have more examples of school pride - logos, shields, etc."

The way we treat the school building shows respect for the school. - impacts (Building Resources)

Agree	20 (87%)
Disagree	1 (4%)
Don't Know	2 (9%)

Evidence / example:

"Some students inevitably do not see this, it is a critical point"

Suggestions:

"Obviously there is a disrespectful minority but we encourage them to think differently"

The school building, we have accurately reflects the needs of the pupils and teachers. - impacts (Planning)

Agree	17 (74%)
Disagree	1 (4%)
Don't Know	5 (22%)

Evidence / example:

"I am a parent not a member of staff so do not know"
"The building was designed to take the school"
"clean, modern classrooms and offices"

Suggestions:

None

The school is held in high regard by its peers, staff and pupils. - impacts (Communication)

Agree	21 (91%)
Disagree	0 (0%)
Don't Know	2 (9%)

Evidence / example:

"I'd say this is true for 90% of the school"
"but more work to be done - alumni, etc."

Suggestions:

None

The school's cultural importance in the community and values of inclusiveness can be seen in the diverse ways that staff, pupils and the community use the building. - impacts (Exemplary Building)

Agree	13 (57%)
Disagree	2 (9%)
Don't Know	8 (35%)

Evidence / example:

"Increasingly the case"
"Range of concerts theatre, exhibitions and sporting activities demonstrate a sound school embedded in the community"
"more could be done with the community"

Suggestions:

"I am unsure what our cultural importance in the community is"

Table 2

Combined Results Matrix Report

	Parents (6)	Pupils (5)	Advisor (1)	Teaching Staff (8)	Male (7)	Female (16)	Prefect (5)
Media Suite 1	Very few areas of alignment with the pupil and school staff, organisation or services but other wise very good. This is counter to all of the other sensor observations which identify a consistent set of records.	In general the pupils thought the room was better than the sensors reported. There are good linkages with the pupil response and poor with the sensor especially with the pupil, staff, organisation and programme spheres. Staff were slightly uncertain as were services. Linkages were much stronger for the perceptive that the measured.	Common ground with yellow results for pupils, staff, organisation and programme. Sensors performed better than perceived in this area. Relations at common levels were poor in both cases and had low alignment between operational and staff	Perceptive records were better for organisation, staff, programme and pupils, in all other areas sensor data was better. There were more relational links at strategic levels than tactical, where they were absent for the sensor relationships	The media suite perceived and recorded datasets were relatively well aligned. The sensors performed slightly worse than perceived at tactical levels and slightly better at strategic and operational. The tactical relationship links were poor	Perceptive results were better for all tactical areas and mostly the remainder except a few don't knows. Similar strategic and operational link relationships . No tactical sensor relationships.	Perceptive results were better for all tactical areas and mostly the remainder except a few don't knows. Similar strategic and operational link relationships . No tactical sensor relationships.
Quiet Study Area 2	Some alignment between pupils, organisation and programme. Little other evidence or relationships between perceived and sensor data. Some common relations at the same community areas little at the strategic levels.	The perceived results for the Quiet Study Area were much better than the measured. Community linkages and relations were better and a small amount of uncertainty in the areas of Planning, Culture and Development transposed to a red response from the sensors. The sensors generally had a poor set of linkages especially away from the pupils, organisation and programme	Common ground for staff, operations, resources and exemplary building at yellow. Only common link is between operations and staff.	Sensor records out performed for pupils, organisation and programme. All other areas didn't perform well, especially development, culture and planning. Few strategic relationships some tactical	The measured performance of this area was much worse that the perceived, except in the area of communications. Relationship links were physically better at tactical level, but worse than perceived. At strategic level the sensor derived relationships were very poor.	Perceived results much better than recorded, except in the tactical areas where only school staff was better. Operational and strategic physical measures were much worse with fewer link relationships	Perceived results much better than recorded, except in the tactical areas where only school staff was better. Operational and strategic physical measures were much worse with fewer link relationships
UCAS Office 3	The alignment of the UCAS office and parents experience was very close. The perceived and measured results in the room were all good with a few perceived misgivings about staff, services and organisation. The measured results were all good but with weaker linkages (probably due to lower sample rates). The relations between exemplary building and culture didn't exist or between Exemplary building and planning or communication	The alignment of the UCAS office and pupils experience was very close. The perceived and measured results in the room were all good with a few perceived misgivings about staff, services and organisation. The measured results were all good but with weaker linkages (probably due to lower sample rates). The relations between exemplary building and culture didn't exist or between Exemplary building and planning or communication	All sensor riding were better than those perceived. Only common link was between operations and staff	Sensor data was the same or better than percieved.in all cases. Relationships were common	The physical data has outperformed all of the perceived records. Perceived performance was poor in communications and programmes. Likes were similar except with communication where the sensor links were poorer.	Very common set of results with perceived records having some "don't knows" for the operational and strategic perceptions. Many shared links at all levels	Very common set of results with perceived records having some "don't knows" for the operational and strategic perceptions. Many shared links at all levels, perceived link between development and programme much better with sensor data
Atrium 4	Few areas of common ground between measured and perceived data. Row common links. Many broken links with sensor data	The Atrium measured values and pupils relationships are very different. Yellow sensor data with few relationships indicated a poor measured performance but a well perceived view with some good comments	Atrium had very close alignment between the perceived and recorded performance all yellow on both sides. Only common link between staff and operations	Perceived data out performed sensor data in all areas	Perceived data out performed sensor data in all areas. Very few common link relationships	Very low alignment of records all sensor performance were worse than perceived, with very few link relationships	Very low alignment of records all sensor performance were worse than perceived, only 1 common link relationships with 3 similar
Room 30 5	Good alignment with Organisation and design, staff and pupils moderate with all others	Room 30 is a general class room and indicated a mixed story for measured performance. Some alignment at pupils, staff and organisational levels but little elsewhere.	Sensor performance was better for organisation, staff and pupils and common at yellow for all other areas.	Common ground with sensor data the same for pupils, staff and organisation, but underperformed with respect to teaching staff in all other areas	Common ground at tactical level for staff, organisation and pupils. Sensor data was worse at operational and strategic levels, except communication. Relatively few links	Common performance for organisational, staff and pupils otherwise building physics performed worse that perception scores. Some common tactical links	Common performance for organisational, staff and pupils otherwise building physics performed worse that perception scores. Some common tactical links
Common Room 6	Some alignment between pupils, staff and organisation Little other evidence or relationships between perceived and sensor data. Some common relations at the same community areas little at the strategic levels.	Common Room measure performance contains many red results for culture, development, resources and operations, but some alignment at pupils and staff levels. There are some relationship links, but few at the strategic level	common room sensor data was better for staff and pupil and worse for operations, development, culture and resources. All other areas were the same. Only common link was operations to staff	Same performance for staff and pupils, dramatically underperformed physically for culture, resources, development and operations underperformed a little for all other areas. Some tactical links no strategic relationships	Sensor data for staff and pupils was better all other areas except communications was worse. Very poor at operational level some tactical links	Tactical scores form staff and pupils was common all other sensor scores are worse with operational being much worse. Some tactical links	Tactical scores form staff and pupils were common all other sensor scores are worse with operational being much worse. Some tactical links
Café Kitchen 7	Common ground between staff and pupils and their links few others	The measured relationships are strongest between staff and programme and services, less close for culture, programme, development and organisation. The Exemplary building was opposite. There were fewer recorded relationships especially at the strategic levels	Staff and programme performance recordings were better, exemplary building recorded was worse all others recorded common results	Common physical performance for programme and services and staff all others underperformed with the exemplary building dramatically poor. Some tactical links	Better physical performance for staff and programmes worse in most other areas except communications. Poor links except at tactical level	Tactical scores from staff and programme and services was common all other sensor scores are worse with exemplary building being much worse. Some tactical links, no strategic	Tactical scores from staff and programme and services was common all other sensor scores are worse with exemplary building being much worse. Some tactical links, no strategic. Blocked perceptive link between development and programme is a "don't know" link for sensors
Room 7 8	Good alignment with Organisation and design, staff and pupils moderate with all others	Room 7 is a general class room and with the exception of pupils there was relatively little overlap between perceived and measured. Exemplary building, communication and development were opposite there was some alignment between culture a, programme, development and organisation. There were fewer weaker relationships.	Pupils sensor data was better, development, communication and exemplary building were worse all others were common. Link between operations and staff was the same	Pupils performance caps common from both data sets, with red physical performance from development, exemplary building and communication some common tactical links	Better pupil results from the sensors, worse or much worse at all other comparators. Communications very poor from both sets on information.	Common pupils scores but operational being worse and strategic much worse. Some tactical links no operational or strategic	Common pupils scores but operational being worse and strategic much worse. Some tactical links no operational or strategic
ICT B 9	Common ground for organisation, but poor match and performance for culture and services	A low level of correlation with no exact matches. Opposites for programme and culture. Few strategic relationships	Organisation performed better physically culture and programme and services performed worse. All other areas were common	Similar organisational performance, all others were worse with programmes and culture much worse	Organisation performed better physically culture and programme and services performed worse. All other areas were physical worse, especially culture and programme. Some common tactical links	Common organisational scores but operational being worse and strategic much worse. Some tactical links no strategic	All sensor scores are worse except organisation and design. Some tactical links all other sensor scores are worse
Lecture Theatre 10	Relates well for the pupils relationship and OK for all others good relations with Organisation and design, staff and services	The lecture theatre scored well in the comparison of measured against perceived for the pupils. There were similarities for programme, development and organisational. There were few relationships	Sensor data for pupils was better than advisors perceived but all others were common. Link between staff and operations was common	Common ground for pupils and community all other sensor records were worse. Some common tactical and operational links	Sensor data for pupils and communications was better all others. Some common tactical and operational links	Common pupils scores but operational and strategic being worse. Some tactical links no strategic	Common pupils scores but operational and strategic being worse. Some tactical links only one strategic
HE Room 11	The HE Room related well to staff needs and overall design and ok in all other area.	There are good alignments between staff and organisational design, few strategic relationships	Recorded performance of organisation and staff was better all others were common	Common performance from organisational and staff community areas. All others were worse. Some tactical links	Sensor data out performed perceptive for organisation, school staff and communication. It was marginally worse in all other areas.	Common organisational and staffing scores but all perceptive scores were better. Some tactical links	Common organisational and staffing scores but all perceptive scores were better. Some tactical links
First Floor Sensors	Very good alignment with Pupils, organisation, staff and services and communication. Common good relationships between design staff pupils and services	The combination of the new first floor gave some alignment of all parts of the community. However the measured results are worse in all cases. There is a shared backing relationship between development and programme. All links at the strategic level are not present in the recorded dataset.	Sensors generally performed better for exemplary building, communications, programme, staff, organisation and pupils. All others were worse	Sensors all performed worse that perceived for the first floor. Operational ones much worse. Some tactical and operational links	Common tactical performance, better perceptive in all other areas except communication	All perceptive scores are better or in most cases much better especially as you progress to wards operational issues. Some good commonality of tactical links	All perceptive scores are better except organisational and staff where the sensors were better. Some tactical links
Ground Floor Sensors	Some common ground in areas such as pupils, staff and communication which showed negative values. Common links between organisation, staff, pupils and programmes	The ground floor sensors are generally similar or worse than the first floor. The relationships are similar to the first floor.	Sensors generally performed better for exemplary building, communications, staff, organisation and pupils. All others were worse	Sensors all performed worse that perceived for the first floor. Operational ones much worse. Some tactical and operational links	Common tactical performance, better perceptive in all other areas	All perceptive scores are better or in most cases much better especially as you progress to wards operational issues. Some good commonality of tactical links	All perceptive scores similar in the tactical area and are in most cases much better especially as you progress to wards operational issues. Some good commonality of tactical links

	Governor (2)	Departmental Head (1)	Head Teacher (1)	Café Staff (1)	Office Staff (3)	Librarian (1)	First Floor Observers (5)	Ground Floor Observers (1)
Media Suite 1	Sensor data has out performed all strategic and operational areas especially communications. Tactically perceptive values were slightly better. Similar pattern with links	Very similar results with better perceived tactical values than measured. Very poor link relationships sort sensor values. Poor sensor relationships between planning and Exemplary Building and communication	Very similar results with better perceived tactical values than measured, except in the perceived readings for development . Very poor link relationships for sensor values in the tactical areas. Poor sensor relationships between planning and Exemplary Building and communication	Strategic and operational sensor values are better than perceived where there was a lot of "don't know" results. Tactical sensor readings were generally worse. There was some level of commonality of all links with some tactical blocks in the sensor readings	Much commonality across the strategic and tactical areas, but sensors performed worse at tactical levels significant commonality of links at all areas except tactical	Common performance in operational area. Sensors had a worse set of results. Many common operational and strategic links	Some level of consistency across all area with closest in the operational areas and less in both tactical and strategic. Many similar strategic and operational links	At tactical level the perceived results were better. At all other levels the perceived results are dominated by "don't know" answers. At operational and strategic levels there are many consistent links
Quiet Study Area 2	Tactically both sets of data performed in a similar manner, operationally the perceptive performance was better, except in the case of communications.	Similar measurements between organisation, pupils and programme. All other sensor recordings are worse or much worse in the cases of development, culture and planning. Some similar tactical common links	Perceived values are all the same or better except in the case of development. Poor tactical link values	tactical values have some similarity all other perceived values are better of don't know. Few common links	Perceptive performance is much better that measured. Complete alignment of organisation and pupils. Very poor sensor performance in the areas of planning, culture and development. Some alignment of links at a tactical level	Common performance in the areas of organisation, programme and pupils. All other sensor performance were worse. Many strategic "don't Knows" from the perceptive measures	Similar tactical areas, including links. Few other common areas with sensors all performing less well	Common ground at tactical levels, but a consistent set of poor physical performance and "don't knows" could indicate an issue. Some common operational links, but many sensor blockers
UCAS Office 3	The sensor data has out performed all of the perceived records except exemplary building, culture and operations. Relational links are also stronger for the sensor records especially strategically.	Nearly identical readings for both perceived and sensor recorded. Missing links between Planning, Exemplary Building and communication. Also Exemplary building and culture	Nearly identical set of results with the exception of the perceived development score which was worse.	Similar values except for a high level of "don't knows". Some commonality of internal values	Very similar performance with the key deviations f found "don't knows" from the office staff, in the areas of planning, communication, resources and programme	The sensors out performed the perceptions, with a lot of "don't knows" at strategic levels. Many common links	Sensors all performed better than the perceived recordings, but not by much. Very similar links with the exception of planning to exemplary building to communication	Very consistent datasets, but with perceptive values being more unknown at strategic levels
Atrium 4	Perceived data out performed all sensor data except communications. There are very few shared link relationships	Sensor readings all are worse than perceived. The only common links are exemplary building to resources, operations to staff and culture to development.	Sensor values all worse than those perceived. Few common links except culture development and exemplary building to building resources	Similar values except for a high level of "don't knows". Very few common links anywhere	Perceptive performance has out performed all areas of measured. Very few common links	All perceptive values are better than recorded. Few common links	Perceptive values were all better but not by much. Few common links	Perceptive values all of performed the measured values. Few common link results
Room 30 5	Tactically there was a better physical performance and all other areas not including communications were batter. Strategic and operational links were poor for sensor records	Common tactical scores except programme and services where perceptions were better. Also common tactical links present between pupils staff and organisation for sensors. Very few other link relationships	Common recordings in the tactical area all other perceived values were better, some common tactical and operational links no sensor links at strategic level	Common records with pupils and organisation most others worse of "don't know". Few common links	Common performance in organisational areas of organisation, staff and pupils. Some tactical common links	Common tactical performance, worse sensors in all other areas. Some tactical common links	Similar performance all round with a few common tactical links	Common tactical results some common operational links
Common Room 6	The sensor data out performed tactically for school staff and pupils all other areas the performance was better perceptively, except communications. There was a better level of link relationships for strategic and operational measures	Common performance at pupils and staff all others performed worse, with development, resources, culture and operations (operational area) performing much worse	Tactical scores form staff and pupils were common all other sensor scores are worse with operational being much worse. Some tactical links	Common values for pupil records. All others worse of much worse for the sensors or "don't know" perceptions. Some common tactical links	Only alignment is in the staff and pupils areas. Operational areas are very poor in the sensors with good perception performance. Some common tactical links	Common performance in pupils and staff. Very poor operational performance some tactical links	Similar tactical performance, but much poorer sensor results for all other areas. Some tactical links	Common tactical results some common operational links
Café Kitchen 7	Tactical sensor data did well with both school staff and programme and services data begin better than perceived. However all operational and strategic perceptions with the exclusion of communications were better.	Similar measurement at tactical levels - staff and programme with all other areas being perceived better. Few strategic and operational links	Perceived measures all better with some tactical and operational common links. Exemplary building sensors performed badly	No common values all perceived values are better or "don't know" some common tactical links. Interesting as this is the key area this resource occupies	Common performance with staff and programme areas. All other perceptive values are better. Some common tactical links	Common staff and programme values. All other sensors values worse.	Similar results with the exception of exemplary building. Some common tactical links	Common values at school staff and programmes all others worse in the sensor data, but outweighed by the don't know values. Some tactical links
Room 7 8	The only alignment was the agreement regarding poor communications which was only slightly worse for the sensor measurements. Development and exemplary building were much worse in real life than perceived. Linkages at operational and strategic levels were very limited	Similar measurement at tactical levels - especially with pupils with all other areas being perceived better, especially exemplary building, communication and development which physically performed badly. Few strategic and operational links	Only common values are in the pupils area. All other sensors performed worse, with exemplary building, communication and development much worse. Some common tactical common links	Pupils values are the same all other sensor values are worse of much worse. Some tactical links	Only area of commonality is the pupils. All other sensor performance is much worse in development, exemplary and communication with some common tactical links	Common pupils values all other sensors worse.	Some level of consistency at tactical level the remainder saw a worse physical performance/ A few common tactical links	Common values at pupils all others worse in the sensor data, but outweighed by the don't know values. Some common tactical and operational links
ICT B 9	A slightly more positive perception than reality. Culture and other strategic issues were better perceived but organisation was physically better. Only tactical link relationships were identified	Poor sensor performance in the operational areas, especially culture and programme. Organisation and design performed in a similar manner. Some common tactical links	Only common values are in the organisation area. All other sensors performed worse, with culture and programme much worse. Some common tactical common links	Organisational values are the same all other sensor values are worse of much worse. Some tactical links	Common performance for organisation all other sensors performed poorly some tactical links	Common organisational scores all other sensors are worse. Some common tactical links	In general except organisation the asset performed worse than the users perceived.	Common values at organisation. All others worse for the sensors.
Lecture Theatre 10	With the exception of communication and pupils all perceived values were better than measured, but not significantly. Communication was perceived as poor and pupils perceived the environment less well that the sensors measured it.	Poor sensor performance in all areas, except pupils. Some common tactical links	All areas perceived better than recorded, except pupils which was the same. Some common operational links	Pupils values are the same all other sensor values are worse of much worse. Some operational and tactical links	Common pupil performance all other areas performed moderate worse. Some tactical common links	Common pupils values all other sensors worse.	In general except organisation the asset performed worse than the users perceived except in the pupils community	Common values at pupils all others worse in the sensor data, but outweighed by the don't know values. Some common tactical and operational links
HE Room 11	Only Organisational & Design and School staff were perceived worse that they were physically measured. Operational and strategic links were rare in measured values	Common organisational and staff scores. Some common tactical links	Common records for organisational and school staff all others worse for the sensors. Some common tactical links	Common values for organisational and design all other perceived values are either "don't know" or better. Few common links	Common performance in tactical areas all others are worst some tactical links	Common scores for organisation and staff. Some tactical links	In general except organisation the asset performed worse than the users perceived except in the organisation and staff communities	Common values at organisation and school staff all others worse in the sensor data, but outweighed by the don't know values. Some common tactical and operational links
First Floor Sensors	A very similar tactical performance both physically and as perceived. Measured sensor data for all other areas except communications was worse. Few strategic link relationships.	Perceptive scores are better in all cases especially in the operational and strategic levels. Better tactical link relationships	Perceived values all between especially at operational and tactical levels, except development which had unclear "don't know" perceived values. Some tactical links	Similar tactical performance better perceived in all other areas. Few common links	Similar tactical performance all others performed worse, some tactical links	Similar tactical performance worse operational from a sensor point of view. Some tactical common links	Some level of commonality at tactical levels but less at strategic and operational levels	Sensors all performed worse than perception. Some common tactical links
Ground Floor Sensors	A very similar tactical performance both physically and as perceived. Measured sensor data for all other areas except communications was worse. Few strategic link relationships.	Perceptive scores are better in all cases especially in the operational and strategic levels. Better tactical link relationships	Perceived values all better especially at operational and tactical levels where they are much better, good tactical links	Very similar performance in organisation and pupils all other sensors much worse	Similar tactical performance all others performed worse, some tactical links	Similar tactical performance worse operational from a sensor point of view. Some tactical common links	Some level of commonality at tactical levels but less at strategic and operational levels. Some tactical level common links	Sensors all performed worse than perception. Some common tactical links

	All Respondents (Hemisphere Map)	Peak / Alarm Sensors	Narrative	Summary Observations	Potential Action 1	Potential Action 2
Media Suite 1	Perception of participants is much better than the recorded results especially at Operational and Strategic Levels. Female users liked the room more than male.	Temperatures peaked and fell to values outside of the specified limits at 31.2 - 19 Degrees C. VOC peaked at 3 times the specification at 3676, Humidity dropped 10 10%, 35 % below specification and noise peaked at 80 dB, which was 20 dB above limits, but only for a very short peak in time.	The smalls rooms and media suite are small and stuffy when I visited. The media suite does seem to communicate that technology was an after thought not centre of thinking during design	Parents observations indicated a lack of understanding of what the Media Suite was for. This was indicated by poor alignment of pupil and staff relationship scores. The pupils liked the space and the linkages between pupils and staff my underlie a better understanding of the potential of technology by pupils that staff. The better perception of the performance of the room may be due to the fact that space is so new to the community and represent such a significant improvement on the past. The peak values for temperature and VOC were recorded in a mild time of year. The performance of the space in more extreme weather conditions may prove to be a significant issue especially as the narrative indicated a stuffy feel to the space already. Female respondents showed the liked the area more than male. This may be because the shape and design of the space encourages a safe and include feel. The Governors were more sceptical and may have external experiences which coloured their view	An improvement in air quality would seem to be the most immediate improvement in this space. The need is evidenced by the peak values and the narrative references to the "stuffy" atmosphere. Potential solutions to this could include both natural and mechanical ventilation.	The number pupils using the media suite was not measured, but may prove to be a useful measure. A larger area would both reduce crowding, air quality and circulation, but may not work commercially. A more innovative approach to the use of technology may provide more options to provide different teaching patterns of areas from media studies activities. Without this option maybe a better more regular spaced area would deliver a better performance.
Quiet Study Area 2	Perception of all participants was significantly better than the sensors predicted. The Operational and strategic sensor scores, especially Planning, culture and development were particularly bad and whilst the was a correspondingly poor or don't know element to the perception to these areas the perceived result was still better.	The peak highland low temperature performance of the quiet room did not story far out of the rage specified by the brief. However VOC execxes at peak by 6 times for some significant periods, enough to pull the rolling average up to 1.5 times specified peak. Noise was above the specified 60dB, which is equivalent to normal speak, to 82dB. The average and peak low humidity was very low.	This is more related to the lack of actual silent study that isn't cramped/noisy etc.'', ''Not Always. Study Room does not accommodate enough students. Some go and work elsewhere which is hard to supervise.'', ''Additional study areas have to be found'', ''but I think the 6th Form suffer from overcrowding and lack of study areas'' , ''Not always, dead for quite study if study room is full'',	The parents are not direct users of this area so it was not surprising that there was little evidence of user level alignment. However the strategic view of having a quiet study area was well thought of. The pupils like the quiet study are, they had a lower connection with the staff in here. The teachers thought the quiet study area was much better than the sensors actually recorded. This was Bourne out by the SOFI processed data and the peak performance data where at busy periods the noise rating reached 82 d, which is about the average noise of traffic from inside a car. This in unlikely to cause and harm but is rather more noise than a teacher may expect from a quiet study area. There was not a major difference in the results for male or female participants, both scored their use of the space better than the sensors predicted. The narrative mentions that there were insufficient spaces for quiet study and that they were often over crowded, this would account for the high VOC readings from the sensors. The alignment of pupil perceptions may indicate an improvement in the old buildings facilities and their use of the space as a communal congregation rather than for quiet stud. This would be supported by the very high VOC and noise levels. The low humidity and high VOC would not provide a healthy environment.	An improvement in air quality would seem to be the most immediate improvement in this space, peak values of over 6 times indicate a significant issue This could include both natural and mechanical ventilation.	There are clearly concerns around the number of spaces for quiet study. The utilisation was not recorded but would be a useful observation. A larger area would both reduce crowding, air quality and circulation and potentially reduce noise which is clearly an issue for this type of space.
UCAS Office 3	Almost all respondents though the room performed well and in line with the results from the sensors. The only slightly worse perceptions came from the male and governor community.	In general this area performed well. However the extremes of temperature at 38.8 down to 17 indicated issues with heating, solar shading and insulation. Peak VOC was above specification but not significantly as was noise at 73 dB. Low humidity was a significant issue.	No comments received regarding this area	This area seemed to perform well and was mostly well liked there appear to be no significant issues	None	None
Atrium 4	The results indicated by all of the respondents with relation to the sensor scores shows the people scoring the space better than the sensors indicated. There are some area of disagreement but they are minor, with perhaps the exception of communication	The sensors in the atrium indicated the space performs moderately well. The temperature however peaked at 31.2 degrees and fell to 19 degree. The rate of fall at night would indicate a lack of insulation and or poorly specified roof glazing. The VOC levels at 9 time the specified at peak and an average at double indicate poor ventilation and high numbers of people congregating. The Cafe may also increase this value. Noise peaks at 87dB, and the humidity is low.	'Atrium particularly attractive as a gathering area. Very popular.'', ''The atrium cafe is always buzzing with staff and pupils chatting and mingling'', ''Easy to move around and an area accessible from a central atrium'', ''The atrium is a good space for socialising'' ''Atrium cafe''	The atrium is clearly a massive improvement on any existing space in the school. It is light, open modern, is in the centre of the sixth from working space and acts as a very effective congregation and relaxation space. Not surprisingly the area gets very noisy but this may be an indication of success with people enjoying the facility. The feeling of a mini university environment with a Cafe and soft furnishings is a vast improvement on past facilities and may indicate a reason for the high perceived results. The area may suffer from heat and cold in seasonal extremes.	Solar shading and insulation on atrium glazing could alleviate some of the peak readings being seen by the sensors in terms of temperature. Thus is likely to be driving up the VOC readings as well and in more extreme seasons this is likely to become a larger issue.	An improvement in air quality would seem to be the most immediate improvement in this space. This could include both natural and mechanical ventilation, or if funds and planning allowed a more attractive solution may include the consideration of an oast to provide greater natural ventilation.
Room 30 5	The combined respondents at tactical levels were well aligned, but at operational and strategic levels the perceived results were better than those measured by the sensors.	Peak temperatures both high and low were outside those in the specification. With a high of VOC (3 times at peak) and very noisy at 90db which is the point which obligatory monitoring is required for industrial applications.	No comments received regarding this area	This space seems to be on the surface providing an area that people like to be in. They have responded positively in all areas except communication. The sensor values also back this up at a tactical level with a matching green status. However the level of divergence increases as the questions become more strategic. If this is read in conjunctions with the peak sensor values this could indicate an area which is functioning well but is beginning to already reach its practical capacity. This is supported by the high VOC values and the high level of noise which is evident at busy times. It is not possible to verify any of these observations as the was not specific narrative provided for this area to provide deeper insights.	The high levels of VOC would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation.	The high levels of noise may make a review of the spaces density desirable. The short term overcrowding may be OK in the short term but may signal a problem for the future. If density isn't the issue a review of acoustic damping may be an appropriate next step.
Common Room 6	The perceived data collected about the common room clearly showed it was well thought of at all levels, with very few deviations from and all green response on the SOFI results. The sensor values at tactical level were ok but at an operational level there were many red results.	The peak values for temperature were only marginally out of specification, but VOC was very high at over 13 times the specified figure, however this was only for short periods. The humidity was very low at peak and the noise was an issue with a peak at nearly 90 dB which is the legally recordable value.	'6th form promotes a studious attitude, although common room is a bit of a distraction'', ''The common room has been a source of conflict''	This room is clearly well thought of by staff and pupils but is operating at the boundaries of its design parameters, There is some interesting narrative which eludes to some operational issues , with the room being seen as a "bit of a distraction" and a "source of conflict". This maybe how the room is supervised or its agreed usage. The high VOC and low humidity could be due to the large amount of soft furnishings, but this does not explain the very peaky nature of the results which on closer analysis of the data may identify coincidence with high occupancy periods such as lunch time.	The high levels of VOC would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation.	The high levels of noise may make a review of the spaces density desirable. The short term overcrowding may be OK in the short term but may signal a problem for the future. If density isn't the issue a review of acoustic damping may be an appropriate next step.
Café Kitchen 7	The all respondents view of the café were clearly with respect to their perception of the café and the fact that the service is very different to all other parts of the school. The experience of all users was well perceived but was not representative of the cafe staff or the sensor data about the cafe staff area (kitchen).	VOC and humidity values were extreme in the kitchen, but this is not that surprising in a cooking area. VOC was 13 times to high at peak and humidity while peaking just above the specified limit, dropped well below the limit.	'The atrium cafe is always buzzing with staff and pupils chatting and mingling'', ''Lovely wide cafe area for 6th form'' , ''The cafe certainly was a welcome addition'', ''Cafeteria is a good resource''.	These results will be contaminated by the fact that much of the community would have answered from the point of view of a café customer not a member of the kitchen staff. The narrative comments provided and the perceived results indicate there us a high level of satisfaction, however the cafe staff were less convinced with lots of "don't knows" in their responses. The shape for the kitchen is rather odd and the optimum layouts may have been challenging to achieve. The high levels of VOC and humidity are not much of a surprise given the way the rest of the building has performed but the low humidity may provide challenges for future cleanliness of the facility	Check that extraction systems are operating as effectively as designed. High VOC and humidity may be a sign of poorly specified or operating extraction plant	Re-run the SOFI data collection process and be more specific about the segregation of location eg kitchen operative or café user. This may provide a deeper insight in to the performance of the facility.
Room 7 8	The perceived performance of this room was very good at all levels. But the performance suffered from the point of view of the building physics. The external communication and exemplary building values suffered badly.	The peak high an low temperatures were way out of specification for significant periods of time, with very high (35) and low (18) values. VOC peaked at over 13 times specified and noise reached 90 dB. The low threshold of humidity was twice the specified value.	No comments received regarding this area	This room is clearly challenged by temperature peaks and troughs which is confirmed by its south facing aspect and likely high solar gain. A vary rapid drop in temperature indicates a high thermal loss through high levels of glazing or a lack of appropriate insulation. The solar gain may also account for the high peak VOC values. The high peak noise levels may indicate there are periods of unsupervised student activity here.	Review the potential for the installation or use of existing blinds to reduce solar gain	Check if the space is used by unsupervised students as 90db is a very noisy environment and whilst the peak values were sporadic they did occur regularly.
ICT B 9	All users perceived the performance of the ICT space very well. This is offset by a relatively poor set of building physics readings which particularly impact the culture and programme/services provision sphere.	The temperature values are both outside the specified with peaks at over 29 degrees C and lows of 19. Noise peaked at 90dB and VOC was peaked very high at 13 times specified.	'I agree, except on one point - I don't think there's enough IT space'', ''although again there is not enough IT provision'', ''Again there's an IT requirement which is not fully met.'',	The significant peaks of thermal performance could indicate a lack of effective insulation and /or significant peak loads through occupation and the use of computer equipment. The VOC readings also support this view with a thirteen time peak during heavy occupation periods. Noise is also an issue which could be managed through supervision or the addition of acoustic damping. The high perception ratings measured may be influenced by the honeymoon effect of the facility being a much better facility than was available before, but also indicate that the future capability of the space to meet future demands may be compromised. This is further evidenced by the narrative comments which identify a lack of capacity. This would also indicate very heavy utilisation and hence the peaks in VOC and temperature.	An improvement in air quality would seem to be the most immediate improvement in this space, peak values of over 13 times indicate a significant issue This could include both natural and mechanical ventilation.	The lack of space will be adding to the high temperatures bad VOC as well as noise. Provision od more space allocate to the ICT activates or identification of other methods of delivering such a pervasive technology may be a more appropriate way forward.
Lecture Theatre 10	The lecture theatre is well perceived by all respondents and performs moderate well for all sensors especially at the tactical levels	The temperature peaks indicated significant peaks both high and low beyond the speciation. VOC reached four times the target and humidity also ranges above and below the brief. Noise peaked 20dB above specified limits.	The lecture theatre in particular is an excellent space for learning'', ''The quality of the classrooms and the lecture theatre including equipment are excellent, ''Atrium and Lecture Theatre' help me carry out my tasks''., lecture theatre in which they give presentations of their ideas - and they want to do well.'', ''Lunchtime talks in the lecture theatre'', ''Sense of 'special' for lower classes to be taught in 6th block. Lecture/theatre allows more formal/university type lecture atmosphere'', 'To have classrooms and a lecture theatre of this quality can only be a good thing for staff. 'The lecture theatre is very useful for this (effective communication),	The provision of this type of lecture theatre is relatively rare in this type of school. It is a nice space and has mechanical ventilation and air conditioning. The acoustic seem to work well and the comments are positive	Check that the air conditioning and change rates are working as specified to try and reduce the peak VOC values	
HE Room 11	The HE Room is well perceived by all respondents and performs moderate well for all sensors especially at the tactical levels	The temperature peaks indicated significant peaks both high and low beyond the speciation. VOC reached thirteen times the target and humidity also ranges well below the brief. Noise peaked 25dB above specified limits.	No comments received regarding this area	Both VOC and noise featured high on the list of potential issues in the HE Room. This may be because the room is only occupied for relatively short periods of time the impact isn't perceived. The noise peaks may be due to the collaborative and community activities undertaken in the space.	The high levels of VOC would indicate a lack of adequate ventilation. As this is an area where people congregate for short periods it may not be a location which lends itself to natural ventilation.	
First Floor Sensors	The overall perception of all of the first floor spaces was good there was some uncertainties in the areas of planning, development, programme and services. All of these uncertainties were at operational rather than tactical pupil level and may well be due to the newness of the facility and people wanting to let the building and its new services settle down. Key measured and building physics issues were identified at strategic levels, especially culture and planning and this is likely to be due to the building not performing as well as the brief asked for at certain peak demand periods			The perception of the new sixth form block is very good at all levels. The buildings physical performance with respect to brief is generally good with some extreme peaks and lows which whilst are OK with current loads may present challenges in maintaining high levels of performance in the future. The first floor performed better than the ground floor. There a number of potential reasons for this. The area is new and has a "honey moon" effect. The data collected so far is for one non-extreme season so peaks and troughs in building performance may become more extreme. The first floor has the "fun" areas including the cafe atrium and common room both of which are very well thought of.		
Ground Floor Sensors	The overall perception of all of the first floor spaces was good there was some uncertainties in the areas of planning, communication, development, programme and services. All of these uncertainties were at operational rather than tactical pupil level and may well be due to the newness of the facility and people wanting to let the building and its new services settle down. Key measured and building physics issues were identified at strategic levels, especially exemplary building, communication, development, programme, culture and planning and this is likely to be due to the building not performing as well as the brief asked for at certain peak demand periods due to limitations in the refurbishment scope of works.			The perception of the new sixth form block is very good at all levels. The buildings physical performance with respect to brief is generally good with some extreme peaks and lows which whilst are OK with current loads may present challenges in maintaining high levels of performance in the future. The first floor performed better than the ground floor. There a number of potential reasons for this. The area is new and has a "honey moon" effect. The data collected so far is for one non-extreme season so peaks and troughs in building performance may become more extreme. The ground floor doesn't have the "fun" areas including the cafe atrium and common room both of which are very well thought of and is a refurbishment of an existing familiar area, it is dominated by a darker demeanour, even though a big effort has been made to make the corridors lighter through decoration.		

South Sensors	Parents link relations are all thick green indicating a good set of community relations. Sensor links are well formed at the pupil, staff, organisation and services levels but are poor elsewhere. It is not possible to break these relations down as the multiple sensor relationships create a many to many with unknown relationships. The general community vies exhibited by the parents are more optimistic (green) than that of the sensors, which are on average all yellow	The south sensors performed more poorly that the perceived records. There was some alignment at pupils, staff, organisation and programme level but little at the strategic levels. There were good linkages at the staff, pupil and organisational levels but few at the more strategic levels	South sensors performed better than perceived for organisation, staff and pupils, worse in all other cases except operations which was the same	Sensors all performed worse that perceived for the first floor. Operational ones much worse. Some better tactical links and a few operational links	Similar tactical performances, worse sensor operational and strategic. Very poor match between operational and strategic links	All perceptive scores are better or in most cases much better especially as you progress to wards operational issues. Some good commonality of tactical links	Some consistency at tactical levels but much better perception at operational and strategic levels. Good tactical relational links few at operational or strategic levels	A very similar tactical performance both physically and as perceived. Measured sensor data for all other areas except communications was worse. Few strategic link relationships.	Perceptive scores are better in all cases especially in the operational and strategic levels. Good tactical link relationships, especially between pupils organisation, staff and programme	Perceptive scores are all better especially at operational and strategic levels poor links at these levels	Common readings from organisation and pupils few common links	Common tactical performance and links. All others out performed by perception	Similar tactical performance except programme and services which along with all other areas performed physically more poorly than what was perceived	Very common results in the tactical area., but a worse sensor performance elsewhere. Some tactical common links but none elsewhere	Sensors all performed worse than perception. Some common tactical links	The overall perception of all of the first floor spaces was good there was some uncertainties in the areas of planning, communication, development, programme and services. All of these uncertainties were at operational rather than tactical pupil level. The building physics results for operational spheres were mostly better that the equivalent south facing sensors.			It is likely to be through the greater light levels on the south side and greater general heat gains making the south side generally warmer. This view is supported by anecdotal information gathered whilst walking around the building with staff on the north side more likely to be asking for the heating to be turned up.		
North Sensors	The relationship with the north sensors indicates a much clearer level of uncertainty that that of the south. The north sensors do have relationships but they are of "don't know" status rather than "no".	The North sensors have a strong set of "don't know" relationships in the middle area of the SOFI results set and some at the strategic level. There is some alignment of community response but the sensor data is general worse than that which is perceived.	Physical performance outperformed all areas except culture, resources, development and operations. Common link between operations and staff	Operationally the sensors performed was but there were some tactical alignments. Good links but mostly operational and of "don't know" status	Common tactical performance, better perceptive in all areas except communication. Common links in operational areas but all measured were of "don't know" status	Some level of commonality across tactical and strategic but much poorer physical performance at operational level. Significant commonality of linkages but all sensors are of "don't know" status	Perceptive scores are all better, being significantly better at operational levels. Significant commonality of linkages but all sensors are of "don't know" status	A very similar tactical performance both physically and as perceived. Measured sensor data for all other areas except communications was worse. Strategic link relationships in the operational areas had good correlation but were of "don't know" status	Sensor measurements all worse than perceived , especially in the operational areas. However very goo commonality in the operational links, which are all of "don't Know" status	measures values all worse especially in the operational areas. Good links at operational level but all at "don't know" status	Similar strategic and tactical performance sensors worse for operational issues. Few common links	Common tactical performance and links. All others out performed by perception. Many common operational performance but with sensor links at "don't know" status	Similar tactical performance but worse sensor performance for operational. The perceived don't knows for perceived records in the strategic area. Many common links in the operational area but all at don't know status	Very common results in the tactical area., but a worse sensor performance elsewhere. Some operational common links but all of don't know status	Sensors all performed worse than perception. Some common operational links but many unknown perceptions and links	The overall perception of all of the first floor spaces was good there was some uncertainties in the areas of planning, communication, development, programme and services. All of these uncertainties were at operational rather than tactical pupil level. The building physics results for operational spheres were mostly better that the equivalent south facing sensors.			It is likely to be through the greater light levels on the south side and greater general heat gains making the south side generally warmer. This view is supported by anecdotal information gathered whilst walking around the building with staff on the north side more likely to be asking for the heating to be turned up.		
All Sensors	Parents link relations are all thick green indicating a good set of community relations. Sensor links are well formed at the pupil, staff, organisation and services levels but are poor elsewhere. It is not possible to break these relations down as the multiple sensor relationships create a many to many with unknown relationships. The general community vies exhibited by the parents are more optimistic (green) than that of the sensors, which are on average all yellow	The combined sensor results performed more poorly that the perceived records. There was some alignment at pupils, staff, organisation and programme level but little at the strategic levels. There were good linkages at the staff, pupil and organisational levels but few at the more strategic levels	Across the building sensors sampled, organisation, staff and pupils out performed recorded and all other areas under performed. Link between staff and operations was common	Operationally the sensors performed was but there were some tactical alignments. Good links at tactical level especially with relationships to pupils in both datasets	Similar tactical performances, worse sensor operational and strategic. Very poor match between operational and strategic links	All perceptive scores are better or in most cases much better especially as you progress to wards operational issues. Some good commonality of tactical links	All perceptive scores are better or in most cases much better especially as you progress to wards operational issues. Some good commonality of tactical links	Tactical scores are identical, but all perceptive scores are better except for communications. Strategic links are very sparse.	Perceptive scores are better in all cases especially in the operational and strategic levels. Better tactical link relationships	Similar performance at tactical level, worse at operational and strategic. Common links at tactical level	Common performance or some tactical areas but dominated by perceived "don't Knows"	Common tactical performance and links all other areas out performed by perception	Common performance or some tactical areas but dominated by perceived "don't Knows". Common tactical links	Very common results in the tactical area., but a worse sensor performance elsewhere. Some tactical common links but none elsewhere	Some tactical commonality links at operational and strategic. Some tactical links, many strategic blockers				All respondents though well of the school buildings and spaces. The Sensors generally at current tactical levels were good. The more strategic readings however indicate a number of areas such as longer term culture and development which may require some of the actions identified to be executed to provide long term effectiveness.		

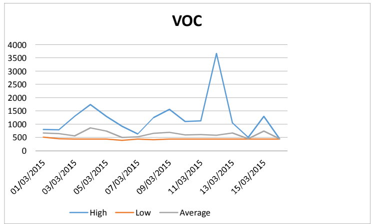
Table 3

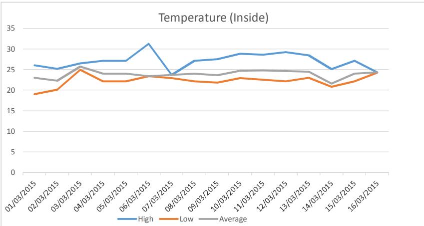
Sensor Daily Peak & Average Values

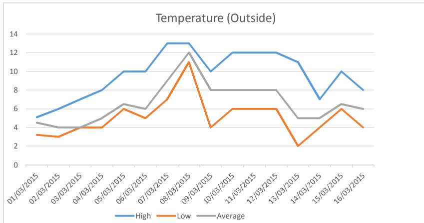
Tables and Graphs

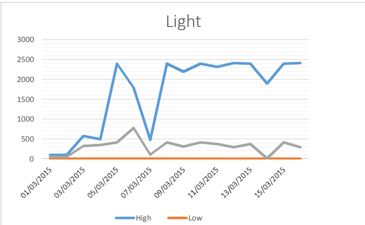
Sensor	S1																					
Location	Media Suite	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	16.0				
Date		**01/03/2015**	**02/03/2015**	**03/03/2015**	**04/03/2015**	**05/03/2015**	**06/03/2015**	**07/03/2015**	**08/03/2015**	**09/03/2015**	**10/03/2015**	**11/03/2015**	**12/03/2015**	**13/03/2015**	**14/03/2015**	**15/03/2015**	**16/03/2015**		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	26	25.2	26.5	27.1	27.1	31.2	23.7	27.1	27.5	28.8	28.6	29.2	28.4	25.1	27.1	24.3				31.2	
	Low	19	20.1	24.9	22.1	22.1	23.4	22.9	22.1	21.8	22.9	22.5	22.1	23	20.8	22.1	24.2					19
	Average	23	22.3	25.7	24	24	23.4	23.7	24	23.6	24.7	24.8	24.6	24.5	21.6	24	24.3		23.9	24.2		
	Temperature (Outside)																					
	High	5.1	6	7	8	10	10	13	13	10	12	12	12	11	7	10	8				13	
	Low	3.2	3	4	4	6	5	7	11	4	6	6	6	2	4	6	4					4
	Average	4.5	4	4	5	6.5	6	9	12	8	8	8	8	5	5	6.5	6		6.6	6.2		
	VOC																					
	High	802	791	1300	1752	1300	926	643	1251	1570	1106	1134	3676	1046	510	1300	455				3676	
	Low	512	453	450	450	450	400	450	420	450	450	450	450	450	450	450	450					400
	Average	670	650	568	864	750	508	534	657	693	601	608	589	672	456	750	453		626.4	632.4		
	Light																					
	High	101	99	572	497	2390	1793	477	2390	2192	2390	2313	2410	2390	1892	2390	2410				2410	
	Low	5	2	0	9	0	0	0	0	0	0	0	0	0	0	0	0					0
	Average	51	50	325	352	416	775	106	416	305	416	369	288	375	9	416	288		309.8	359.9		
	Noise																					
	High	44	47	54	72	57	74	56	57	72	57	69	78	80	49	57	43				80	
	Low	43	45	41	42	42	42	42	42	42	42	42	42	42	42	42	42					41
	Average	43	46	44	51	44	47	43	44	46	44	46	45	45	43	44	42		44.8	45.5		
	Humidity																					
	High	40	45	33	33	39	33	32	39	40	39	38	42	35	30	39	33				45	
	Low	36	32	26	10	29	25	25	29	27	29	27	20	22	23	29	33					10
	Average	37	36	28	27	35	28	30	35	35	35	33	31	27	28	35	33		32.1	31.6		
	Pressure																					
	High	1011	1018	1016	1028	1027	1029	1026	1027	1023	1027	1027	1024	1019	1025	1027	1018				1028	
	Low	1006	1010	1010	1025	1016	1023	1016	1016	1014	1016	1019	1014	1012	1019	1016	1015					1006
	Average	1010	1012	1013	1026	1022	1026	1021	1022	1019	1022	1023	1020	1016	1022	1022	1016		1019.5	1019.5		

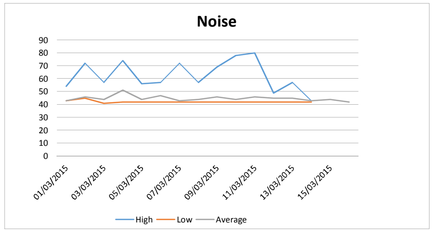
All data collected during a normal operational school day, 0900-1700 Mon - Friday

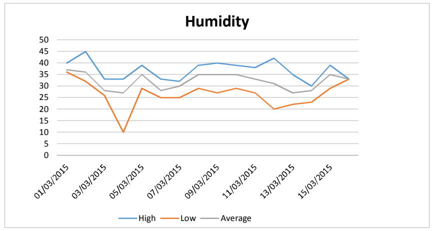


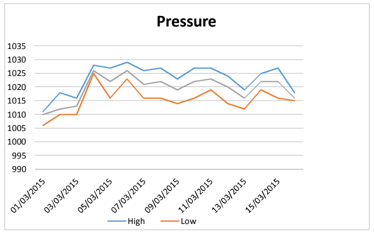






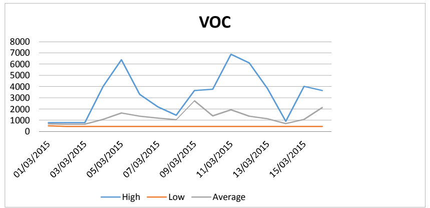


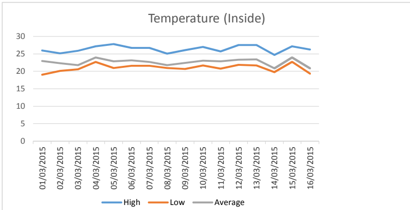


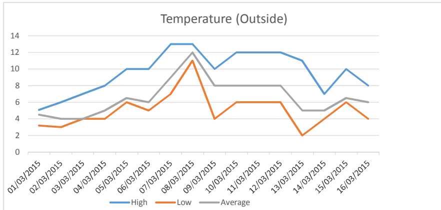


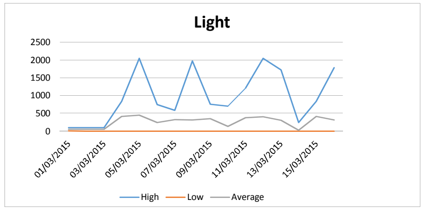
Sensor	D 3																					
Location	Quiet Study Area	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	16.0				
Date		**01/03/2015**	**02/03/2015**	**03/03/2015**	**04/03/2015**	**05/03/2015**	**06/03/2015**	**07/03/2015**	**08/03/2015**	**09/03/2015**	**10/03/2015**	**11/03/2015**	**12/03/2015**	**13/03/2015**	**14/03/2015**	**15/03/2015**	**16/03/2015**		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	26	25.2	25.9	27.2	27.8	26.7	26.7	25.1	26.1	27	25.7	27.6	27.6	24.7	27.2	26.3				27.6	
	Low	19	20.1	20.6	22.7	21	21.6	21.6	21	20.7	21.7	20.8	21.9	21.7	19.8	22.7	19.3					19
	Average	23	22.3	21.8	24	22.9	23.2	22.7	21.8	22.4	23.1	22.9	23.3	23.4	20.9	24	20.9		22.7	22.7		
	Temperature (Outside)																					
	High	5.1	6	7	8	10	10	13	13	10	12	12	12	11	7	10	8				13	
	Low	3.2	3	4	4	6	5	7	11	4	6	6	6	2	4	6	4					4
	Average	4.5	4	4	5	6.5	6	9	12	8	8	8	8	5	5	6.5	6		6.6	6.2		
	VOC																					
	High	802	791	784	4026	6418	3323	2204	1443	3647	3773	6898	6120	3832	913	4026	3647				6898	
	Low	512	453	450	450	450	450	450	450	450	450	450	450	450	450	450	450					450
	Average	670	650	647	1081	1653	1372	1193	1036	2740	1391	1932	1362	1122	698	1081	2143		1298.2	1463.0		
	Light																					
	High	101	99	99	843	2047	745	584	1983	758	701	1210	2047	1724	239	843	1793				2047	
	Low	5	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0					0
	Average	51	50	50	412	453	242	320	310	351	130	378	408	305	26	412	310		263.0	280.8		
	Noise																					
	High	44	47	47	77	80	82	59	45	68	76	75	77	72	55	77	74				82	
	Low	43	45	43	43	43	43	43	43	43	43	43	43	43	43	43	42					42
	Average	43	46	44	47	46	46	44	43	46	45	46	45	46	44	47	46		45.3	45.7		
	Humidity																					
	High	40	45	33	41	43	40	38	37	51	44	44	44	40	32	41	48				51	
	Low	36	32	28	26	27	28	30	30	31	29	27	23	25	25	26	28					25
	Average	37	36	33	33	34	35	36	35	39	37	36	34	32	31	33	36		34.8	35.0		
	Pressure																					
	High	1011	1018	1020	1033	1035	1033	1027	1019	1024	1026	1027	1024	1020	1025	1033	1020				1035	
	Low	1006	1010	1012	1023	1030	1024	1016	1013	1015	1016	1019	1015	1012	1019	1023	1014					1006
	Average	1010	1012	1016	1028	1032	1029	1021	1016	1019	1022	1023	1019	1015	1022	1028	1017		1020.6	1021.1		

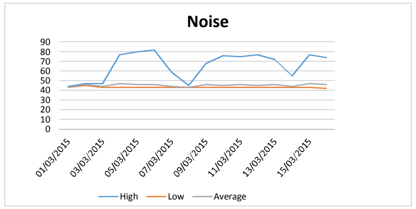
All data collected during a normal operational school day, 0900-1700 Mon - Friday

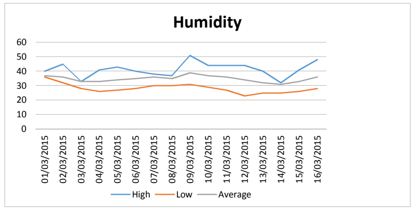


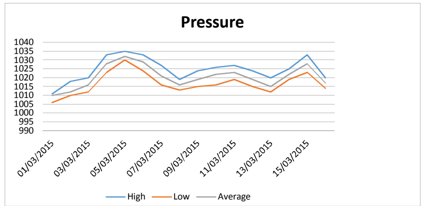






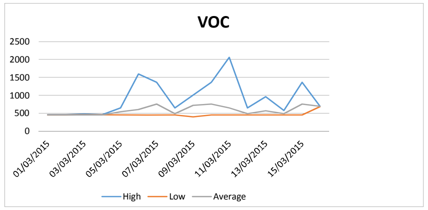


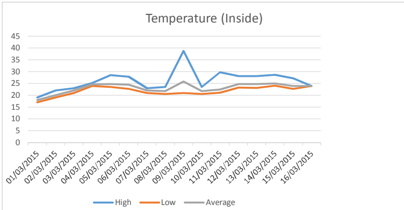


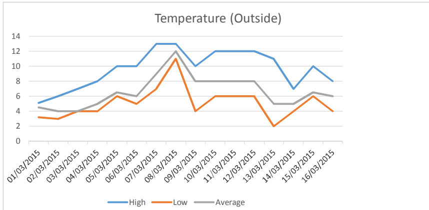


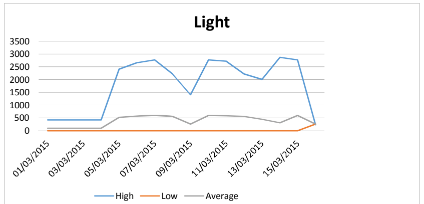
Sensor	B 2	Stat = 22																				
Location	UCAS Office	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	16.0				
Date		**01/03/2015**	**02/03/2015**	**03/03/2015**	**04/03/2015**	**05/03/2015**	**06/03/2015**	**07/03/2015**	**08/03/2015**	**09/03/2015**	**10/03/2015**	**11/03/2015**	**12/03/2015**	**13/03/2015**	**14/03/2015**	**15/03/2015**	**16/03/2015**		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	19	22	23	25.1	28.6	27.9	23	23.6	38.8	23.6	29.7	28.1	28.1	28.7	27.2	24				38.8	
	Low	17	19	21	24	23.5	22.7	21	20.5	20.9	20.5	21.1	23.3	23.1	24.1	22.7	24					17
	Average	18	20	22	24.6	24.7	24.5	22	21.8	25.8	21.8	22.5	24.8	24.8	25	24	24		23.1	23.6		
	Temperature (Outside)																					
	High	5.1	6	7	8	10	10	13	13	10	12	12	12	11	7	10	8				12	
	Low	3.2	3	4	4	6	5	7	11	4	6	6	6	2	4	6	4					5.1
	Average	4.5	4	4	5	6.5	6	9	12	8	8	8	8	5	5	6.5	6		6.6	6.2		
	VOC																					
	High	465	465	480	465	650	1596	1369	650	1005	1369	2066	650	968	582	1369	695				1596	
	Low	450	450	460	450	450	450	450	450	400	450	450	450	450	450	450	688					450
	Average	451	451	451	451	540	602	754	488	721	754	653	488	569	486	754	692		581.6	579.3		
	Light																					
	High	430	430	430	430	2410	2667	2779	2225	1417	2779	2721	2225	2020	2871	2779	246				2779	
	Low	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1	263					0
	Average	104	104	104	104	528	579	599	571	265	599	587	571	448	316	599	263		396.3	377.5		
	Noise																					
	High	48	48	48	48	65	63	69	64	57	69	64	64	73	47	69	42				73	
	Low	42	42	42	42	41	41	42	41	42	42	41	41	41	41	42	42					41
	Average	43	43	43	43	43	43	43	43	43	43	43	43	44	43	43	42		43.0	43.0		
	Humidity																					
	High	31	37	29	30	31	33	38	29	37	38	36	29	33	25	38	26				38	
	Low	28	15	20	29	24	11	24	20	15	24	24	20	18	18	24	26					15
	Average	29	30	26	29	29	30	32	26	30	32	30	26	24	23	32	26		28.4	28.4		
	Pressure																					
	High	1032	1032	1032	1032	1035	1034	1026	1025	1020	1026	1028	1025	1020	1026	1026	1017				1034	
	Low	1024	1024	1024	1024	1030	1026	1016	1015	1014	1016	1019	1015	1013	1020	1016	1015					1013
	Average	1028	1028	1028	1028	1033	1031	1022	1020	1017	1022	1023	1020	1016	1023	1022	1017		1023.6	1023.9		

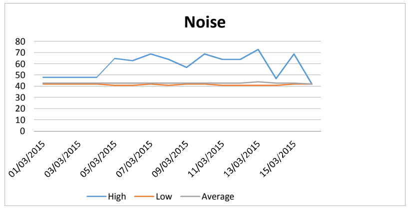
All data collected during a normal operational school day, 0900-1700 Mon - Friday

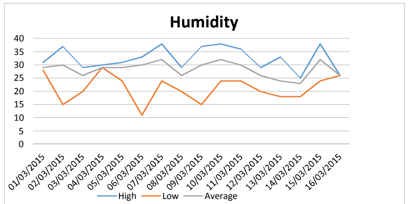


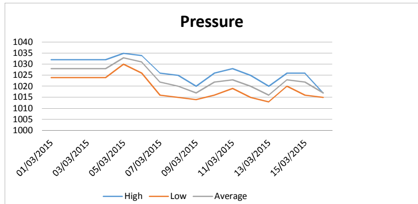






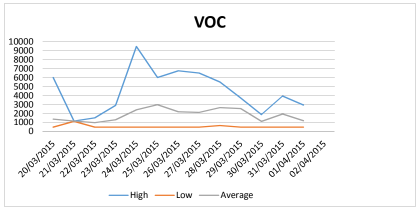


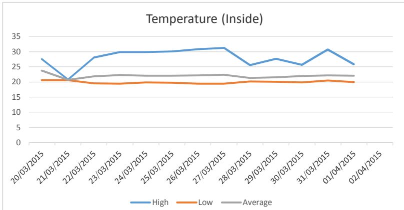


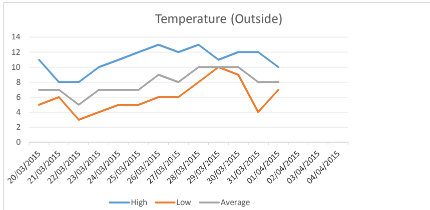


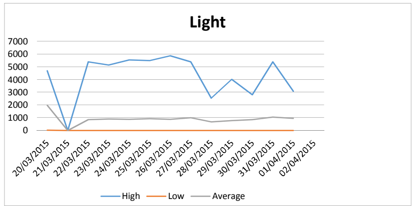
Sensor	D3																					
Location	Atrium	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	13.0				
Date		**20/03/2015**	**21/03/2015**	**22/03/2015**	**23/03/2015**	**24/03/2015**	**25/03/2015**	**26/03/2015**	**27/03/2015**	**28/03/2015**	**29/03/2015**	**30/03/2015**	**31/03/2015**	**01/04/2015**	**02/04/2015**	**03/04/2015**	**04/04/2015**		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	27.5	20.8	28.1	29.9	29.9	30.1	30.8	31.2	25.5	27.7	25.6	30.7	25.9							31.2	
	Low	20.6	20.6	19.5	19.4	19.8	19.7	19.4	19.4	20.2	20.1	19.8	20.5	19.9								19.4
	Average	23.8	20.7	21.9	22.3	22.1	22.1	22.2	22.4	21.3	21.5	22	22.2	22.1					22.0	22.4		
	Temperature (Outside)																					
	High	11	8	8	10	11	12	13	12	13	11	12	12	10							13	
	Low	5	6	3	4	5	5	6	6	8	10	9	4	7								4
	Average	7	7	5	7	7	7	9	8	10	10	10	8	8					7.9	7.9		
	VOC																					
	High	6016	1145	1482	2871	9474	6021	6762	6511	5486	3713	1842	3920	2912							9474	
	Low	450	1105	450	450	450	450	450	450	622	450	450	450	450								450
	Average	1341	1123	941	1292	2393	2960	2185	2107	2634	2524	1097	1906	1182					1821.9	1829.2		
	Light																					
	High	4693	2	5406	5143	5549	5498	5863	5406	2542	4014	2809	5406	3080							5863	
	Low	17	1	1	1	1	1	1	1	1	1	1	1	1								1
	Average	1991	2	847	896	880	921	864	988	685	772	842	1049	943					898.5	1041.6		
	Noise																					
	High	87	47	51	84	85	86	86	87	87	49	53	64	57							87	
	Low	44	44	43	43	43	43	43	43	44	44	43	44	43								43
	Average	56	46	45	50	51	51	51	52	47	46	46	46	46					48.7	49.9		
	Humidity																					
	High	45	36	37	39	47	46	45	45	43	42	39	40	37							47	
	Low	28	36	25	25	26	26	26	25	34	29	26	21	24								21
	Average	37	36	34	34	38	38	38	37	40	40	35	35	33					36.5	36.1		
	Pressure																					
	High	1024	1023	1023	1018	1008	1008	1007	1017	1016	1004	1008	1012	1020							1024	
	Low	1015	1020	1014	1005	1000	1000	993	1005	1000	987	992	990	1008								990
	Average	1019	1021	1019	1011	1003	1002	1000	1013	1007	995	1001	999	1015					1008.1	1007.0		

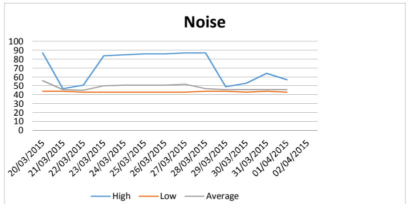
All data collected during a normal operational school day, 0900-1700 Mon - Friday

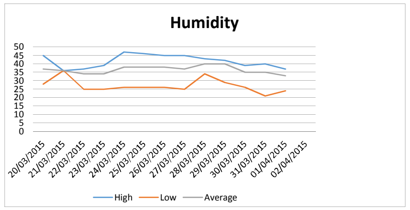


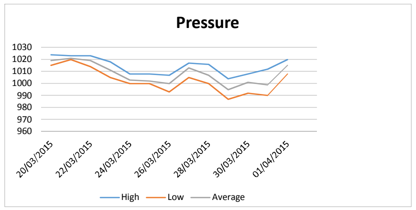












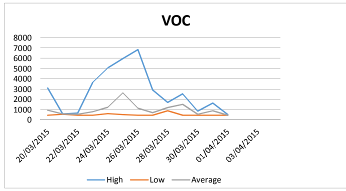
Sensor BR2
Location Room 30

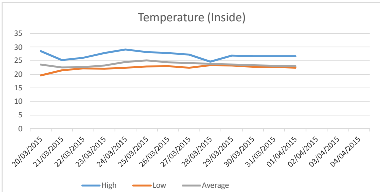
Date	F **20/03/2015**	S **21/03/2015**	S **22/03/2015**	M **23/03/2015**	T **24/03/2015**	W **25/03/2015**	T **26/03/2015**	F **27/03/2015**	S **28/03/2015**	S **29/03/2015**
Temperature (Sensor)										
High	28.5	25.2	26	27.8	29.1	28.2	27.8	27.2	24.6	26.9
Low	19.6	21.5	22.2	22.1	22.4	22.9	23	22.4	23.4	23.2
Average	23.6	22.5	22.6	23.2	24.5	25.1	24.4	24.1	23.9	23.6
Temperature (Outside)										
High	11	8	8	10	11	12	13	12	13	11
Low	5	6	3	4	5	5	6	6	8	10
Average	7	7	5	7	7	7	9	8	10	10
VOC										
High	3119	579	669	3688	5090	5987	6839	2922	1718	2562
Low	450	568	450	450	603	512	450	450	891	450
Average	965	573	555	797	1249	2631	1141	722	1214	1525
Light										
High	2452	0	309	1936	1913	1920	1947	1947	580	454
Low	0	0	0	0	0	0	0	0	0	0
Average	540	0	51	228	230	231	231	292	40	57
Noise										
High	90	43	45	73	75	72	73	83	51	54
Low	41	42	41	41	41	41	41	41	41	41
Average	49	43	43	45	44	44	44	46	42	42
Humidity										
High	39	29	29	38	38	39	31	34	33	36
Low	29	29	24	22	23	23	22	20	24	26
Average	33	29	28	28	30	30	27	25	30	33
Pressure										
High	1024	1022	1024	1019	1008	1008	1008	1017	1016	1004
Low	1016	1020	1015	1005	1000	1001	994	1006	1000	988
Average	1020	1021	1020	1012	1004	1003	1000	1013	1008	995

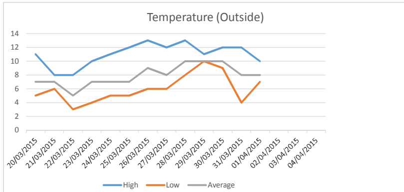
Date	M **30/03/2015**	T **31/03/2015**	W **01/04/2015**	T **02/04/2015**	F **03/04/2015**	S **04/04/2015**	16.0	**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
Temperature (Sensor)											
High	26.6	26.6	26.7							29.1	
Low	22.8	22.8	22.4								19.6
Average	23.3	23.1	23					23.6	23.8		
Temperature (Outside)											
High	12	12	10							13	
Low	9	4	7								5
Average	10	8	8					7.9	7.9		
VOC											
High	864	1639	517							3839	
Low	450	450	450								450
Average	548	885	464					1020.7	1044.7		
Light											
High	402	448	490							2452	
Low	0	0	0								0
Average	94	103	99					168.9	227.6		
Noise											
High	52	46	61							90	
Low	41	41	41								41
Average	42	42	42					43.7	44.2		
Humidity											
High	52	33	26							39	
Low	41	24	21								21
Average	42	29	25					29.9	29.9		
Pressure											
High	1008	1012	1021							1024	
Low	992	990	1009								992
Average	1001	1000	1016					1008.7	1007.7		

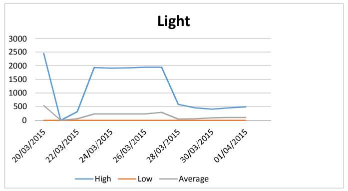
All data collected during a normal operational school day, 0900-1700 Mon - Friday

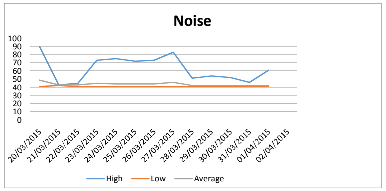

0300 and 1500 every day

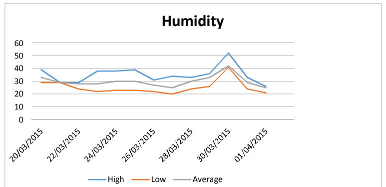


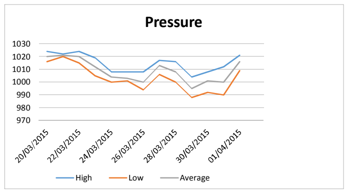






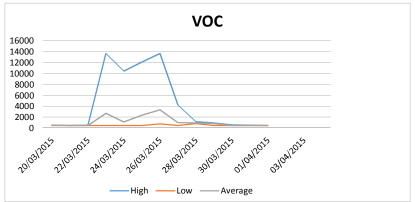


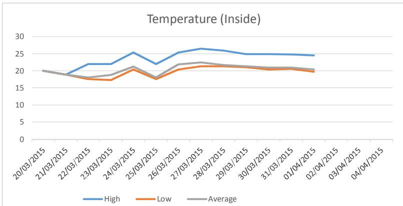


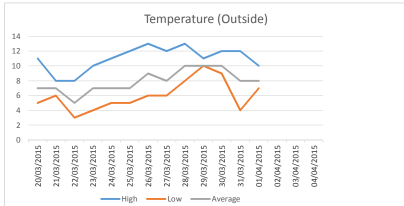


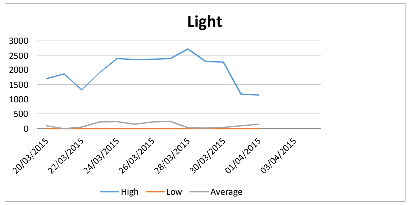
Sensor	S1																					
Location	Common Room	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	16.0				
Date		**20/03/2015**	**21/03/2015**	**22/03/2015**	**23/03/2015**	**24/03/2015**	**25/03/2015**	**26/03/2015**	**27/03/2015**	**28/03/2015**	**29/03/2015**	**30/03/2015**	**31/03/2015**	**01/04/2015**	**02/04/2015**	**03/04/2015**	**04/04/2015**		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	20	18.9	22	22	25.3	22	25.3	26.5	25.9	24.9	24.9	24.8	24.5							26.5	
	Low	20	18.9	17.6	17.3	20.4	17.6	20.4	21.3	21.3	21	20.4	20.6	19.7								17.3
	Average	20	18.9	18	18.8	21.2	18	21.9	22.4	21.7	21.3	20.9	20.9	20.4					16.5	20.5		
	Temperature (Outside)																					
	High	11	8	8	10	11	12	13	12	13	11	12	12	10							13	
	Low	5	6	3	4	5	5	6	6	8	10	9	4	7								5
	Average	7	7	5	7	7	7	9	8	10	10	10	8	8					6.4	7.9		
	VOC																					
	High	546	463	509	13647	10452	12088	13647	4230	1199	960	571	547	490								13647
	Low	482	450	450	450	450	450	737	450	790	450	450	450	450							450	
	Average	524	453	461	2692	1100	2356	3342	990	941	793	467	470	456					940.3	1377.4		
	Light																					
	High	1700	1874	1325	1913	2390	2366	2370	2390	2720	2294	2277	1181	1142							2390	
	Low	1	1	1	1	1	1	1	1	1	1	1	1	1								1
	Average	101	1	50	229	243	152	228	246	29	17	43	98	147					99.0	165.2		
	Noise																					
	High	44	46	47	80	89	88	83	84	75	47	59	62	54							89	
	Low	43	46	42	42	42	42	42	42	42	42	42	42	42								42
	Average	43	46	45	48	47	47	48	49	43	43	43	43	43					36.8	45.7		
	Humidity																					
	High	36	37	37	52	49	51	54	48	45	41	40	39	37							36	
	Low	36	37	30	29	31	30	28	29	29	33	33	32	31								28
	Average	36	37	36	39	39	39	41	39	38	40	39	38	36					31.1	38.4		
	Pressure																					
	High	1018	1023	1024	1018	1008	1008	1007	1017	1017	1003	1008	1011	1020							1024	
	Low	1016	1020	1015	1006	1000	1001	993	1005	1000	988	992	990	1008								990
	Average	1017	1021	1020	1012	1004	1003	1000	1013	1007	995	1001	1000	1016					819.3	1007.3		

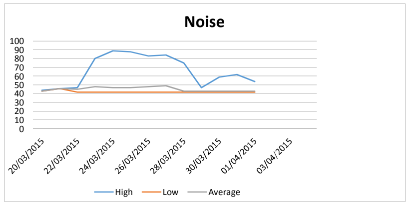
All data collected during a normal operational school day, 0900-1700 Mon - Friday

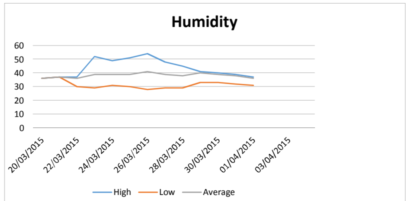


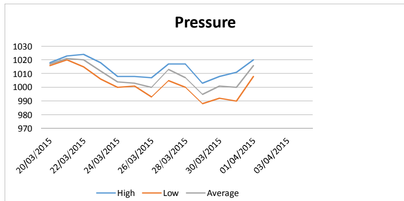






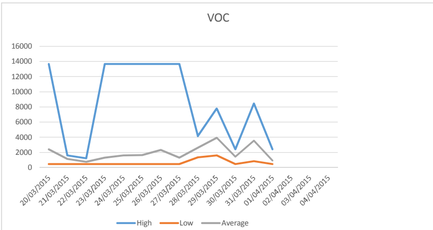


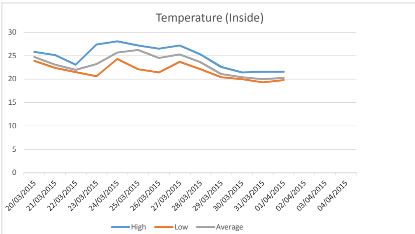


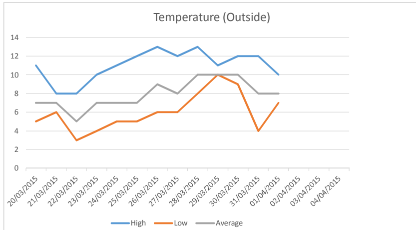


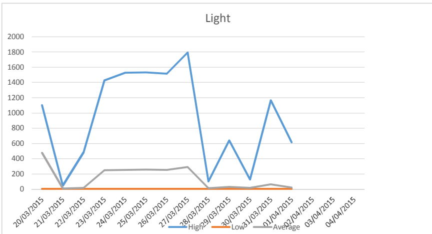
Sensor	K4																					
Location	Kitchen	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	16.0				
Date		**20/03/2015**	**21/03/2015**	**22/03/2015**	**23/03/2015**	**24/03/2015**	**25/03/2015**	**26/03/2015**	**27/03/2015**	**28/03/2015**	**29/03/2015**	**30/03/2015**	**31/03/2015**	**01/04/2015**	**02/04/2015**	**03/04/2015**	**04/04/2015**		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	25.8	25.1	23.1	27.4	28.1	27.2	26.5	27.2	25.3	22.6	21.4	21.6	21.6							27.2	
	Low	23.9	22.4	21.5	20.6	24.3	22.1	21.4	23.7	22.1	20.4	20	19.3	19.8								19.3
	Average	24.7	23.1	22	23.2	25.7	26.2	24.5	25.3	23.6	21.1	20.4	20	20.3					23.1	23.4		
	Temperature (Outside)																					
	High	11	8	8	10	11	12	13	12	13	11	12	12	10							13	
	Low	5	6	3	4	5	5	6	6	8	10	9	4	7								3
	Average	7	7	5	7	7	7	9	8	10	10	10	8	8					7.9	7.9		
	VOC																					
	High	13647	1592	1207	13647	13647	13647	13647	13647	4138	7778	2414	8481	2419							13647	
	Low	450	450	450	450	450	450	450	450	1365	1602	450	852	450								450
	Average	2418	1124	763	1296	1593	1650	2340	1297	2620	3913	1439	3560	939					1919.4	1836.9		
	Light																					
	High	1102	49	483	1426	1527	1531	1516	1793	100	639	126	1165	617							1793	
	Low	4	4	4	4	5	4	5	6	6	6	6	6	6								4
	Average	476	9	16	251	255	257	253	290	12	31	16	64	20					150.0	209.1		
	Noise																					
	High	80	49	49	86	83	81	77	82	67	48	62	66	64							48	
	Low	47	46	46	46	46	46	46	46	46	46	46	46	46								46
	Average	56	47	47	51	51	52	51	51	47	47	47	47	47					49.3	50.3		
	Humidity																					
	High	50	34	32	45	46	47	49	43	38	43	62	43	37							50	
	Low	27	30	28	25	25	25	24	23	30	34	46	32	28								23
	Average	33	32	31	30	30	31	31	28	34	38	47	38	31					33.4	33.2		
	Pressure																					
	High	1025	1023	1024	1019	1008	1007	1007	1017	1017	1004	1008	1012	1021							1025	
	Low	1017	1014	1015	1005	1006	1001	994	1006	1001	988	993	990	1009								993
	Average	1020	1019	1020	1012	1007	1003	1000	1013	1008	996	1001	1000	1016					1008.8	1008.0		

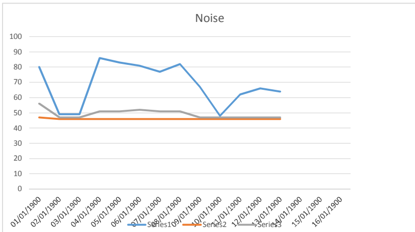
All data collected during a normal operational school day, 0900-1700 Mon - Friday

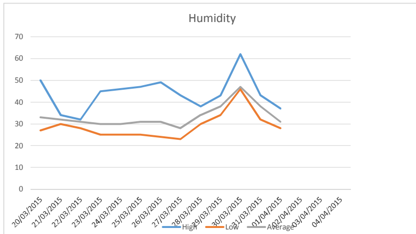


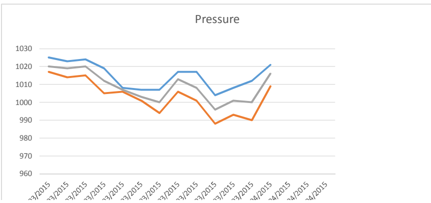






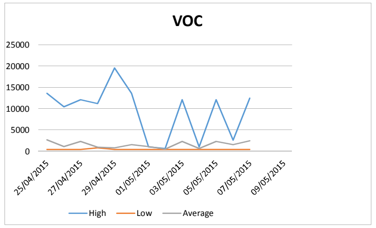


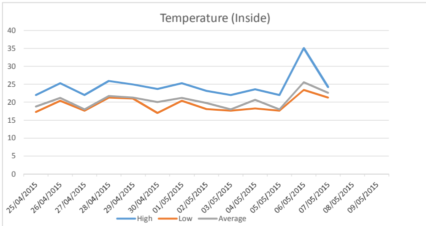


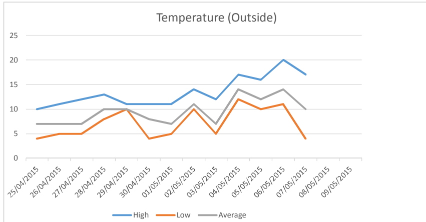


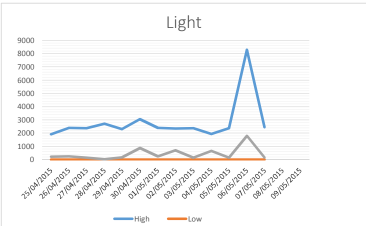
Sensor	S1																				
Location	Room 7 Downstairs	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	16.0				
Date		**25/04/2015**	**26/04/2015**	**27/04/2015**	**28/04/2015**	**29/04/2015**	**30/04/2015**	**01/05/2015**	**02/05/2015**	**03/05/2015**	**04/05/2015**	**05/05/2015**	**06/05/2015**	**07/05/2015**	**08/05/2015**	**09/05/2015**	**10/05/2015**	**11/05/2015**	**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	22	25.3	22	25.9	24.9	23.7	25.3	23.2	22	23.6	22	35.1	24.2							35.1	
	Low	17.3	20.4	17.6	21.3	21	17	20.4	18.1	17.6	18.3	17.6	23.4	21.3								18
	Average	18.8	21.2	18	21.7	21.3	20	21.2	19.8	18	20.7	18	25.6	22.6					20.5	21.0		
	Temperature (Outside)																					
	High	10	11	12	13	11	11	11	14	12	17	16	20	17							17	
	Low	4	5	5	8	10	4	5	10	5	12	10	11	4								5
	Average	7	7	7	10	10	8	7	11	7	14	12	14	10					9.5	10.2		
	VOC																					
	High	13647	10452	12088	11199	19610	13647	1052	631	12088	1059	12088	2654	12460							13647	
	Low	450	450	450	790	450	450	450	450	450	450	450	450	450								450
	Average	2692	1100	2356	941	793	1608	1100	520	2356	675	2356	1541	2466					1577.2	1537.3		
	Light																					
	High	1913	2390	2366	2720	2294	3042	2395	2350	2366	1947	2366	8286	2452							8286	
	Low	1	1	1	1	1	0	1	0	1	0	1	0	0								0
	Average	229	243	152	29	170	874	255	712	152	657	152	1798	154					429.0	471.2		
	Noise																					
	High	80	89	88	75	47	86	90	56	88	52	88	82	80							90	
	Low	42	42	42	42	42	42	42	42	42	42	42	43	44								42
	Average	48	47	47	43	43	48	48	44	47	44	47	49	48					46.4	46.3		
	Humidity																					
	High	52	49	51	45	41	56	50	42	51	47	51	47	55							56	
	Low	29	31	30	29	33	24	31	34	30	36	30	28	31								24
	Average	39	39	39	38	40	40	40	39	39	43	39	43	43					40.1	40.6		
	Pressure																					
	High	1018	1008	1008	1017	1003	1015	1008	1009	1008	1002	1008	1016	1017							1018	
	Low	1006	1000	1001	1000	988	1004	1001	998	1001	993	1001	1011	1011								993
	Average	1012	1004	1003	1007	995	1010	1004	1004	1003	998	1003	1013	1014					1005.4	1005.2		

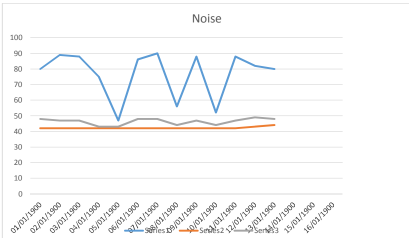
All data collected during a normal operational school day, 0900-1700 Mon - Friday

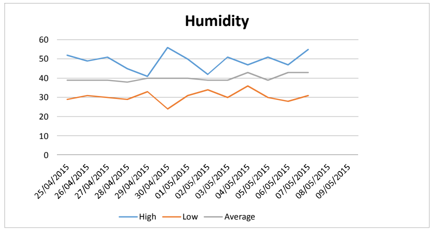


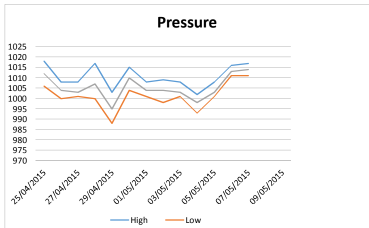








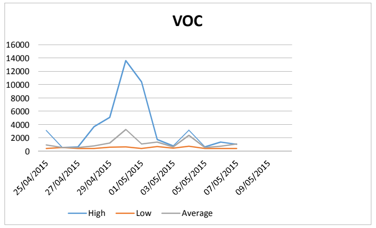


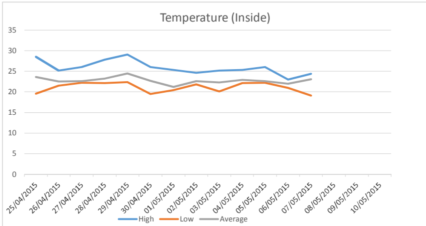


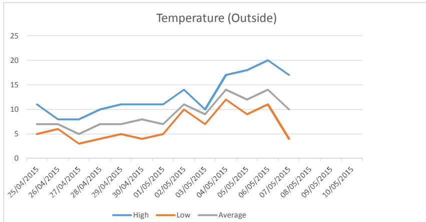
Sensor	BR 2													
Location	ICT B - Down stairs	S	S	M	T	W	T	F	S	S	M	T	W	T
Date		**25/04/2015**	**26/04/2015**	**27/04/2015**	**28/04/2015**	**29/04/2015**	**30/04/2015**	**01/05/2015**	**02/05/2015**	**03/05/2015**	**04/05/2015**	**05/05/2015**	**06/05/2015**	**07/05/2015**
	Temperature (Sensor)													
	High	28.5	25.2	26	27.8	29.1	26	25.3	24.6	25.2	25.3	26	23	24.4
	Low	19.6	21.5	22.2	22.1	22.4	19.5	20.4	21.8	20.1	22.1	22.2	21	19.1
	Average	23.6	22.5	22.6	23.2	24.5	22.7	21.2	22.6	22.3	22.9	22.6	22	23.1
	Temperature (Outside)													
	High	11	8	8	10	11	11	11	14	10	17	18	20	17
	Low	5	6	3	4	5	4	5	10	7	12	9	11	4
	Average	7	7	5	7	7	8	7	11	9	14	12	14	10
	VOC													
	High	3119	579	669	3688	5090	13647	10452	1755	791	3197	669	1369	1052
	Low	450	568	450	450	603	664	450	726	453	782	450	450	450
	Average	965	573	555	797	1249	3285	1100	1391	650	2416	555	754	1100
	Light													
	High	2452	0	309	1936	1913	2020	2390	1793	99	8.7	309	2779	2395
	Low	0	0	0	0	0	0	1	1	2	1	0	1	1
	Average	540	0	51	228	230	470	243	182	50	175	51	599	255
	Noise													
	High	90	43	45	73	75	92	89	75	47	52	45	69	90
	Low	41	42	41	41	41	43	42	43	45	43	41	42	42
	Average	49	43	43	45	44	50	47	45	46	45	43	43	48
	Humidity													
	High	39	29	29	38	38	52	49	34	45	38	29	38	50
	Low	29	29	24	22	23	24	31	29	32	32	24	24	31
	Average	33	29	28	28	30	32	39	32	36	37	28	32	40
	Pressure													
	High	1024	1022	1024	1019	1008	1015	1008	1019	1018	1003	1024	1026	1008
	Low	1016	1020	1015	1005	1000	1005	1000	1005	1010	993	1015	1016	1001
	Average	1020	1021	1020	1012	1004	1010	1004	1012	1012	998	1020	1022	1004

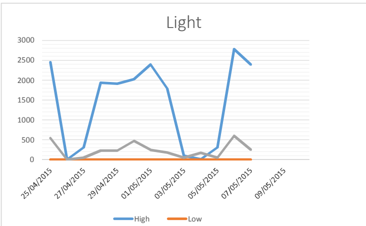
	F	S	S	16.0				
	08/05/2015	**09/05/2015**	**10/05/2015**	**####**	**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
Temperature (Sensor)								
High							29.1	
Low								19.1
Average					22.8	22.8		
Temperature (Outside)								
High							20	
Low								3
Average					9.1	9.3		
VOC								
High							13647	
Low								450
Average					1183.8	1312.3		
Light								
High							2779	
Low								0
Average					236.5	255.8		
Noise								
High							90	
Low								41
Average					45.5	45.3		
Humidity								
High							29	
Low								22
Average					32.6	32.7		
Pressure								
High							1026	
Low								993
Average					1012.2	1010.4		

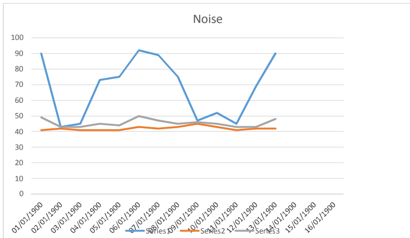
All data collected during a normal operational school day, 0900-1700 Mon - Friday

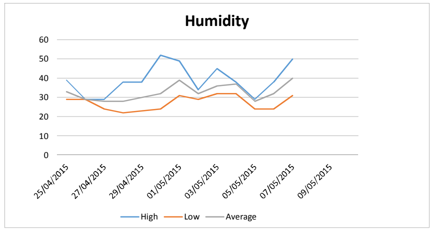


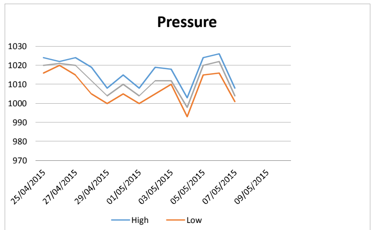






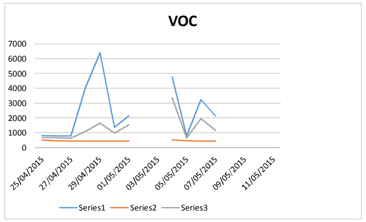


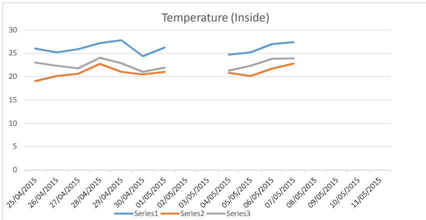


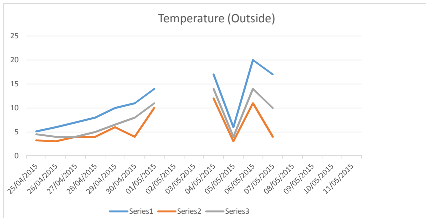


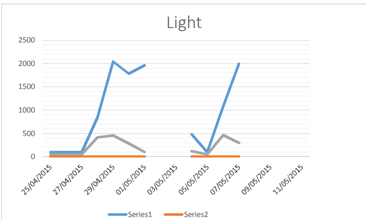
Sensor	D 3																					
Location	Lecture Theatre	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	16.0				
Date		**25/04/2015**	**26/04/2015**	**27/04/2015**	**28/04/2015**	**29/04/2015**	**30/04/2015**	**01/05/2015**	**02/05/2015**	**03/05/2015**	**04/05/2015**	**05/05/2015**	**06/05/2015**	**07/05/2015**	**08/05/2015**	**09/05/2015**	**10/05/2015**	**####**	**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High	26	25.2	25.9	27.2	27.8	24.4	26.2			24.7	25.2	27	27.4							27.8	
	Low	19	20.1	20.6	22.7	21	20.5	21			20.8	20.1	21.7	22.8								19
	Average	23	22.3	21.8	24	22.9	21	21.9			21.3	22.3	23.8	23.9					22.6	20.1		
	Temperature (Outside)																					
	High	5.1	6	7	8	10	11	14			17	6	20	17							20	
	Low	3.2	3	4	4	6	4	10			12	3	11	4								3
	Average	4.5	4	4	5	6.5	8	11			14	4	14	10					7.7	7.3		
	VOC																					
	High	802	791	784	4026	6418	1364	2153			4763	791	3253	2124							4763	
	Low	512	453	450	450	450	450	450			525	453	450	450								450
	Average	670	650	647	1081	1653	987	1552			3352	650	1959	1164					1305.9	1277.0		
	Light																					
	High	101	99	99	843	2047	1784	1959			484	99	1085	1995							2047	
	Low	5	2	2	0	0	1	0			0	2	0	0								0
	Average	51	50	50	412	453	284	101			118	50	460	295					211.3	235.8		
	Noise																					
	High	44	47	47	77	80	75	60			46	47	75	76							80	
	Low	43	45	43	43	43	43	43			42	45	43	43								42
	Average	43	46	44	47	46	45	44			43	46	46	46					45.1	40.3		
	Humidity																					
	High	40	45	33	41	43	42	35			41	45	47	44							47	
	Low	36	32	28	26	27	25	28			33	32	38	34								25
	Average	37	36	33	33	34	33	34			39	36	43	41					36.3	32.4		
	Pressure																					
	High	1011	1018	1020	1033	1035	1014	1008			1002	1018	1015	1018							1035	
	Low	1006	1010	1012	1023	1030	1004	998			993	1010	1011	1009								993
	Average	1010	1012	1016	1028	1032	1009	1004			997	1012	1013	1013					1013.3	902.2		

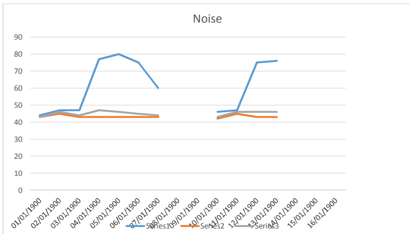
All data collected during a normal operational school day, 0900-1700 Mon - Friday

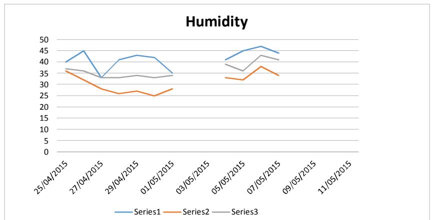


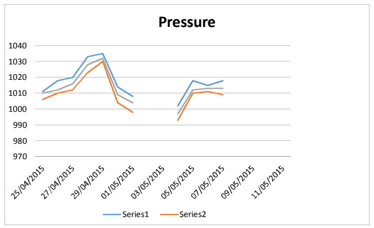






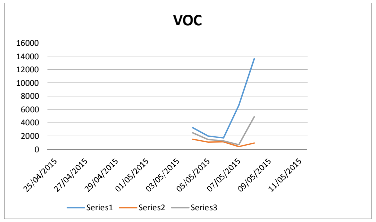


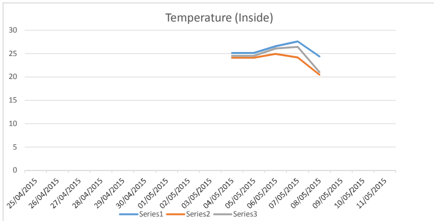


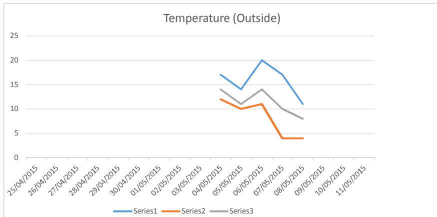


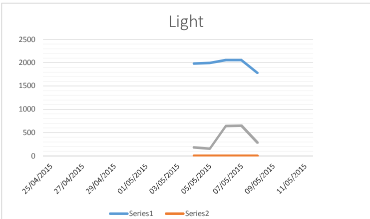
Sensor	K																					
Location	HE Room	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	16.0				
Date		**25/04/2015**	**26/04/2015**	**27/04/2015**	**28/04/2015**	**29/04/2015**	**30/04/2015**	**01/05/2015**	**02/05/2015**	**03/05/2015**	**04/05/2015**	**05/05/2015**	**06/05/2015**	**07/05/2015**	**08/05/2015**	**09/05/2015**	**10/05/2015**	**11/05/2015**	**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**
	Temperature (Sensor)																					
	High										25.1	25.1	26.6	27.6	24.4						27.6	
	Low										24.1	24.1	24.9	24.2	20.5							20.5
	Average										24.5	24.5	26.1	26.4	21				24.5	24.5		
	Temperature (Outside)																					
	High										17	14	20	17	11						11	
	Low										12	10	11	4	4							4
	Average										14	11	14	10	8				11.4	11.4		
	VOC																					
	High										3280	1996	1745	6622	13647						13647	
	Low										1554	1099	1154	450	944							450
	Average										2507	1508	1317	729	4928				2197.8	2197.8		
	Light																					
	High										1983	1995	2060	2060	1784						2060	
	Low										1	0	1	0	1							0
	Average										183	152	644	647	284				382.0	382.0		
	Noise																					
	High										51	49	63	85	75						85	
	Low										42	41	42	42	43							41
	Average										46	45	45	47	45				45.6	45.6		
	Humidity																					
	High										37	32	40	50	42						50	
	Low										34	27	38	27	25							25
	Average										36	30	39	33	33				34.2	34.2		
	Pressure																					
	High										1002	1009	1016	1018	1014						1018	
	Low										994	998	1011	1010	1004							994
	Average										998	1005	1013	1015	1009				1008.0	1008.0		

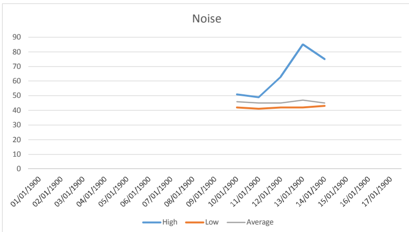
All data collected during a normal operational school day, 0900-1700 Mon - Friday

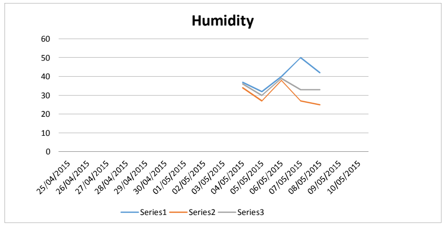












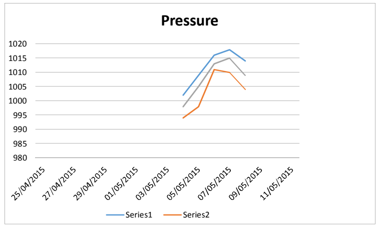
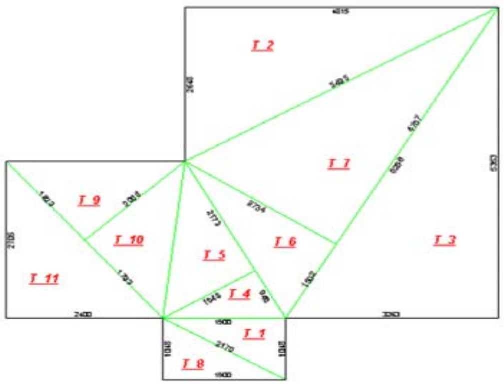


Table 4

Sensor RAG Analysis by Space

Direct Building Physics	Direct Building Physics
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red



#	Calculation	Area
	Triangles	
1	½ * 1900 * 1048	1 m²
2	½ * 2648 * 4815	6 m²
3	½ * 5353 * 3263	9 m²
4	½ * 1648 * 946	1 m²
5	½ * 1648 * 2173	2 m²
6	½ * 2734 * 1502	2 m²
7	½ * 2734 * 4767	7 m²
8	½ * 1900 * 1048	1 m²
9	½ * 2055 * 1823	2 m²
10	½ * 2055 * 1793	2 m²
11	½ * 2400 * 2705	3 m²
	Gross area is 35 m².	

S1

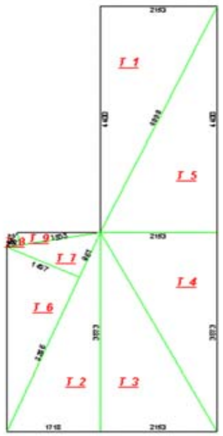
Media Suite	Actual Average Overall	Average Weekday	Peak High	Peak Low	Specification High	Low	RAG	Ave
Temperature (Sensor)								
High			31.2		26			
Low				19.0		23		
Average	23.9	24.2						
Temperature (Outside)								
High			13.0					
Low				4.0				
Average	6.6	6.2						
VOC								
High			3676.0		1000			
Low				400.0		450		
Average	626.4	632.4						
Light								
High			2410.0		8000			
Low				0.0		300		
Average	309.8	359.9						
Noise								
High			80.0		60			
Low				41.0		40		
Average	44.8	45.5						
Humidity								
High			45.0		55			
Low				10.0		45		
Average	32.1	31.6						
Pressure								
High			1028.0					
Low				1006.0				
Average	1019.5	1019.5						

Overall Rating based on weekday average

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Direct Building Physics	Direct Building Physics
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

#	Calculation	Area
	Triangles	
1	½ * 4400 * 2153	5 m²
2	½ * 3873 * 1718	3 m²
3	½ * 3873 * 2153	4 m²
4	½ * 2153 * 3873	4 m²
5	½ * 2153 * 4400	5 m²
6	½ * 1457 * 3285	2 m²
7	½ * 1457 * 951	1 m²
8	½ * 244 * 237	0 m²
9	½ * 244 * 1503	0 m²
	Gross area is 24 m².	



							Specification		
Sensor	D 3								
Location	Quiet Study Area	16.0							
Date			Average Overall	Average Weekday	Peak High	Peak Low	High	Low	RAG
	Temperature (Sensor)								
	High				27.6		26		
	Low					19.0		23	
	Average		22.7	22.7					
	Temperature (Outside)								
	High				13.0				
	Low					3.2			
	Average		6.6	6.2					
	VOC								
	High				6898.0		1000		
	Low					450.0		450	
	Average		1298.2	1463.0					
	Light								
	High				2047.0		8000		
	Low					0.0		300	
	Average		263.0	280.8					
	Noise								
	High				82.0		60		
	Low					42.0		40	
	Average		45.3	45.7					
	Humidity								
	High				51.0		55		
	Low					25.0		45	
	Average		34.8	35.0					
	Pressure								
	High				1035.0				
	Low					1006.0			
	Average		1020.6	1021.1					

Overall Rating based on weekday average

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

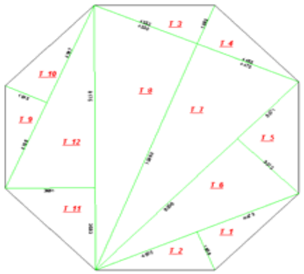
Sensor	B 2								
Location	UCAS Office	16.0					**Specification**		
Date			**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**
	Temperature (Sensor)								
	High				38.8		26		
	Low					17.0		23	
	Average		23.1	23.6					
	Temperature (Outside)								
	High				12.0				
	Low					5.1			
	Average		6.6	6.2					
	VOC								
	High				1596.0		1000		
	Low					450.0		450	
	Average		581.6	579.3					
	Light								
	High				2779.0		8000		
	Low					0.0		300	
	Average		396.3	377.5					
	Noise								
	High				73.0		60		
	Low					41.0		40	
	Average		43.0	43.0					
	Humidity								
	High				38.0		55		
	Low					15.0		45	
	Average		28.4	28.4					
	Pressure								
	High				1034.0				
	Low					1013.0			
	Average		1023.6	1023.9					

Overall Rating based on weekday average

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Direct Building Physics	Direct Building Physics
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

#	Calculation	Area
	Triangles	
1	½ * 1858 * 4473	4 m²
2	½ * 1858 * 4500	4 m²
3	½ * 1868 * 4552	4 m²
4	½ * 1868 * 4468	4 m²
5	½ * 3512 * 3571	6 m²
6	½ * 3512 * 8256	14 m²
7	½ * 10950 * 4470	24 m²
8	½ * 10950 * 4550	25 m²
9	½ * 1848 * 4186	4 m²
10	½ * 1848 * 4767	4 m²
11	½ * 3651 * 3683	7 m²
12	½ * 3651 * 8175	15 m²
	Gross area is 117 m².	



						Specification High	Low
Sensor	D3						
Location	Atrium						
Date		Average Over	Average Weekday	Peak High	Peak Low	High	Low
	Temperature (Sensor)						
	High			31.2		26	
	Low				19.4		23
	Average	22.0	22.4				
	Temperature (Outside)						
	High			13			
	Low				4		
	Average	7.9	7.9				
	VOC						
	High			9474		1000	
	Low				450		450
	Average	1821.9	1829.2				
	Light						
	High			5863		8000	
	Low				1		300
	Average	898.5	1041.6				
	Noise						
	High			87		60	
	Low				43		40
	Average	48.7	49.9				
	Humidity						
	High			47		55	
	Low				21		45
	Average	36.5	36.1				
	Pressure						
	High			1024			
	Low				990		
	Average	1008.1	1007.0				

RAG

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Overall Rating based on weekday average

Direct Building Physics	Direct Building Physics	
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	

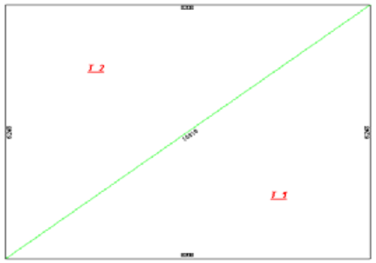
						Specification		
Sensor	BR2							
Location	Room 30							
Date		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**
	Temperature (Sensor)							
	High			29.1		26		
	Low				19.6		23	
	Average	23.6	23.8					
	Temperature (Outside)							
	High			13				
	Low				5			
	Average	7.9	7.9					
	VOC							
	High			3839		1000		
	Low				450		450	
	Average	1020.7	1044.7					
	Light							
	High			2452		8000		
	Low				0		300	
	Average	168.9	227.6					
	Noise							
	High			90		60		
	Low				41		40	
	Average	43.7	44.2					
	Humidity							
	High			39		55		
	Low				21		45	
	Average	29.9	29.9					
	Pressure							
	High			1024				
	Low				992			
	Average	1008.7	1007.7					

Overall Rating based on weekday average

Ambient Li	300	8000
Max Temp	26	
Min Temp		23
Max Humi	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Direct Building Physics	Direct Building Physics
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

#	Calculation	Area
Triangles		
1	½ * 6248 * 8208	26 m²
2	½ * 6248 * 8208	26 m²
Gross area is 51 m².		

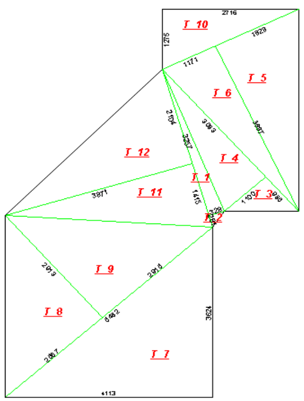


Sensor	S1							
Location	Common Room					**Specification**		
Date		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**
	Temperature (Sensor)							
	High			26.5		26		
	Low				17.3		23	
	Average	16.5	20.5					
	Temperature (Outside)							
	High			13				
	Low				5			
	Average	6.4	7.9					
	VOC							
	High				13647	1000		
	Low			450			450	
	Average	940.3	1377.4					
	Light							
	High			2390		8000		
	Low				1		300	
	Average	99.0	165.2					
	Noise							
	High			89		60		
	Low				42		40	
	Average	36.8	45.7					
	Humidity							
	High			36		55		
	Low				28		45	
	Average	31.1	38.4					
	Pressure							
	High			1024				
	Low				990			
	Average	819.3	1007.3					

Overall Rating based on weekday average

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Direct Building Physics	Direct Building Physics	
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	?
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	



#	Calculation	Area
	Triangles	
1	½ * 328 * 3257	1 m²
2	½ * 328 * 261	0 m²
3	½ * 1100 * 986	1 m²
4	½ * 1100 * 3083	2 m²
5	½ * 3897 * 1829	4 m²
6	½ * 3897 * 1171	2 m²
7	½ * 3624 * 4113	7 m²
8	½ * 2913 * 2567	4 m²
9	½ * 2913 * 2915	4 m²
10	½ * 1275 * 2716	2 m²
11	½ * 3871 * 1415	3 m²
12	½ * 3871 * 2104	4 m²
	Gross area is 33 m².	

						Specification			
Sensor	K4								
Location	Kitchen								
Date		Average Overall	Average Weekday	Peak High	Peak Low	High	Low	RAG	
	Temperature (Sensor)								
	High			27.2		26			
	Low				19.3		23		
	Average	23.1	23.4						
	Temperature (Outside)								
	High			13					
	Low				3				
	Average	7.9	7.9						
	VOC								
	High			13647		1000			
	Low				450		450		
	Average	1919.4	1836.9						
	Light								
	High			1793		8000			
	Low				4		300		
	Average	150.0	209.1						
	Noise								
	High			48		60			
	Low				46		40		
	Average	49.3	50.3						
	Humidity								
	High			50		55			
	Low				23		45		
	Average	33.4	33.2						
	Pressure								
	High			1025					
	Low				993				
	Average	1008.8	1008.0						
									Overall Rating based on weekday average

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Direct Building Physics	Direct Building Physics	
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	?
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	

Sensor	S1							
Location	Room 7 Downstairs					**Specification**		
Date		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**
	Temperature (Sensor)							
	High			35.1		26		
	Low				18		23	
	Average	20.5	21.0					
	Temperature (Outside)							
	High			17				
	Low				5			
	Average	9.5	10.2					
	VOC							
	High			13647		1000		
	Low				450		450	
	Average	1577.2	1537.3					
	Light							
	High			8286		8000		
	Low				0		300	
	Average	429.0	471.2					
	Noise							
	High			90		60		
	Low				42		40	
	Average	46.4	46.3					
	Humidity							
	High			56		55		
	Low				24		45	
	Average	40.1	40.6					
	Pressure							
	High			1018				
	Low				993			
	Average	1005.4	1005.2					

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Overall Rating based on weekday average

Direct Building Physics	Direct Building Physics	
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	?
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red	

						Specification		
Sensor	BR 2							
Location	ICT B - Down stairs							
Date		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**
	Temperature (Sensor)							
	High			29.1		26		
	Low				19.1		23	
	Average	22.8	22.8					
	Temperature (Outside)							
	High			20				
	Low				3			
	Average	9.1	9.3					
	VOC							
	High			13647		1000		
	Low				450		450	
	Average	1183.8	1312.3					
	Light							
	High			2779		8000		
	Low				0		300	
	Average	236.5	255.8					
	Noise							
	High			90		60		
	Low				41		40	
	Average	45.5	45.3					
	Humidity							
	High			29		55		
	Low				22		45	
	Average	32.6	32.7					
	Pressure							
	High			1026				
	Low				993			
	Average	1012.2	1010.4					

Overall Rating based on weekday average

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Direct Building Physics	Direct Building Physics
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green If No = Red

		Average Overall	Average Weekday	Peak High	Peak Low	Specification High	Low	RAG
Sensor	D 3							
Location	Lecture Theatre							
Date								
	Temperature (Sensor)							
	High			27.8		26		
	Low				19		23	
	Average	22.6	20.1					
	Temperature (Outside)							
	High			20				
	Low				3			
	Average	7.7	7.3					
	VOC							
	High			4763		1000		
	Low				450		450	
	Average	1305.9	1277.0					
	Light							
	High			2047		8000		
	Low				0		300	
	Average	211.3	235.8					
	Noise							
	High			80		60		
	Low				42		40	
	Average	45.1	40.3					
	Humidity							
	High			47		55		
	Low				25		45	
	Average	36.3	32.4					
	Pressure							
	High			1035				
	Low				993			
	Average	1013.3	902.2					

Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

Overall Rating based on weekday average

Direct Building Physics	Direct Building Physics	
The building spaces are operating within its briefed cost envelope	Where SOFI.World = User.role AND User.Space_Description THEN P_Rooms.Room_Target_Cost <= Impact.Name.Cost	
Calculation to check if the actual delivered spaces meet the spaces specified in the brief and standards	p_room.requirednettarea >= space.nettarea	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors related to the consumption of fossil fuels	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp If Yes = Green If No = Red	
Comparison of identified environmental performance specified in the brief and the actual data collected using the remore sensors	Where SOFI.World = User.role AND User.Space_Description THEN Sensor_Data.Light = P_Rooms.AmbientLight +/- 10% (or tolerance as briefed) Sensor_Data.Thermal < P_Rooms.MaxTemp Sensor_Data.Thermal > P_Rooms.MinTemp Sensor_Data.Humidity < P_Rooms.MaxHumidity Sensor_Data.Humidity > P_Rooms.MinHumidity Sensor_Data.Noise = P_Rooms.NoiseLevel +/- 10% (or tolerance as briefed) Sensor_Data.VOC = P_Rooms.AirRecycle +/- 10% (or tolerance as briefed) If Yes = Green	

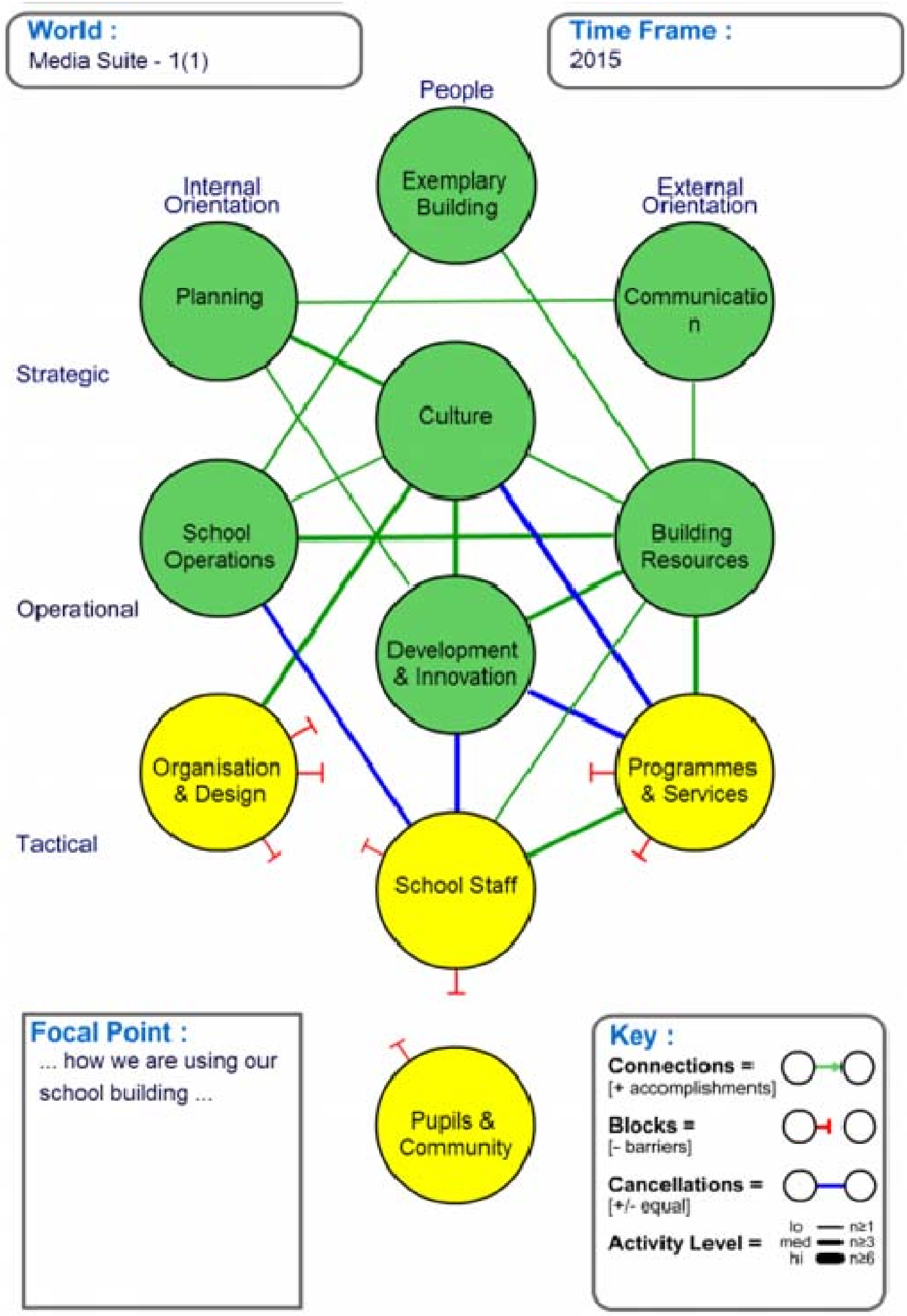
Sensor	K							
Location	??					**Specification**		
Date		**Average Overall**	**Average Weekday**	**Peak High**	**Peak Low**	**High**	**Low**	**RAG**
	Temperature (Sensor)							
	High			27.6		26		
	Low				20.5		23	
	Average	24.5	24.5					
	Temperature (Outside)							
	High			11				
	Low				4			
	Average	11.4	11.4					
	VOC							
	High			13647		1000		
	Low				450		450	
	Average	2197.8	2197.8					
	Light							
	High			2060		8000		
	Low				0		300	
	Average	382.0	382.0					
	Noise							
	High			85		60		
	Low				41		40	
	Average	45.6	45.6					
	Humidity							
	High			50		55		
	Low				25		45	
	Average	34.2	34.2					
	Pressure							
	High			1018				
	Low				994			
	Average	1008.0	1008.0					

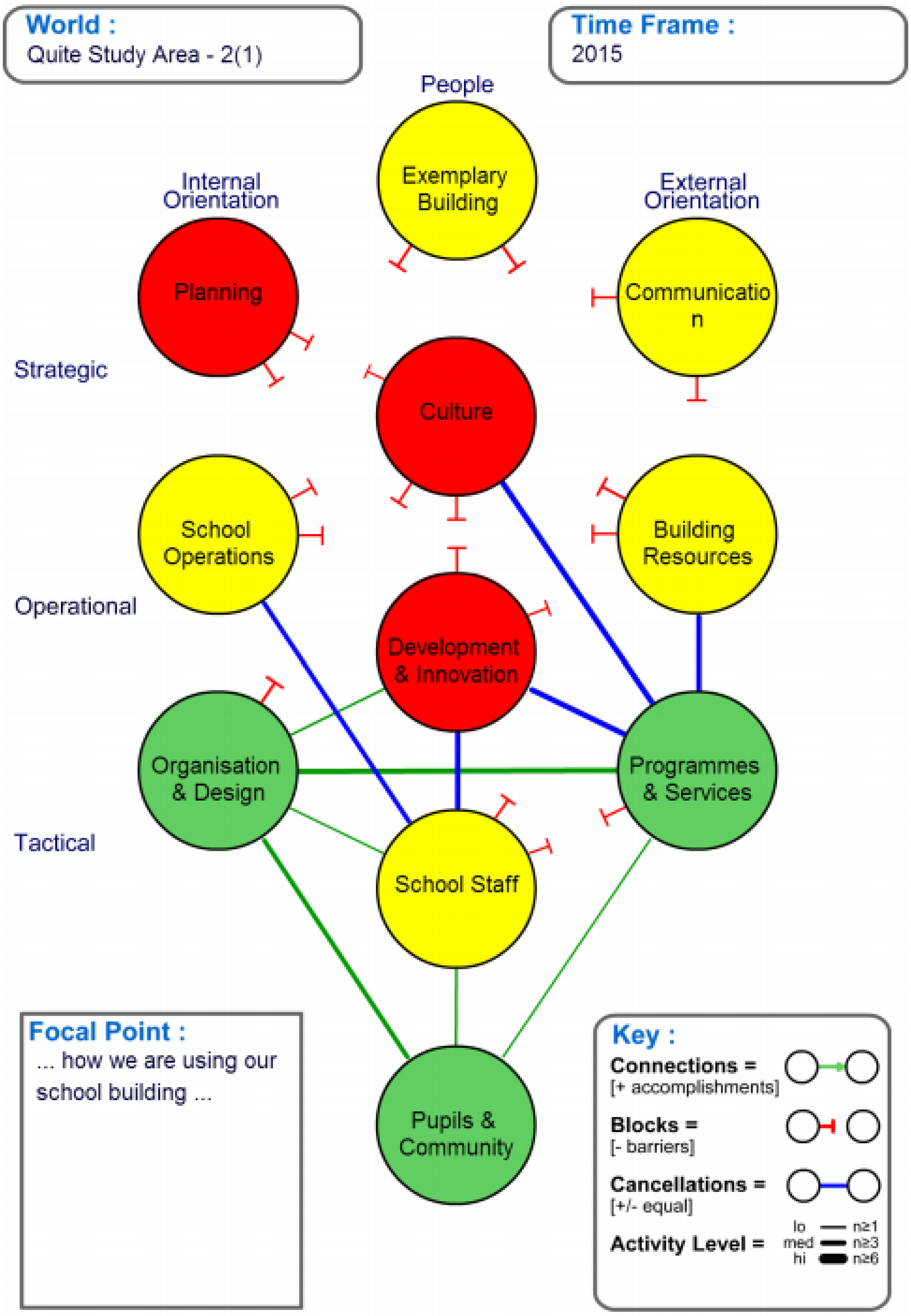
Overall Rating based on weekday average

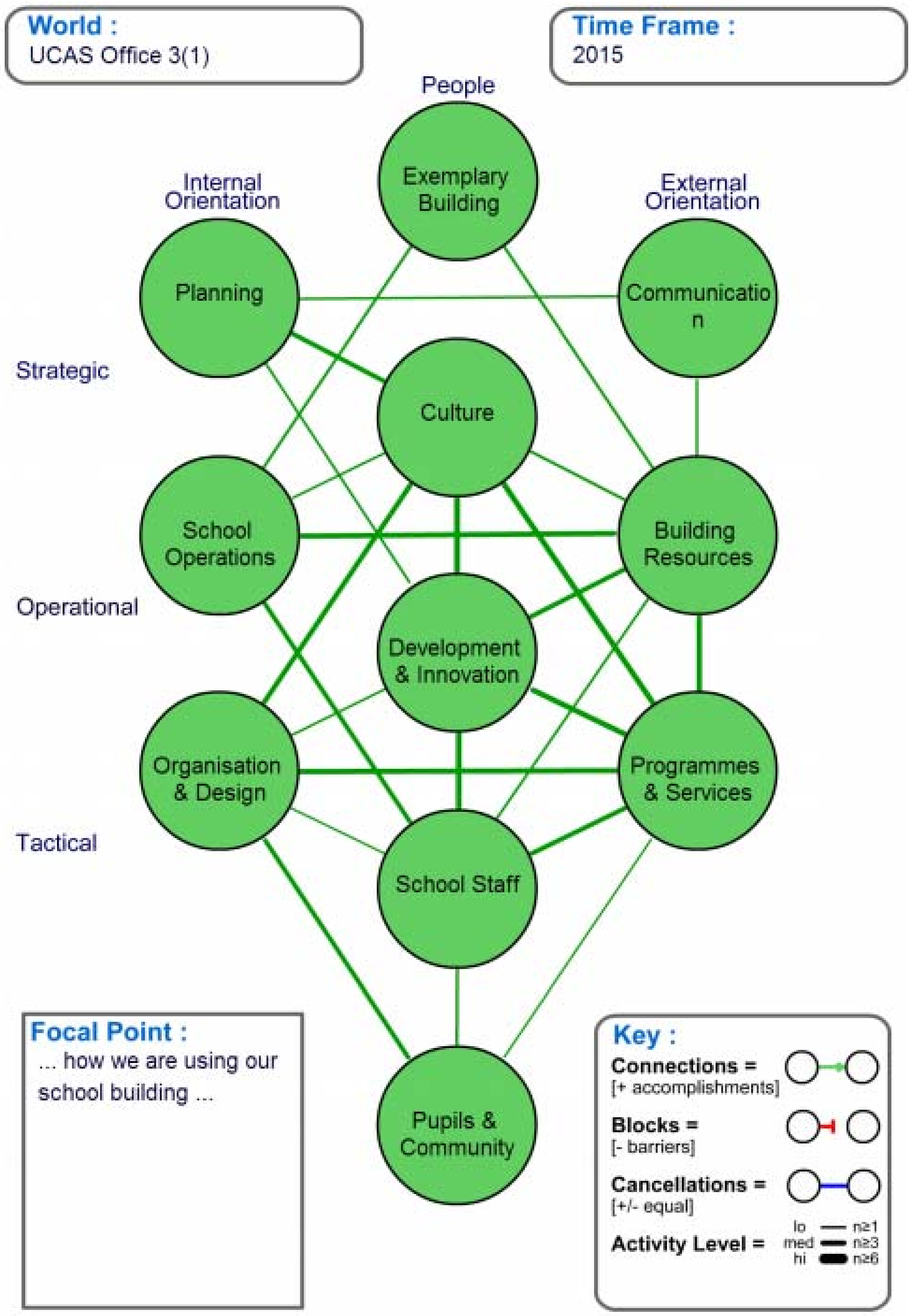
Ambient Light	300	8000
Max Temp	26	
Min Temp		23
Max Humidity	45	
Min Humidity		55
Noise	40	60
VOC	450	1000

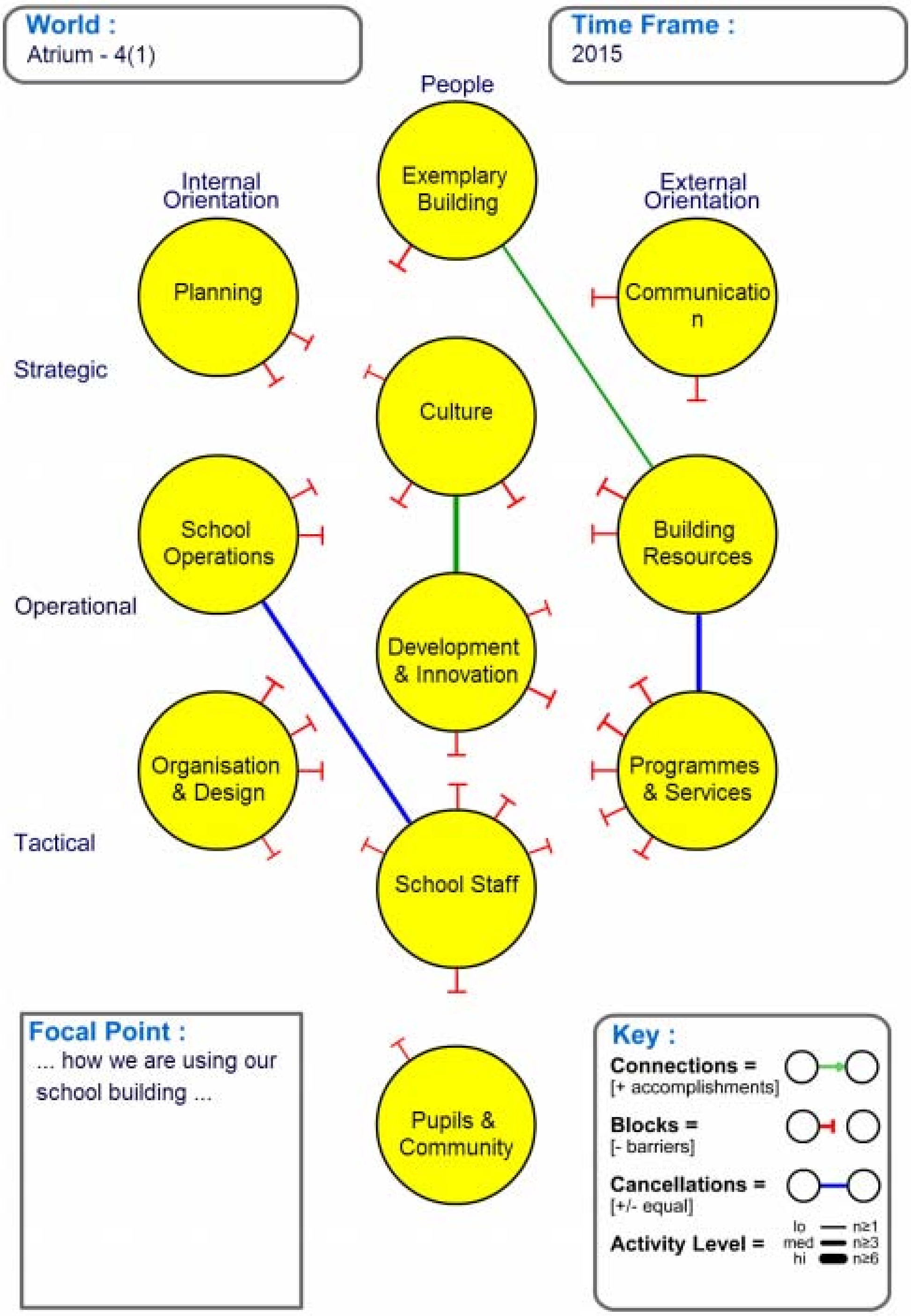
Table 5

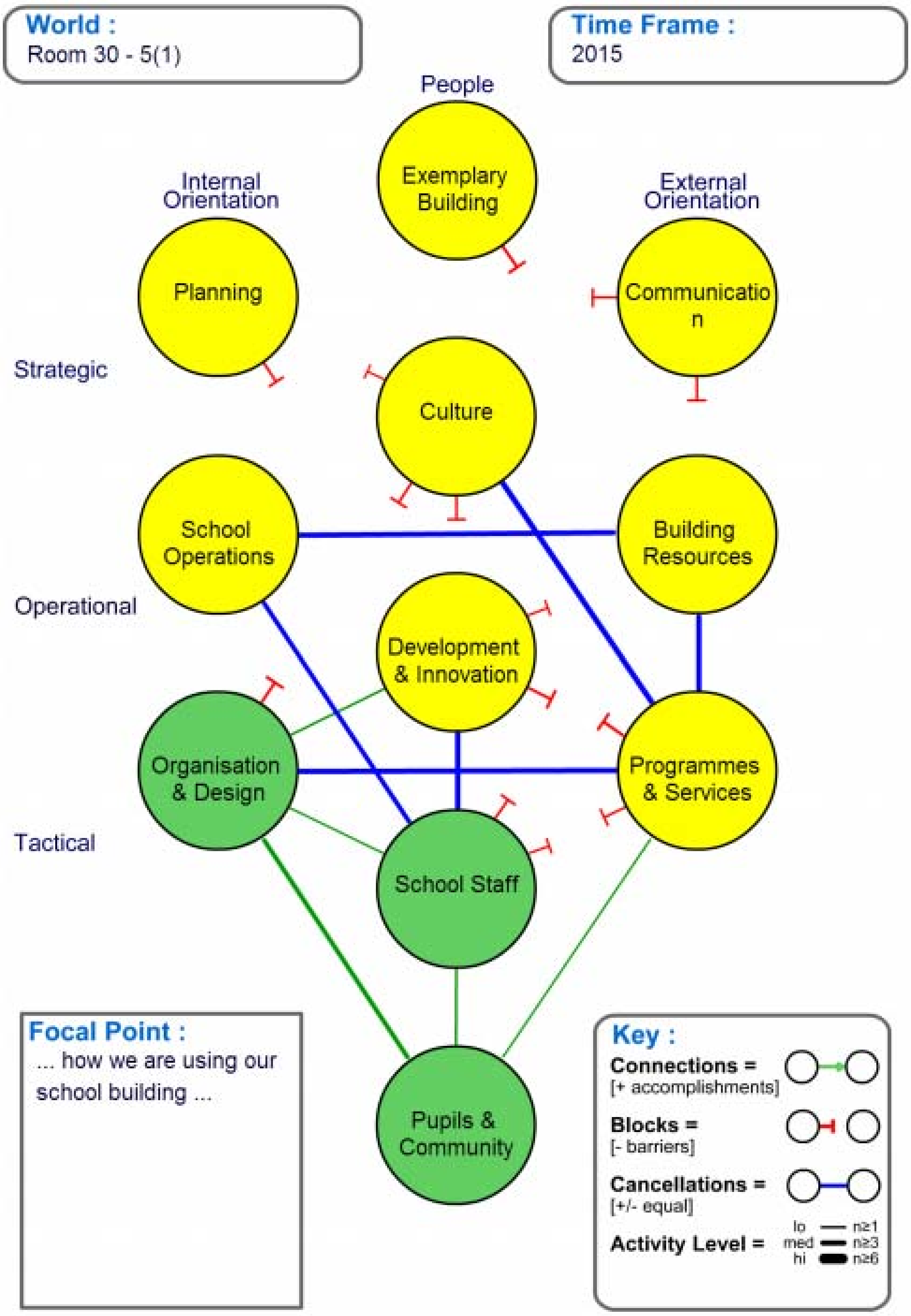
Sensor Influence Maps

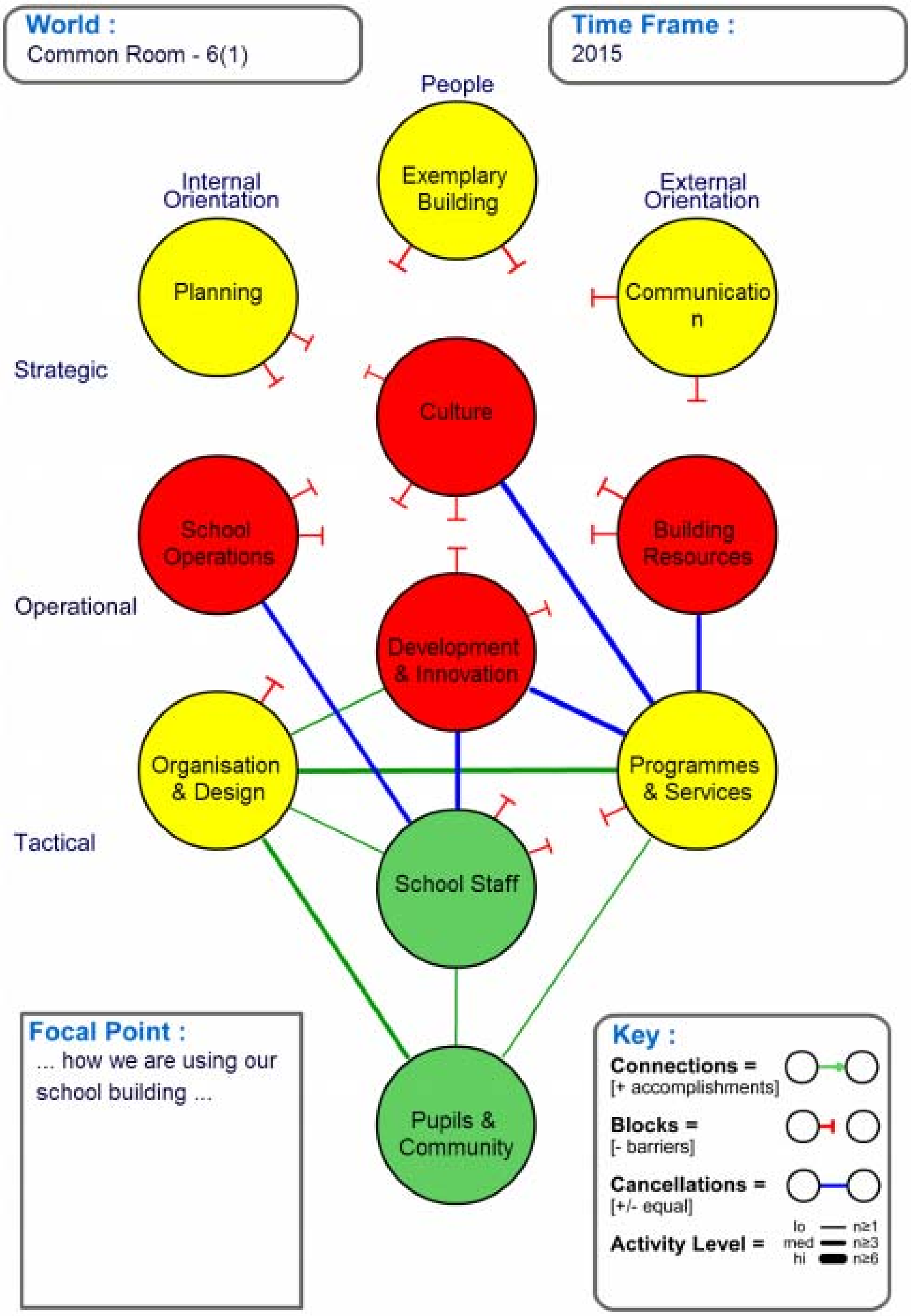

World :
Media Suite - 1(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6

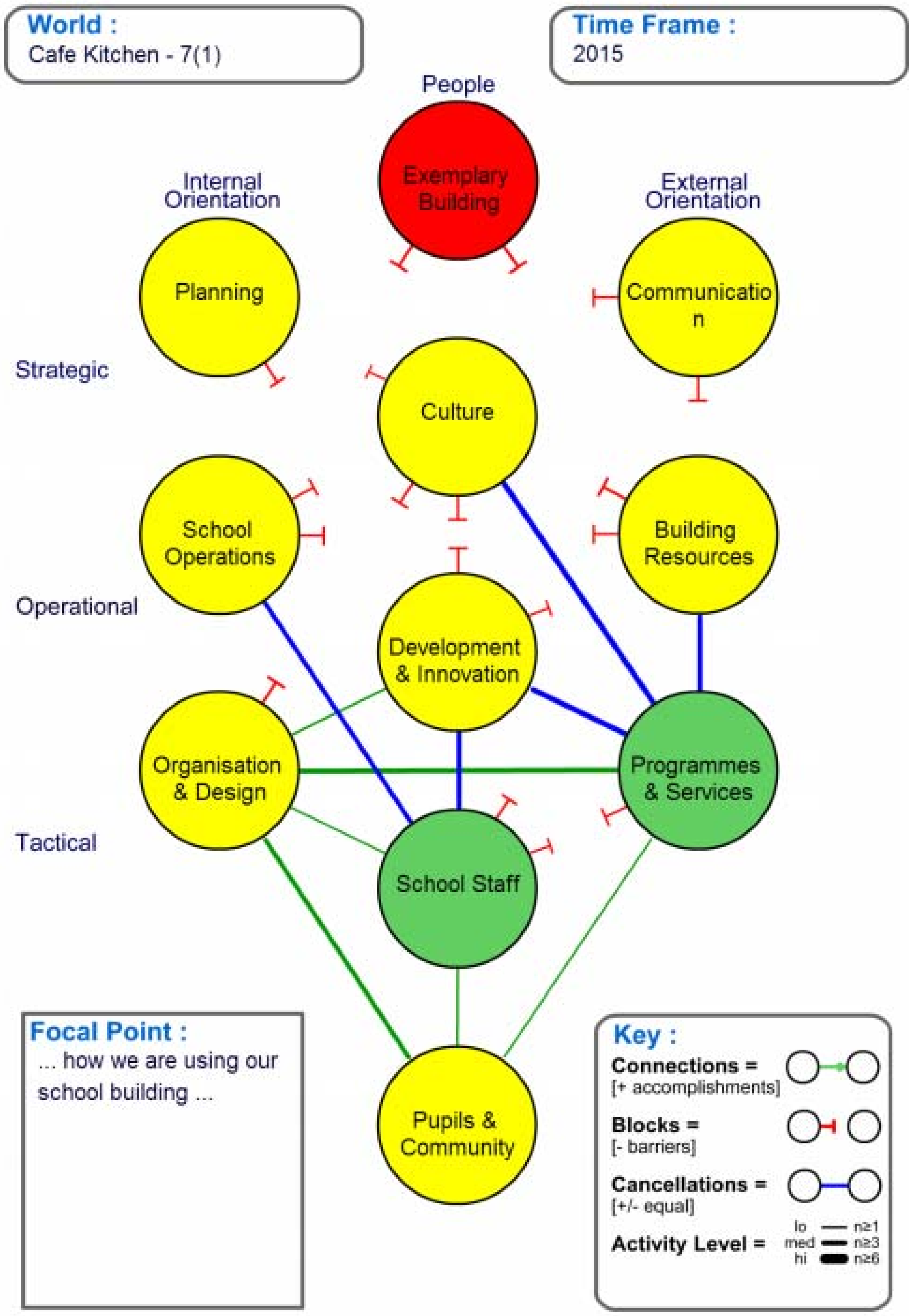

World :
Quite Study Area - 2(1)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communication
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
UCAS Office 3(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6

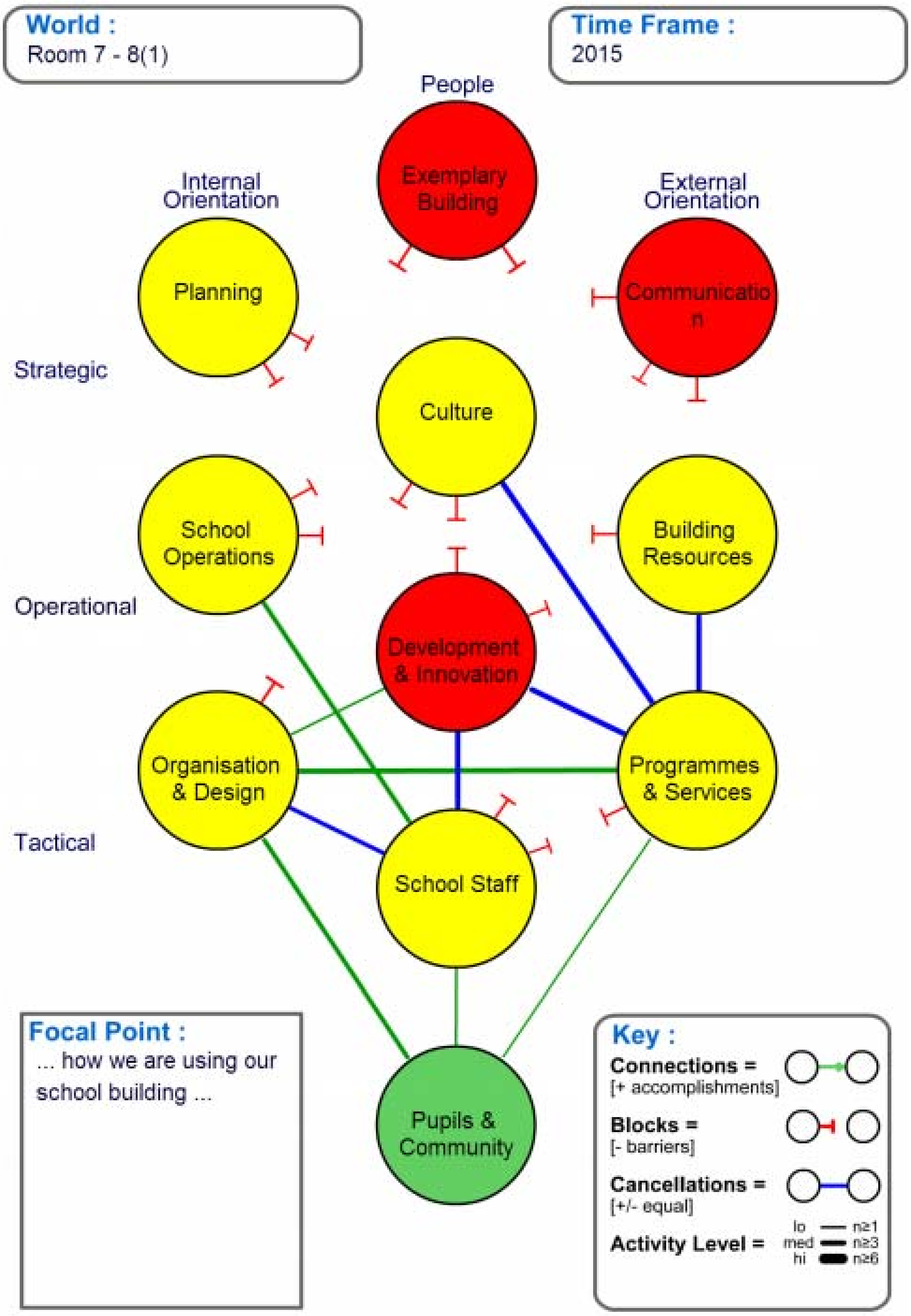

World :
Atrium - 4(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
Room 30 - 5(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
Common Room - 6(1)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
Planning
External Orientation
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6



World :
Cafe Kitchen - 7(1)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6



World :
Room 7 - 8(1)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
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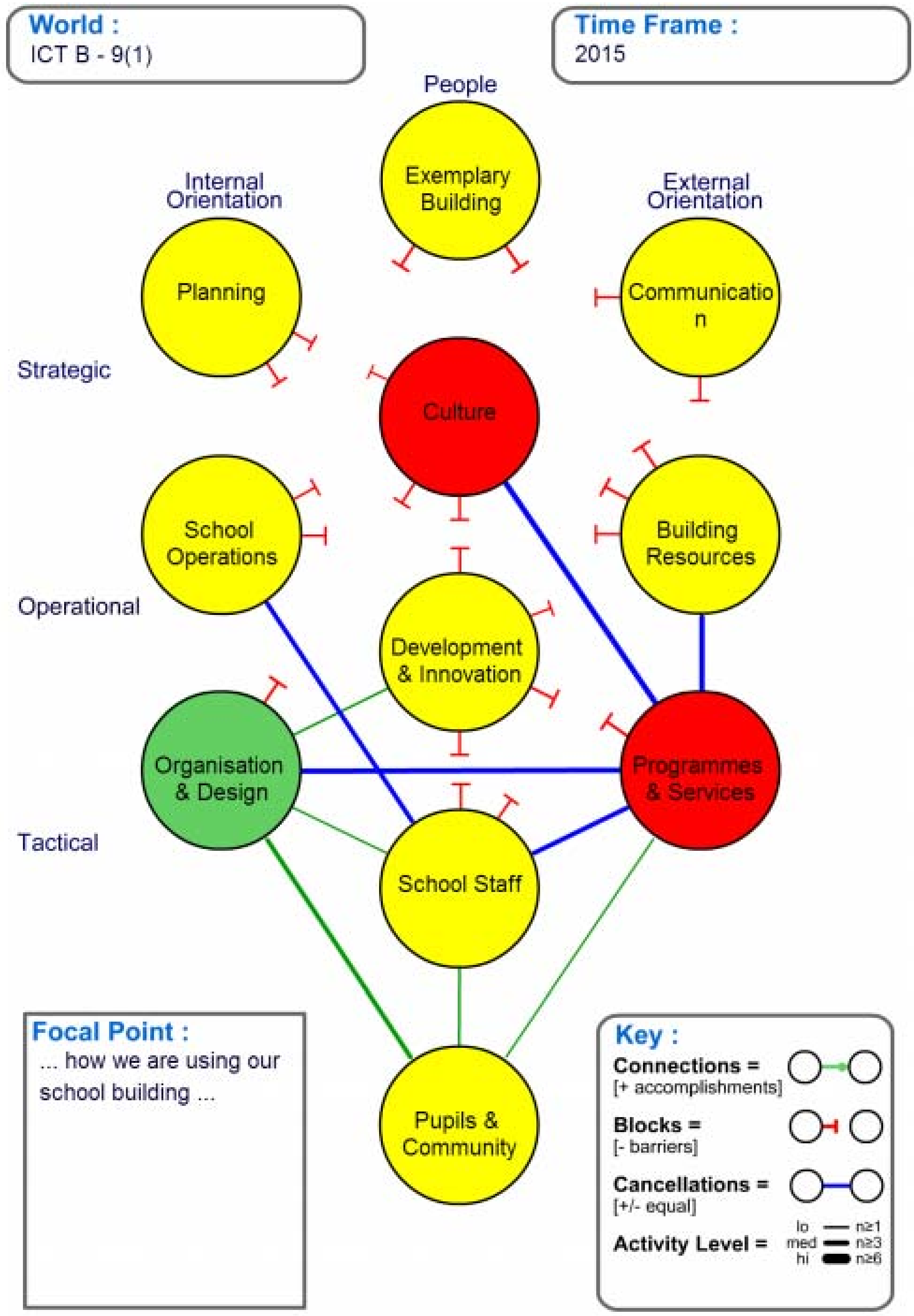
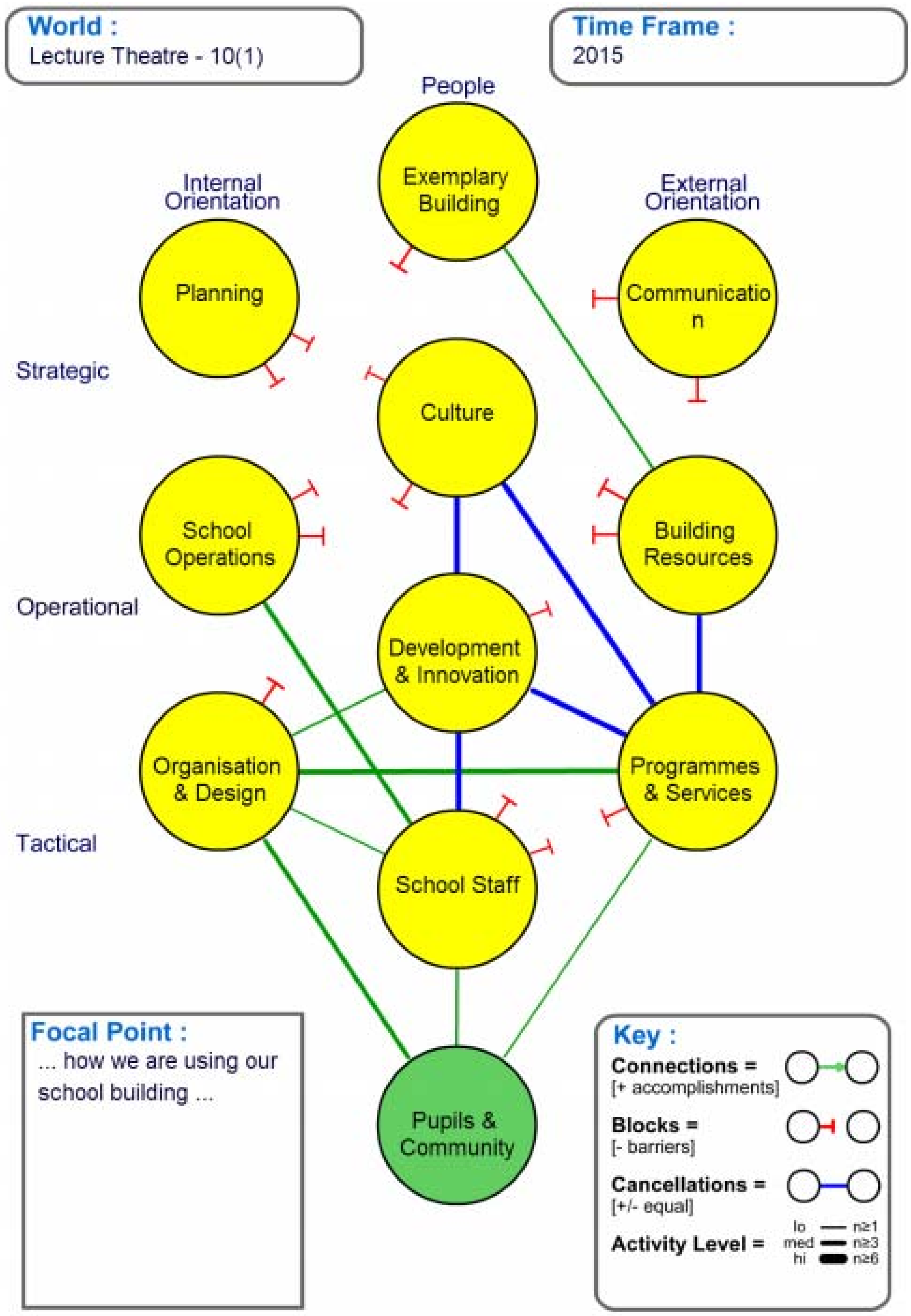
n≥1
n≥3
n≥6


World :
ICT B - 9(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
Lecture Theatre - 10(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
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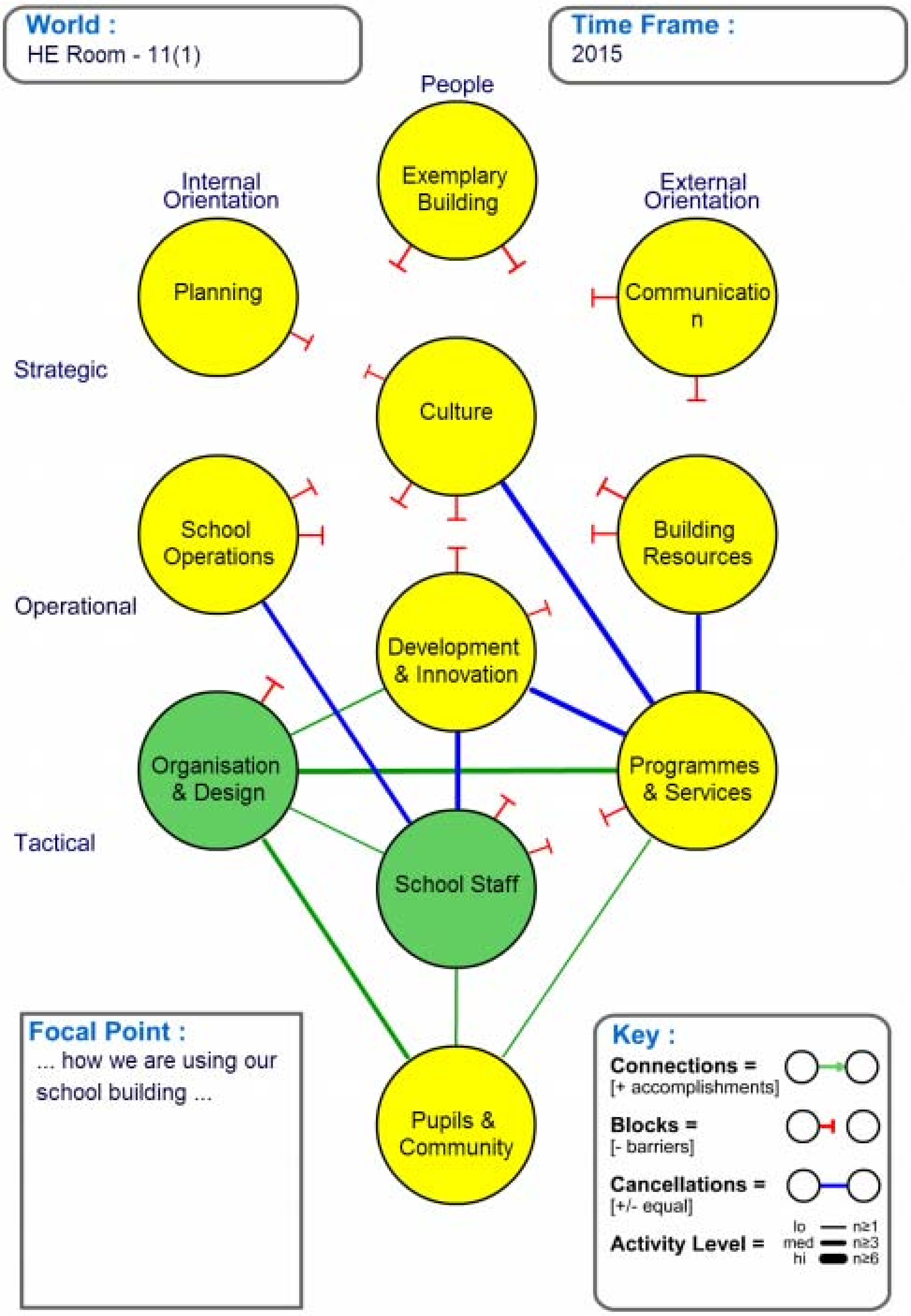
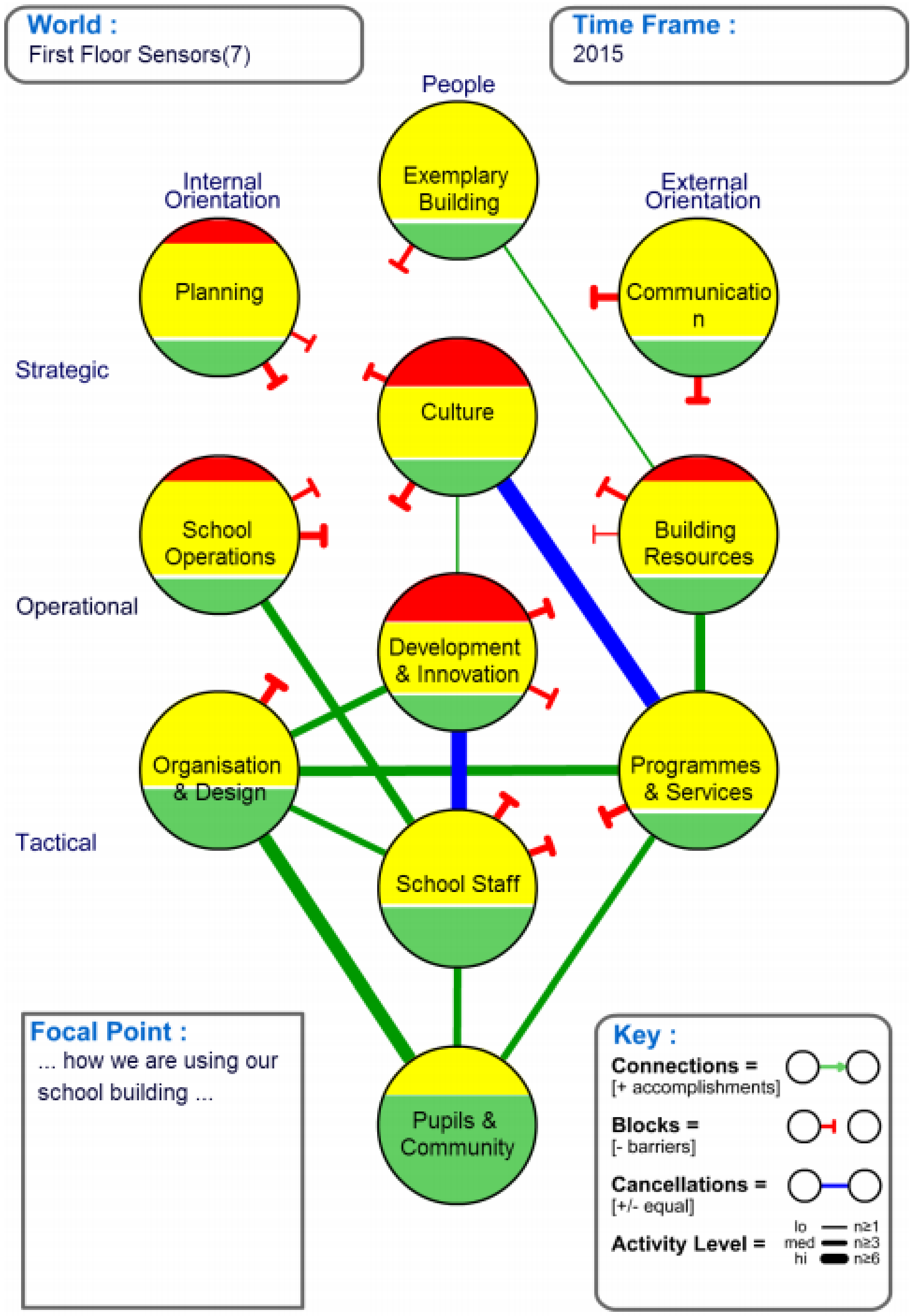
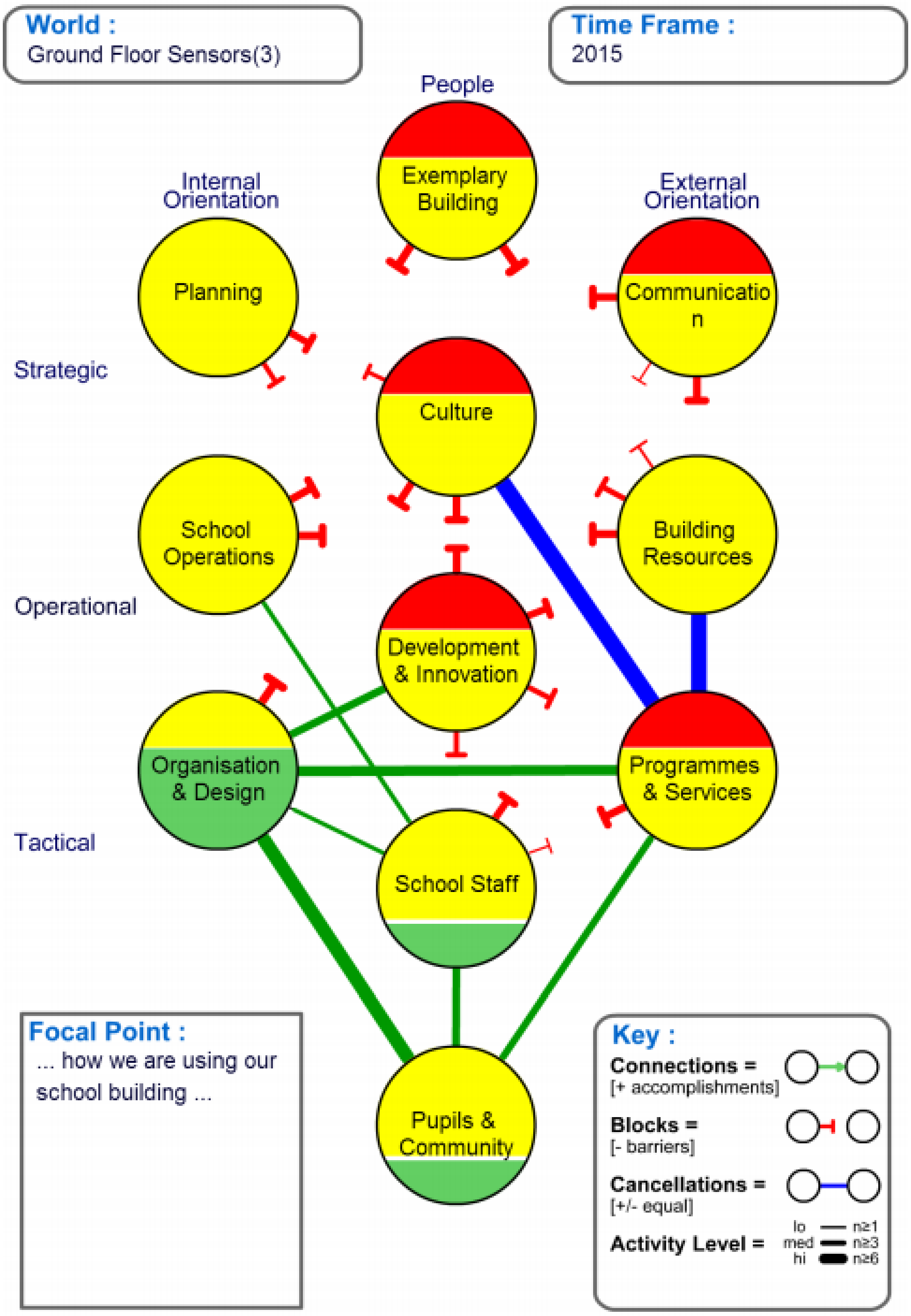
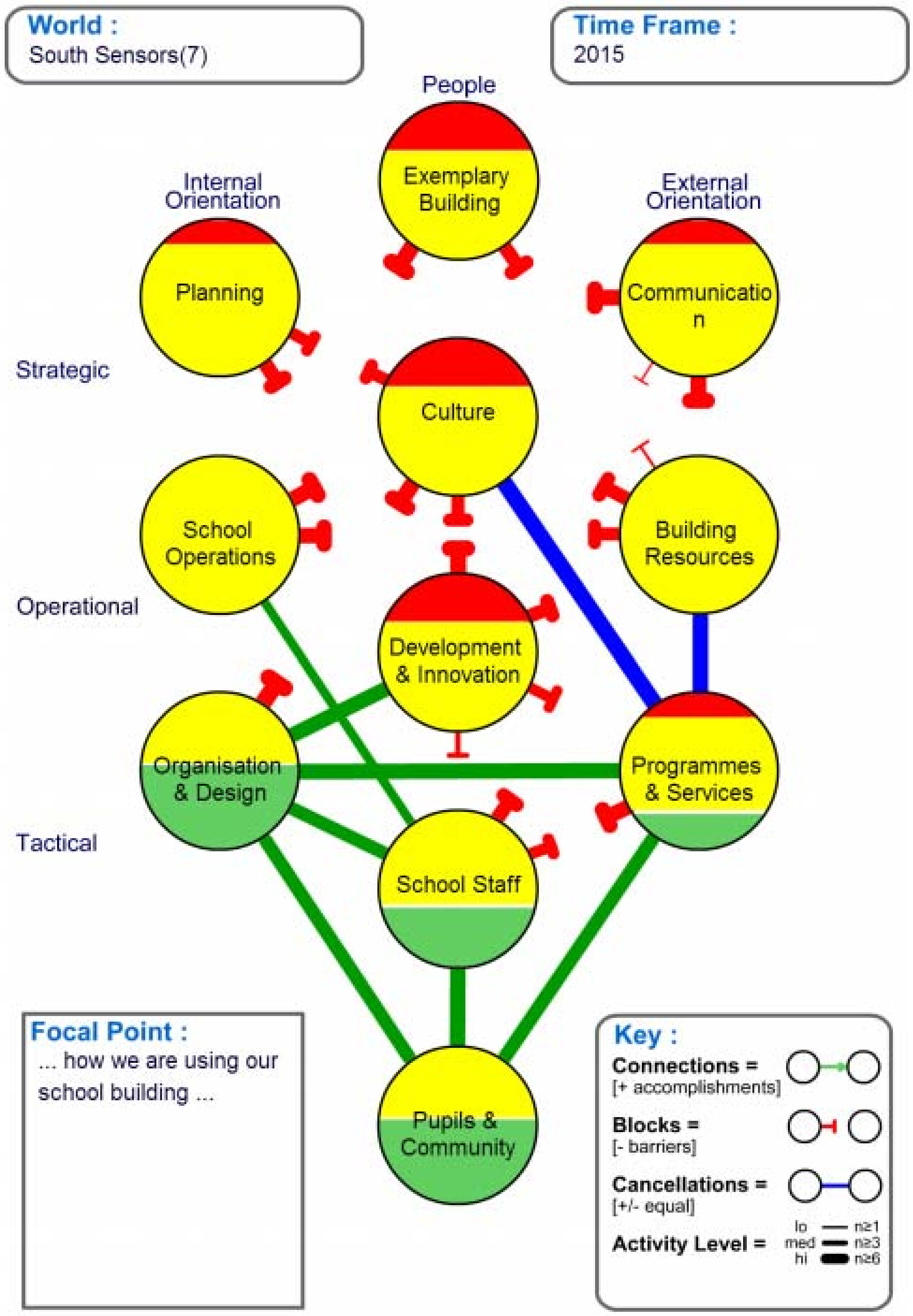
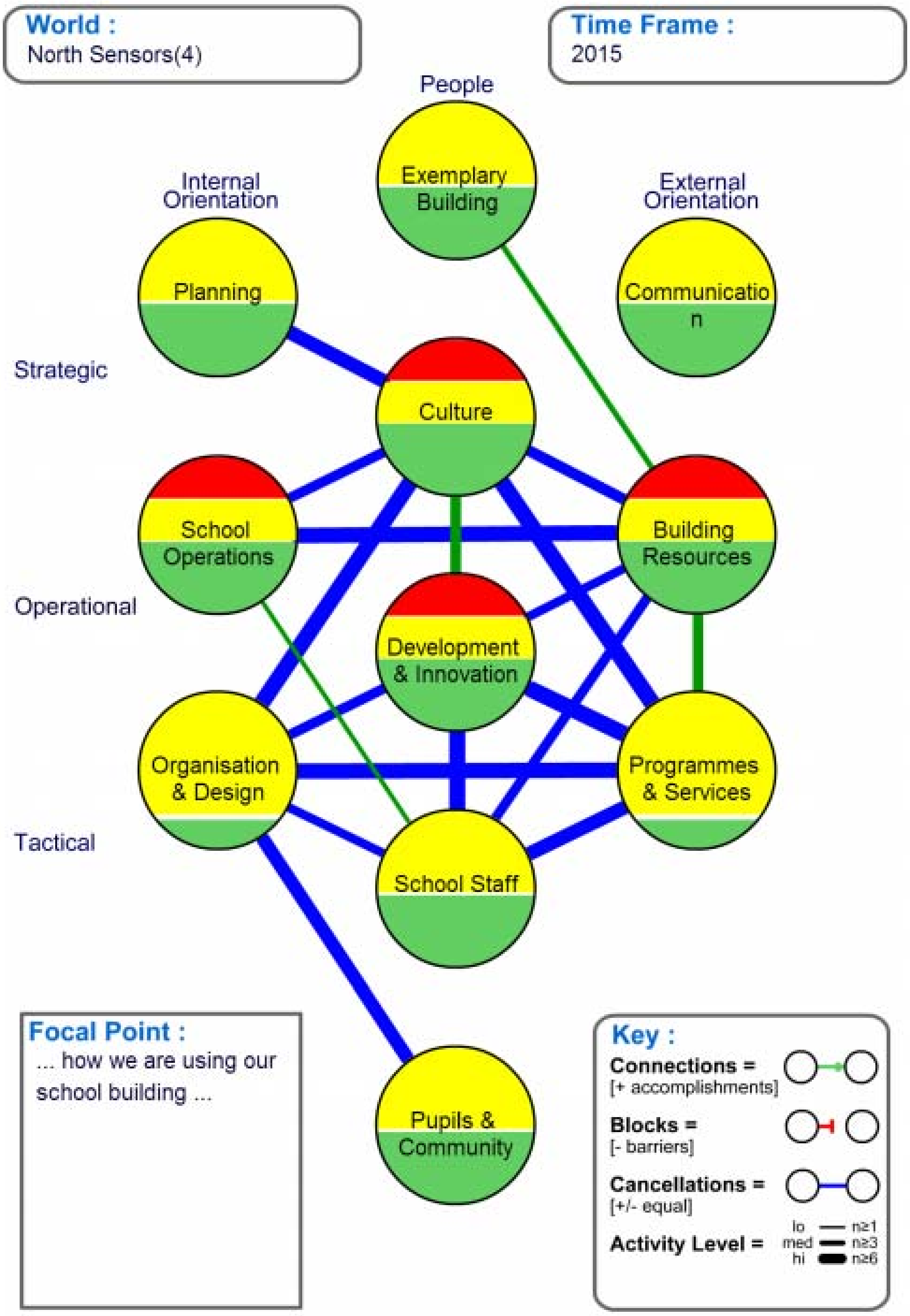
hi
n≥1
n≥3
n≥6


World :
HE Room - 11(1)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communication
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
First Floor Sensors(7)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
Ground Floor Sensors(3)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
South Sensors(7)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
Planning
External Orientation
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
North Sensors(4)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6

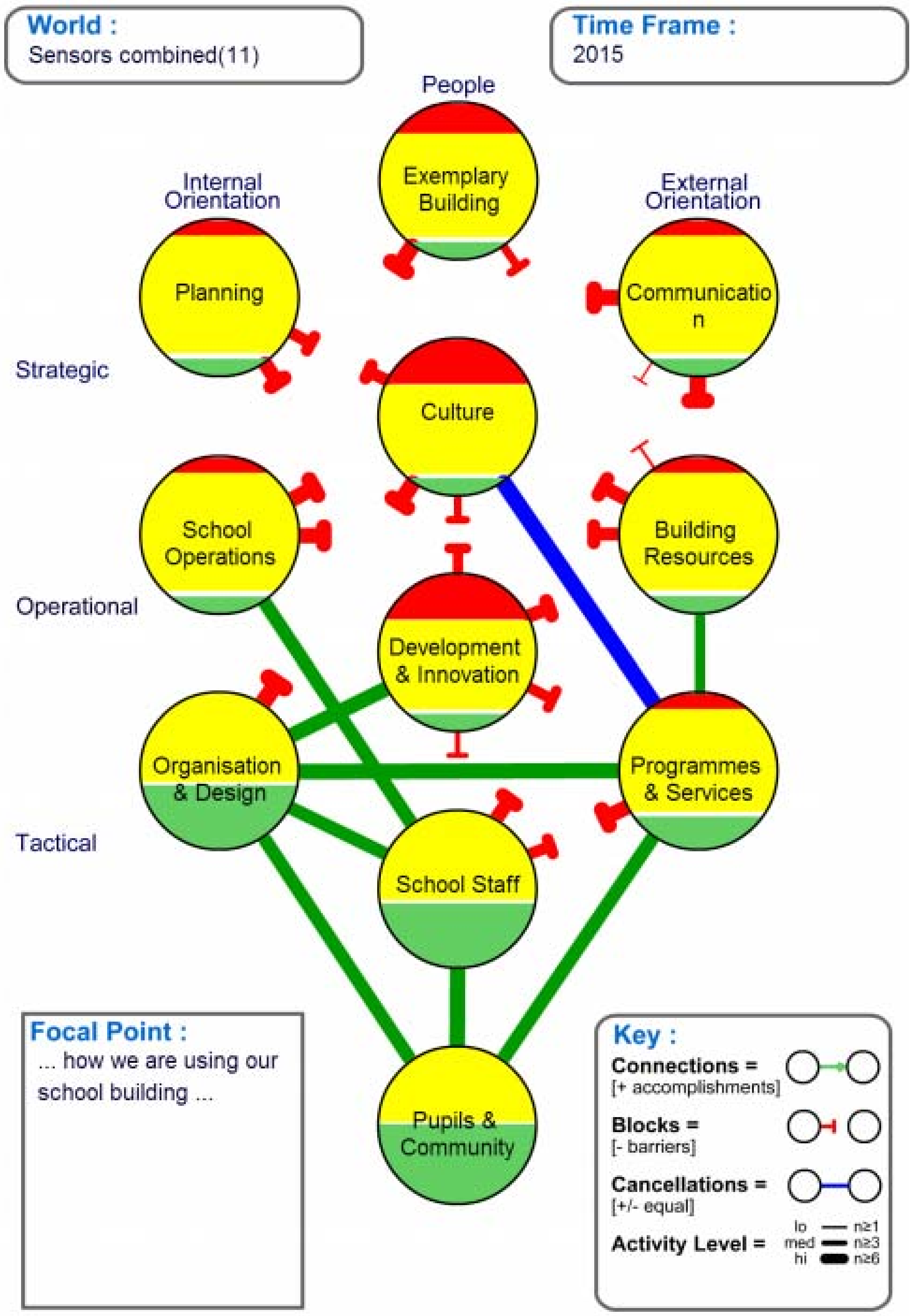
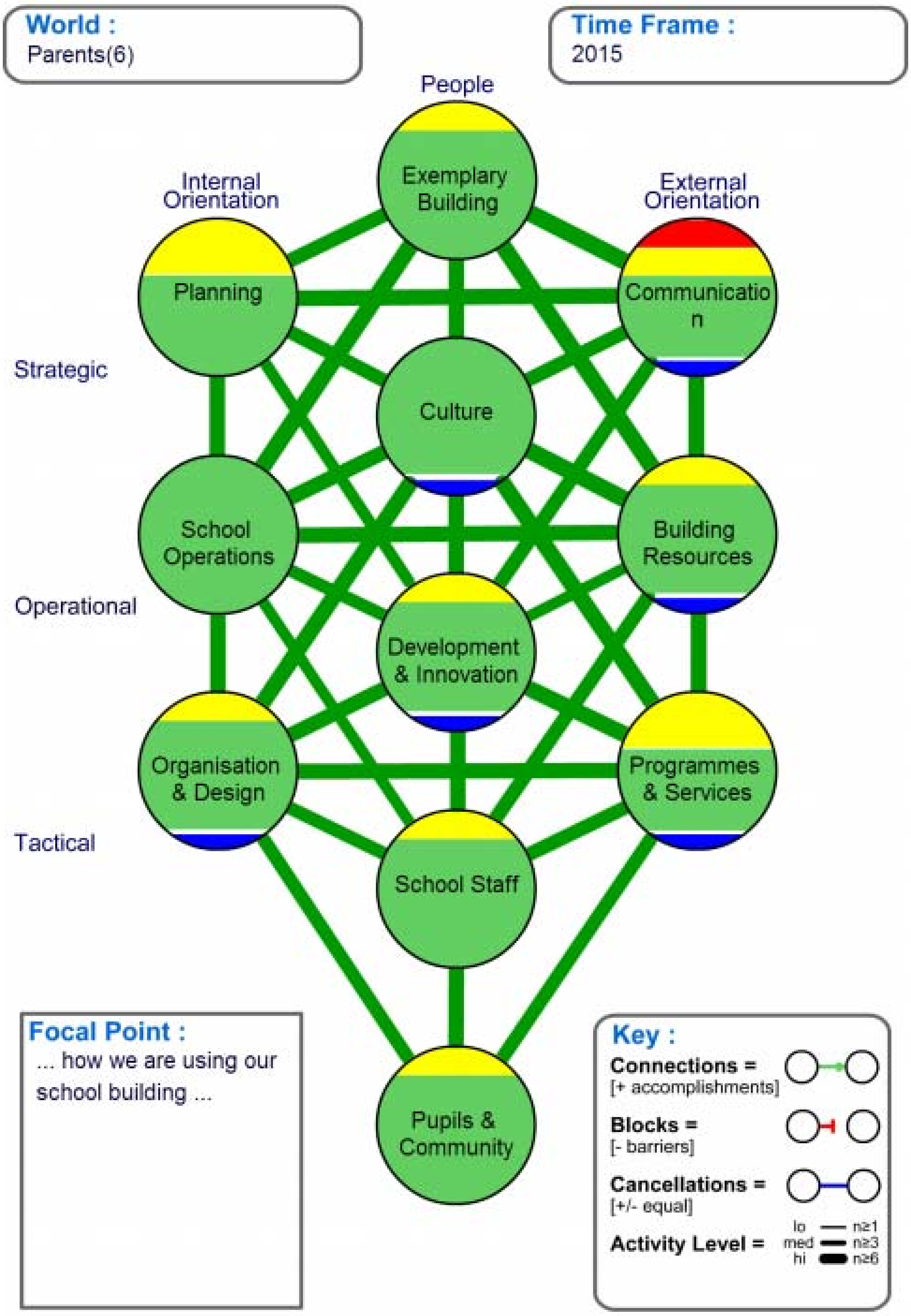
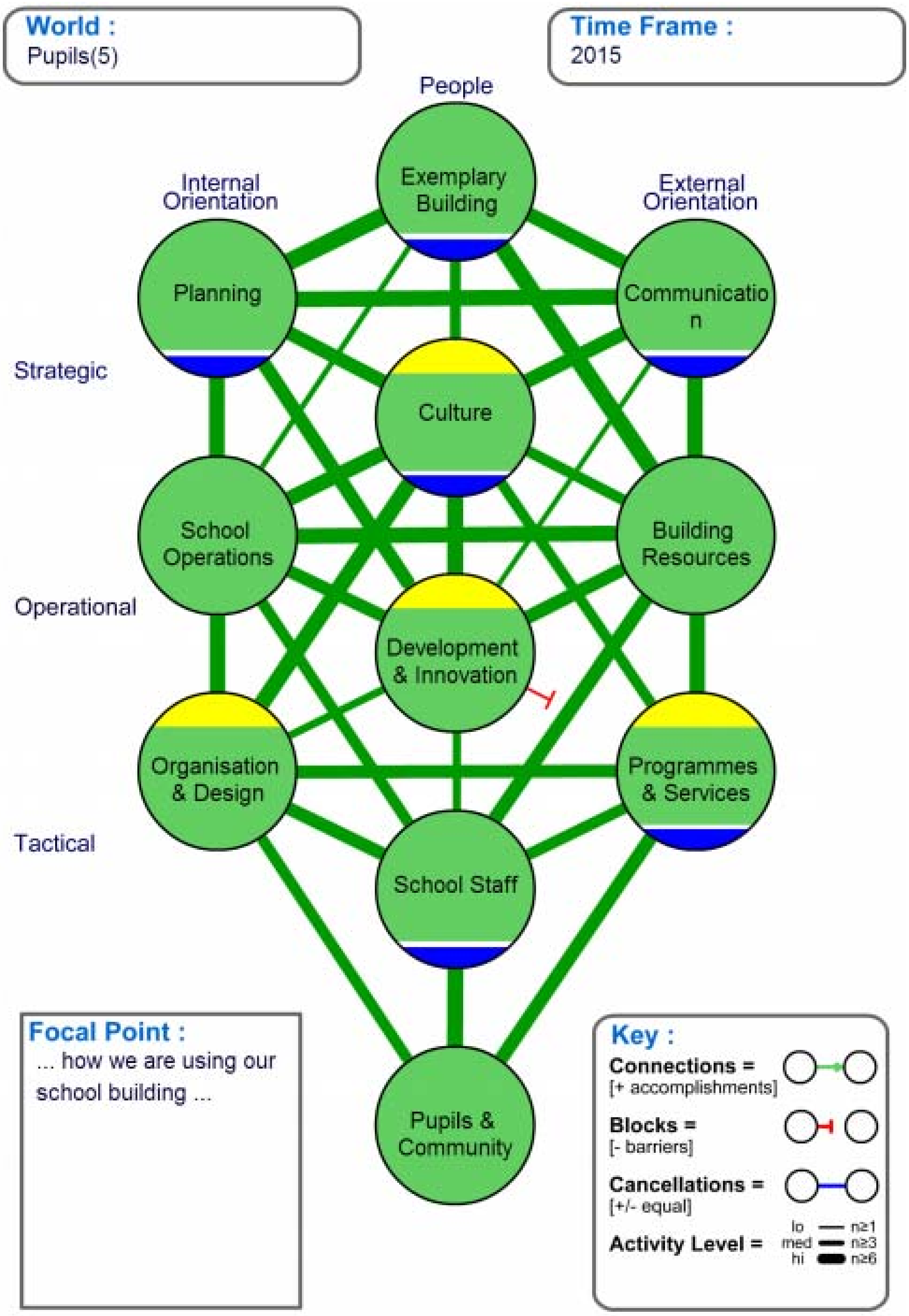

World :
Sensors combined(11)
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6

Table 6

Perception Influence Maps


World :
Parents(6)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
Pupils(5)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
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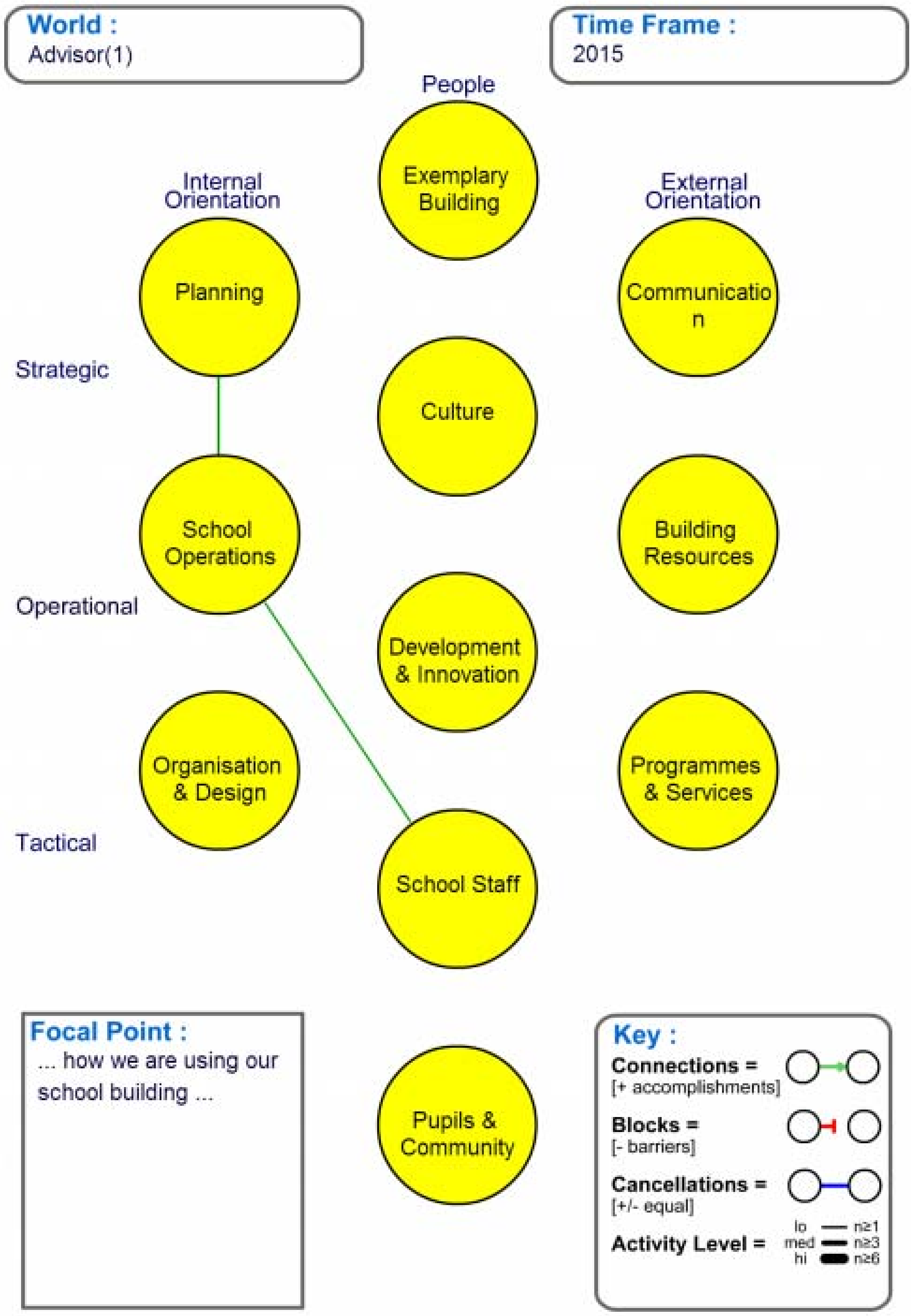
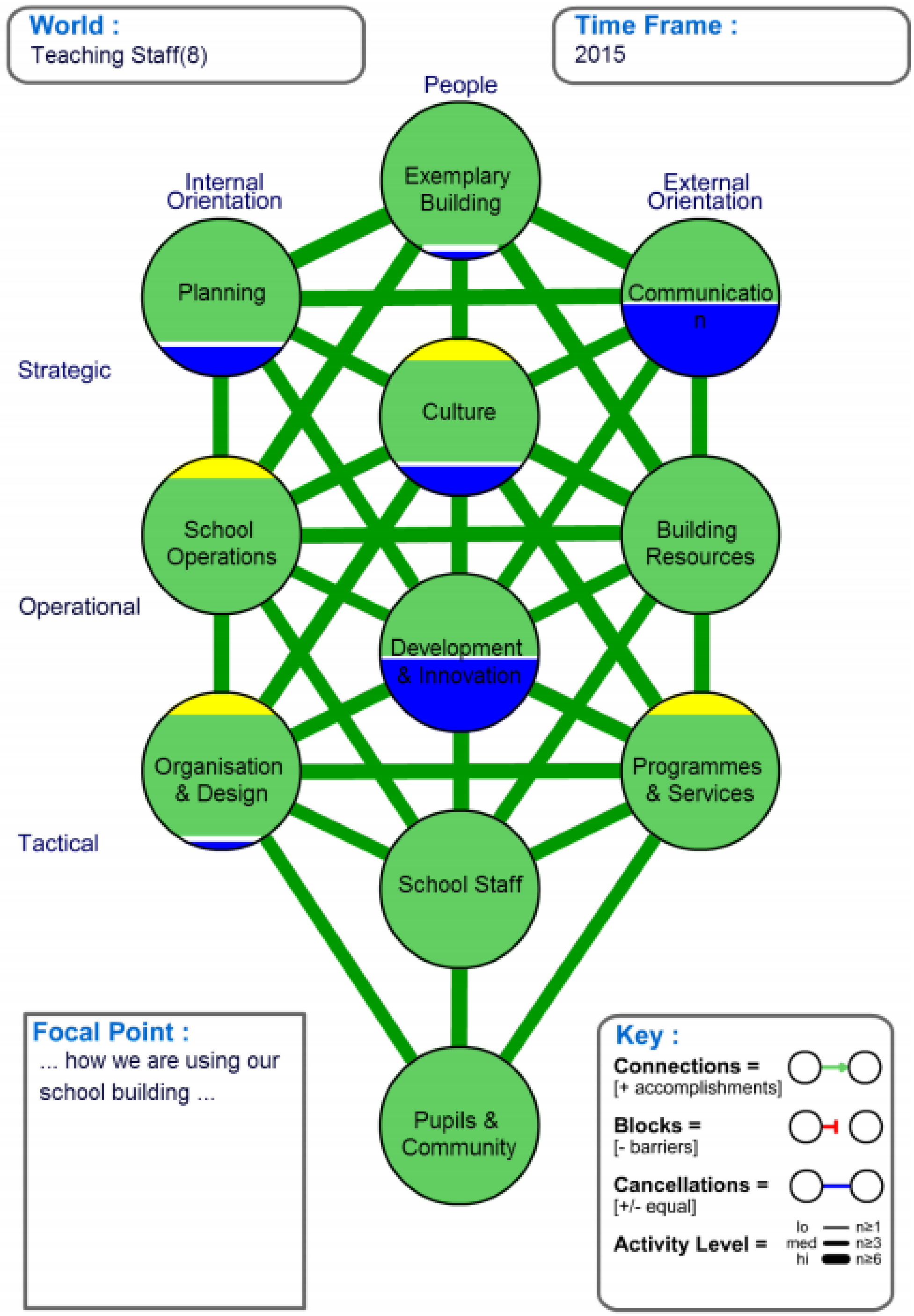
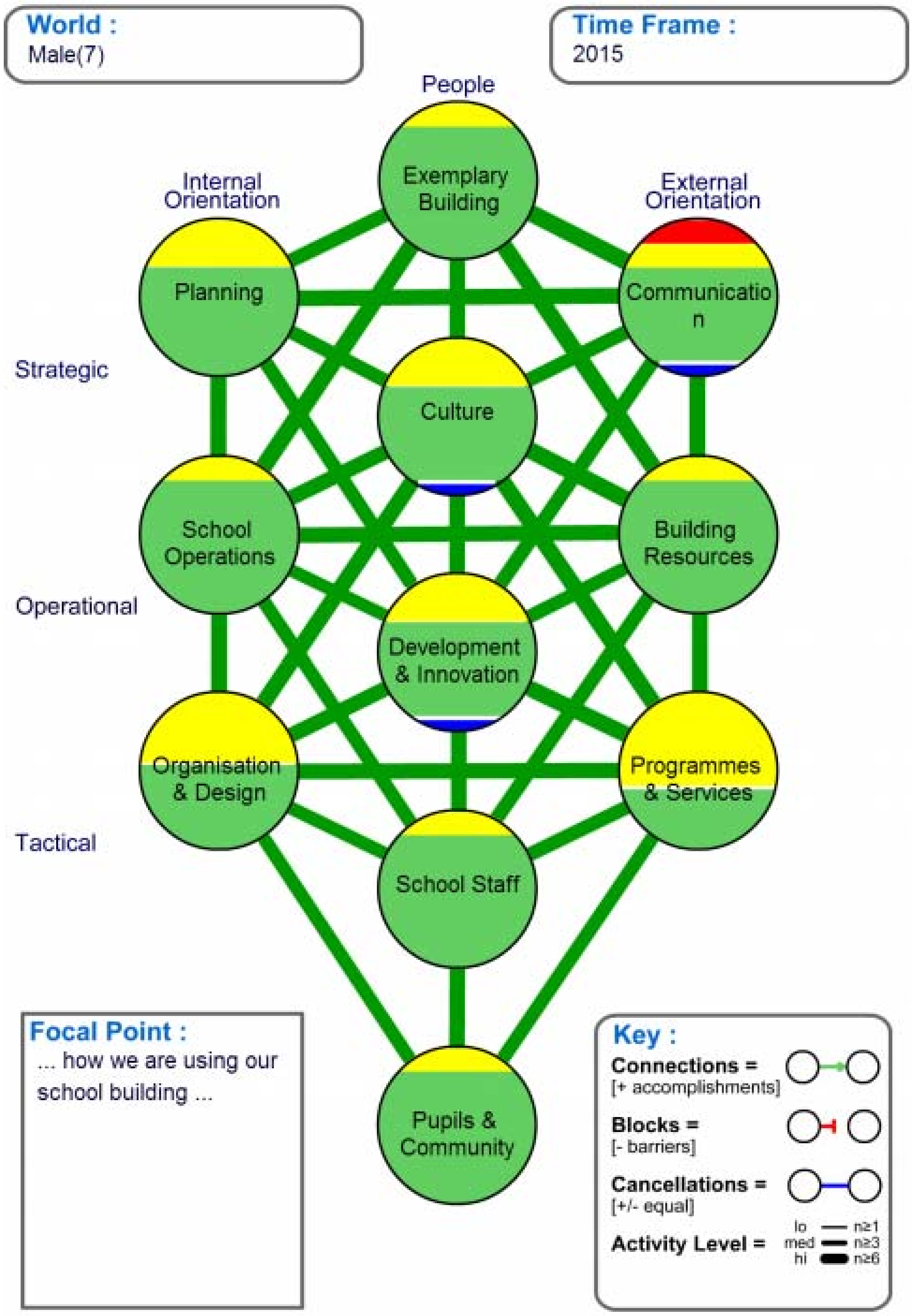
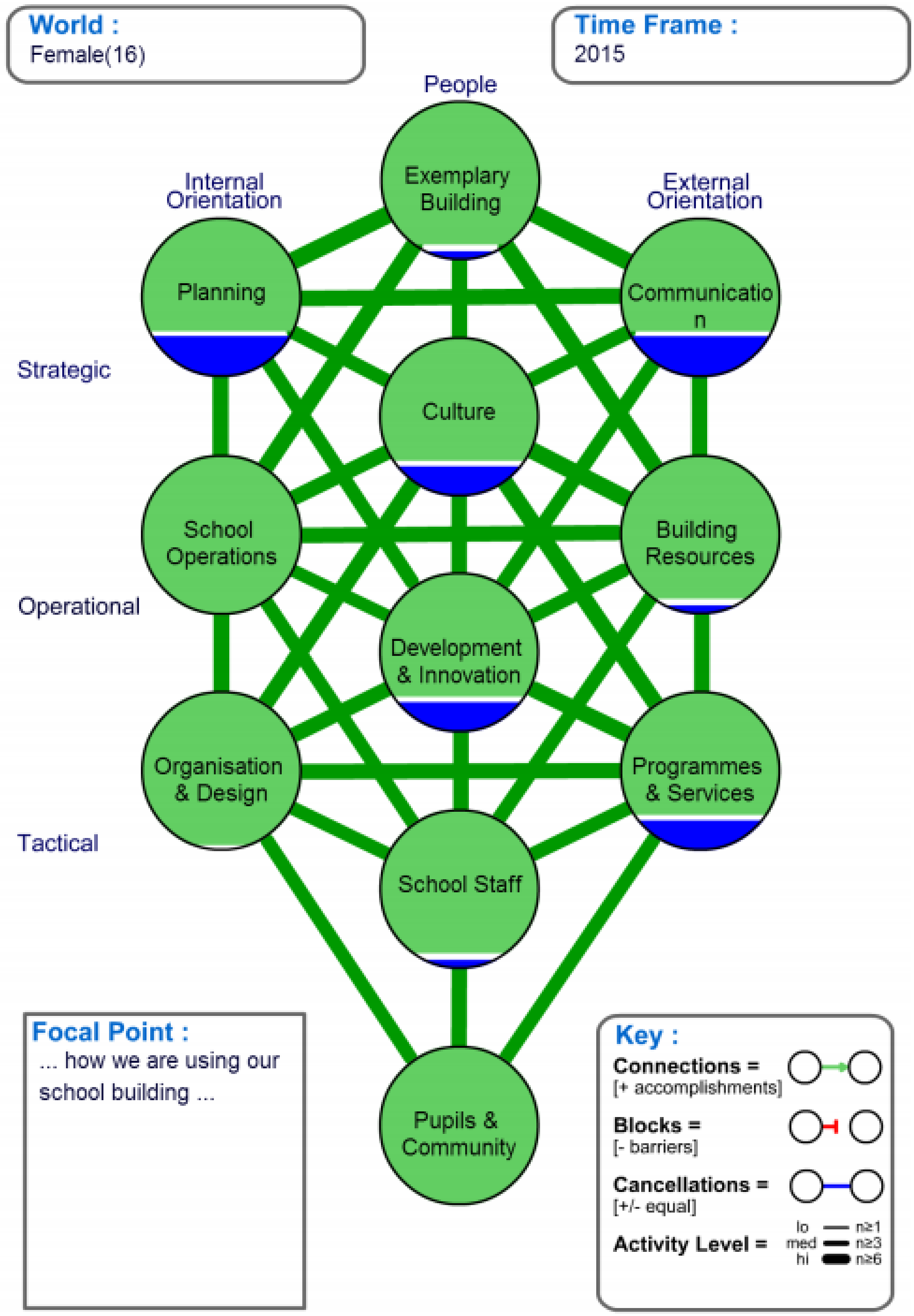
n≥1
n≥3
n≥6


World :
Advisor(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
Teaching Staff(8)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
Male(7)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
Female(16)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
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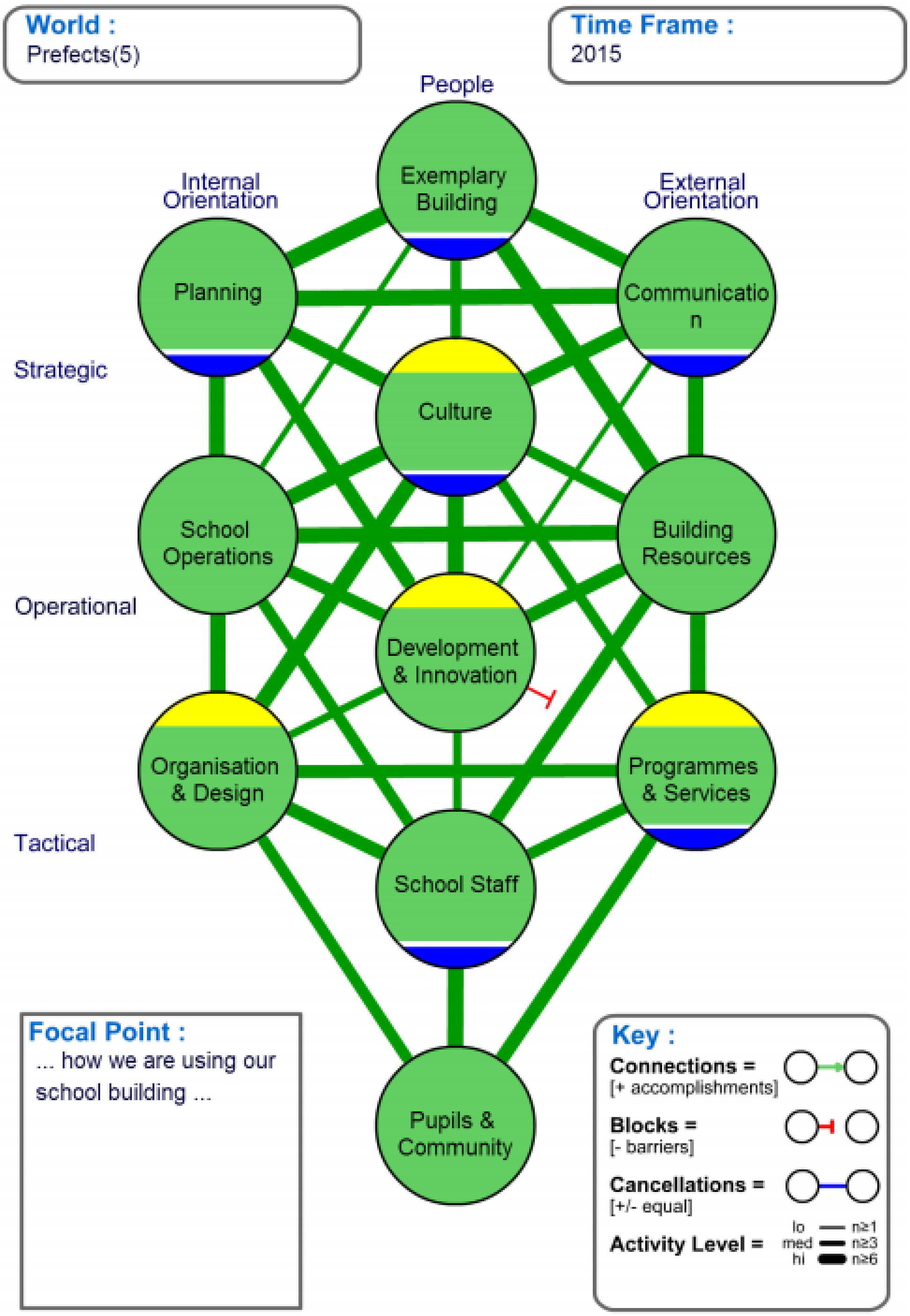
hi
n≥1
n≥3
n≥6



World :
Prefects(5)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
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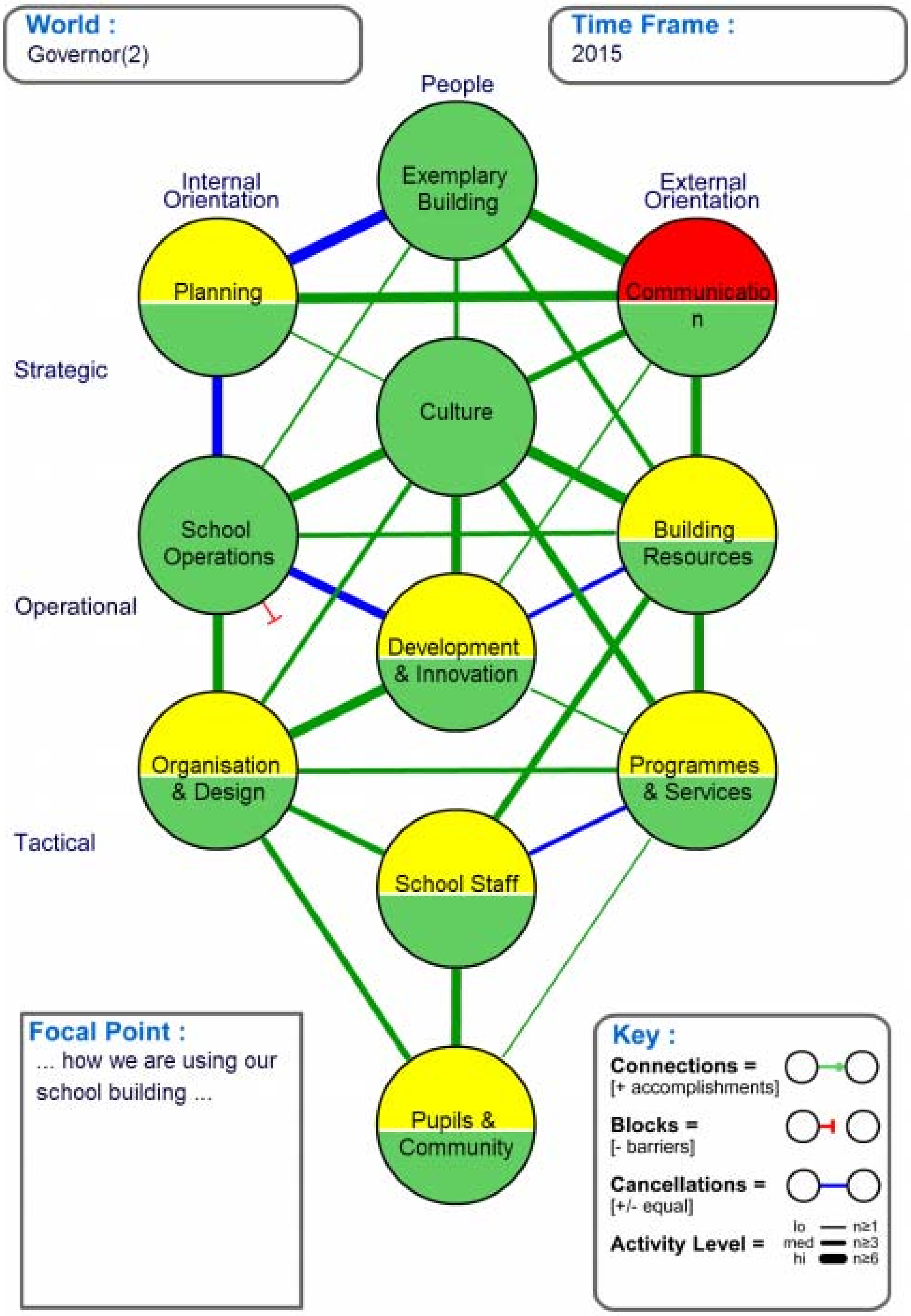
hi
n≥1
n≥3
n≥6


World :
Governor(2)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
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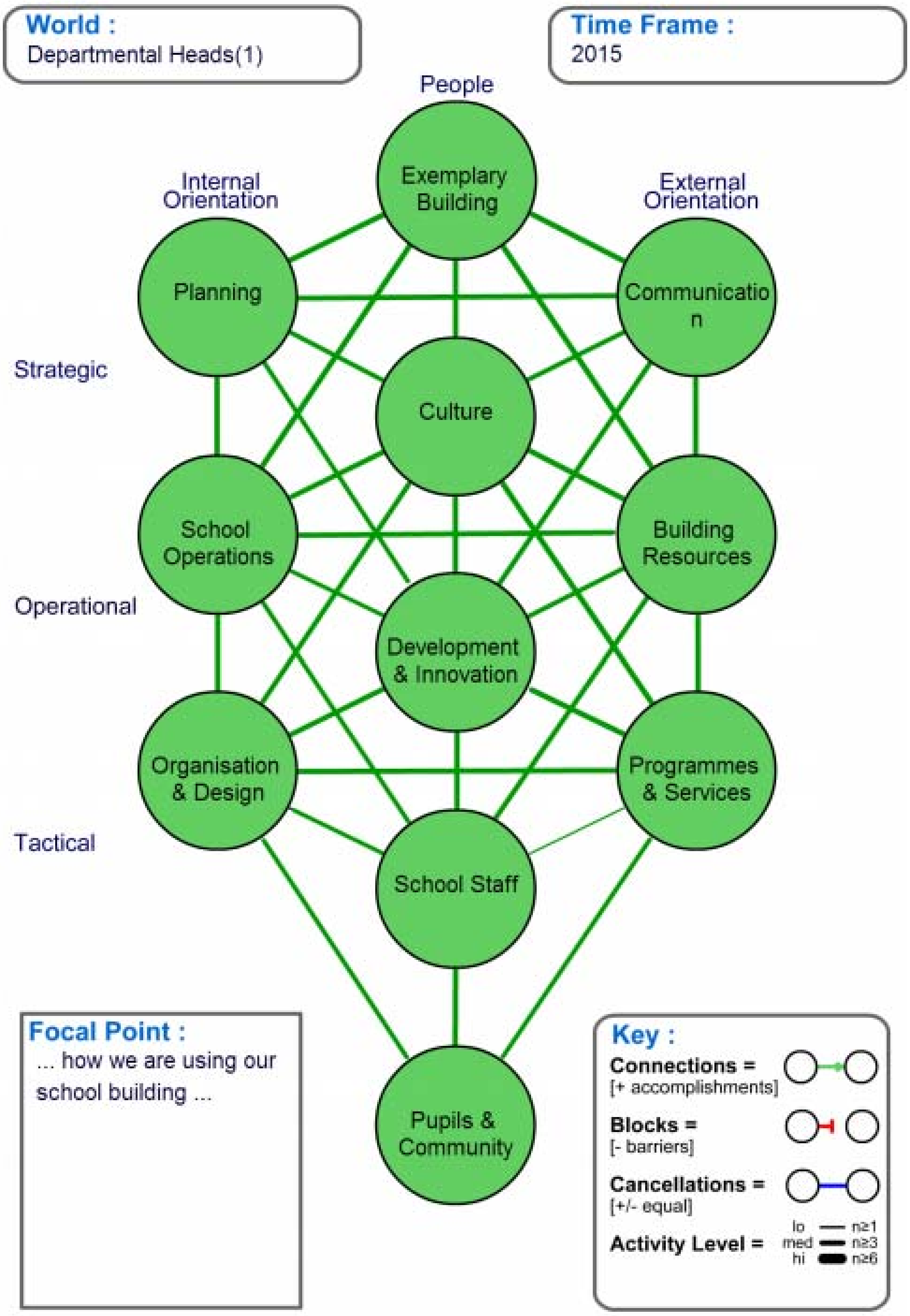
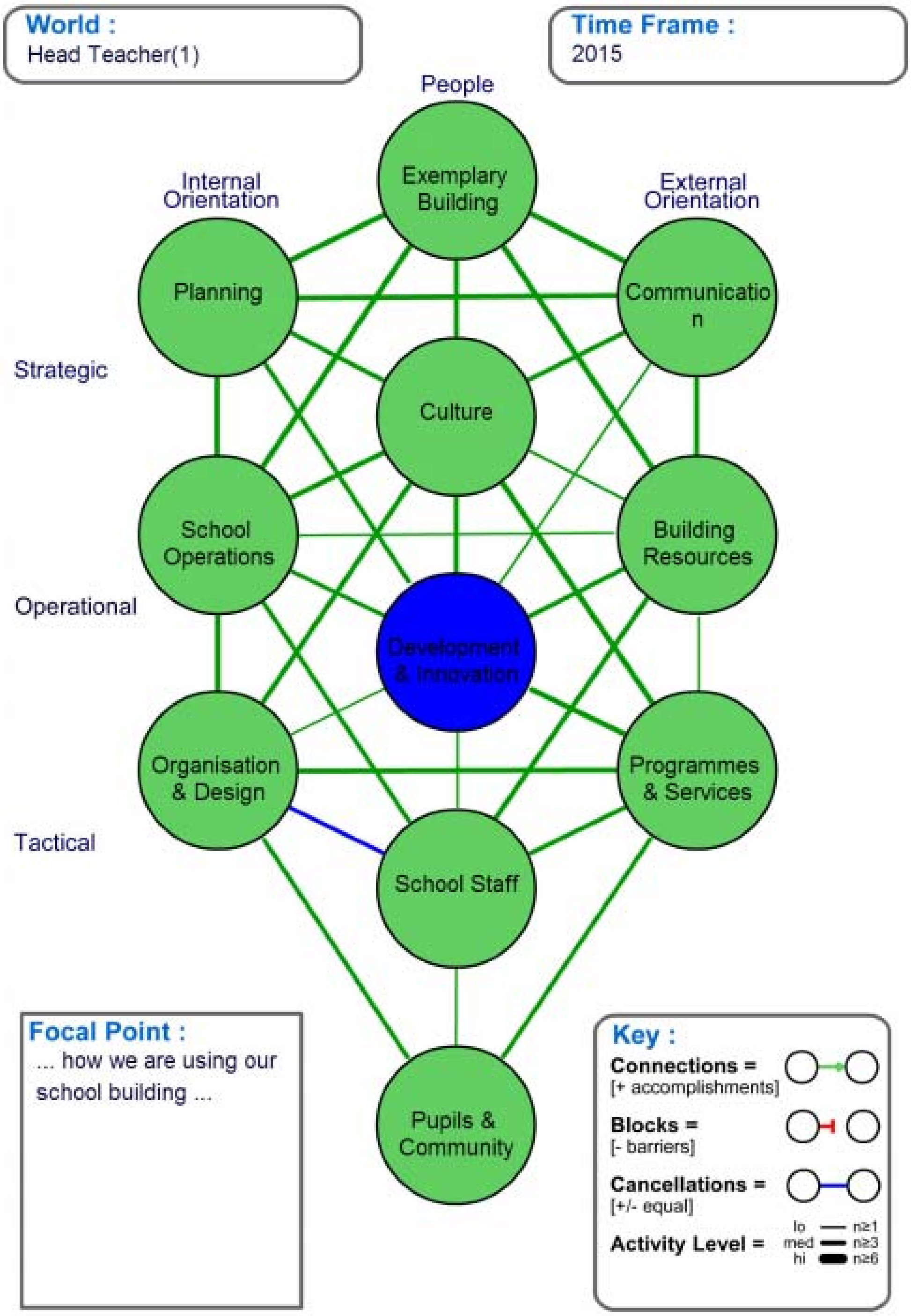
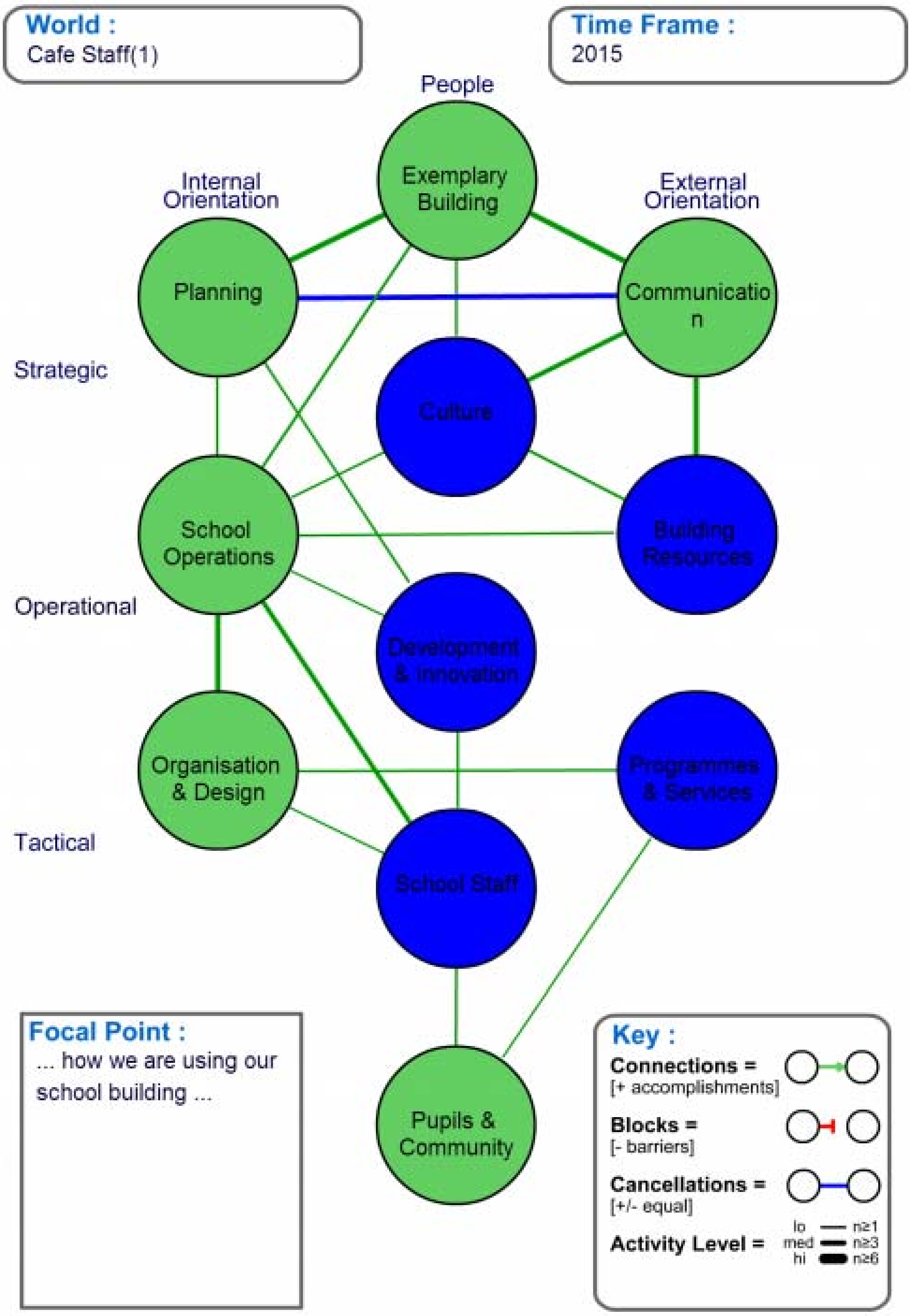
hi
n≥1
n≥3
n≥6


World :
Departmental Heads(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communication
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
Head Teacher(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6


World :
Cafe Staff(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
School Operations
Operational
Organisation & Design
Tactical
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
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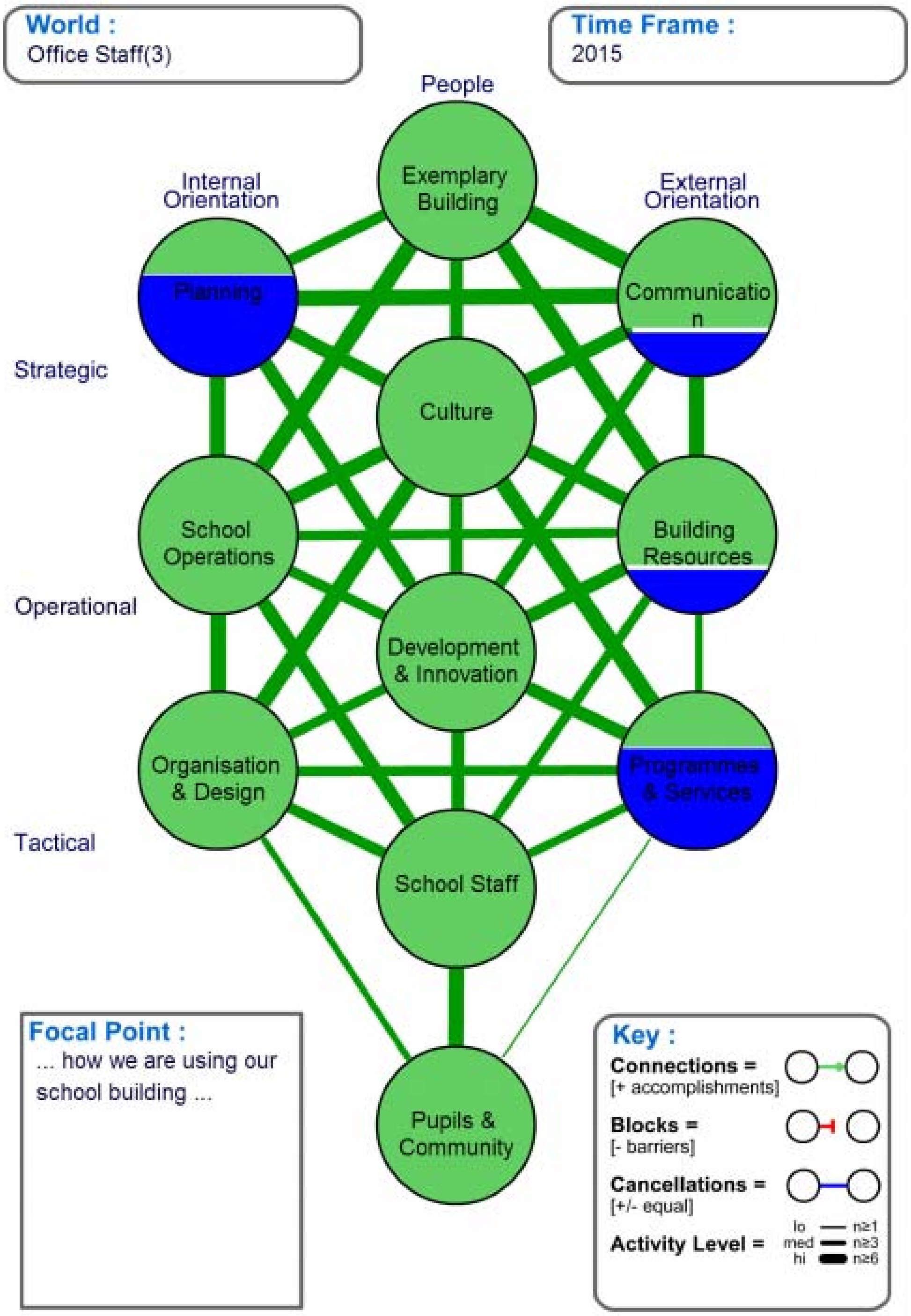
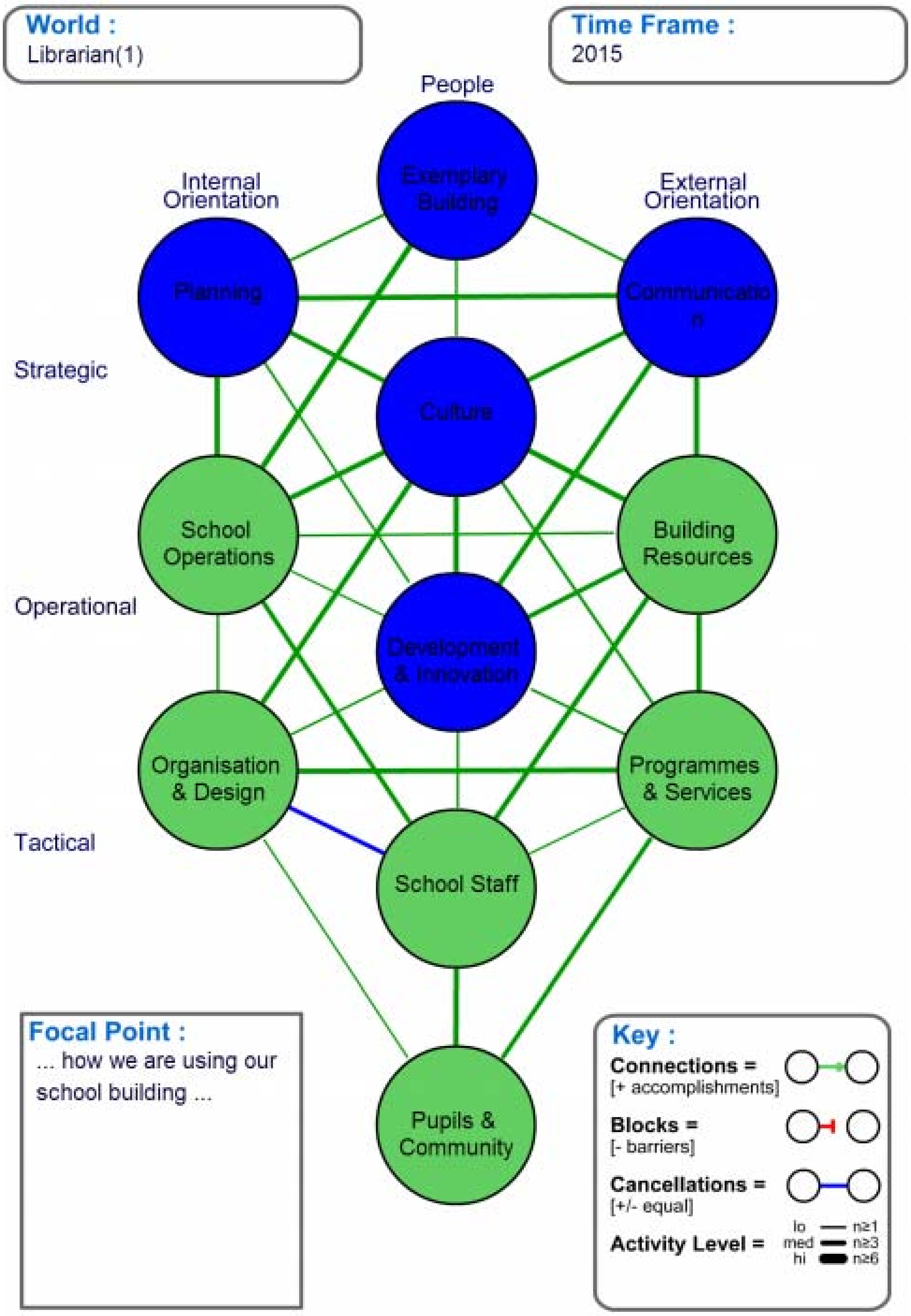
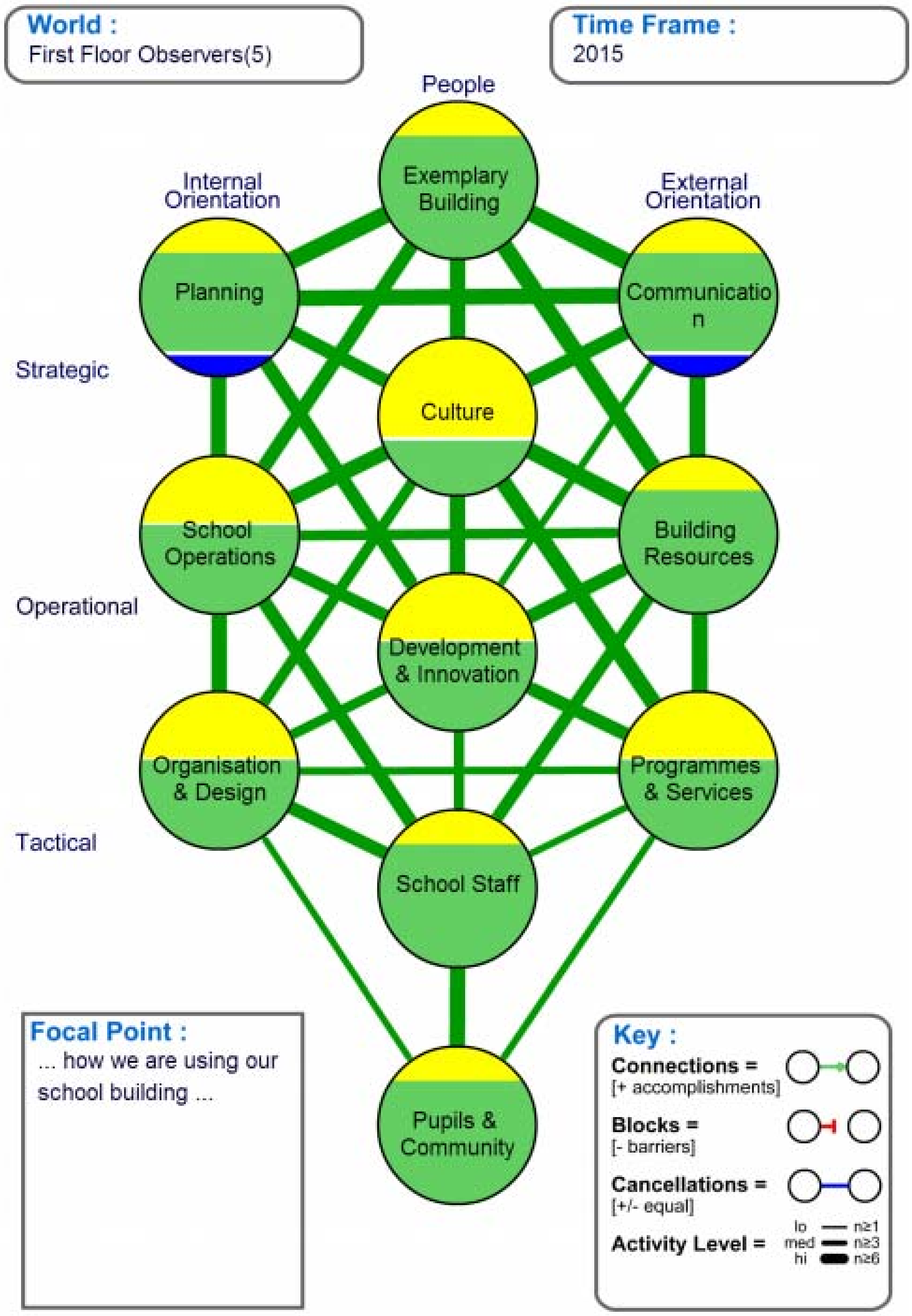
hi
n≥1
n≥3
n≥6


World :
Office Staff(3)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communication
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6



World :
Librarian(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communication
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6


World :
First Floor Observers(5)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo
med
hi
n≥1
n≥3
n≥6

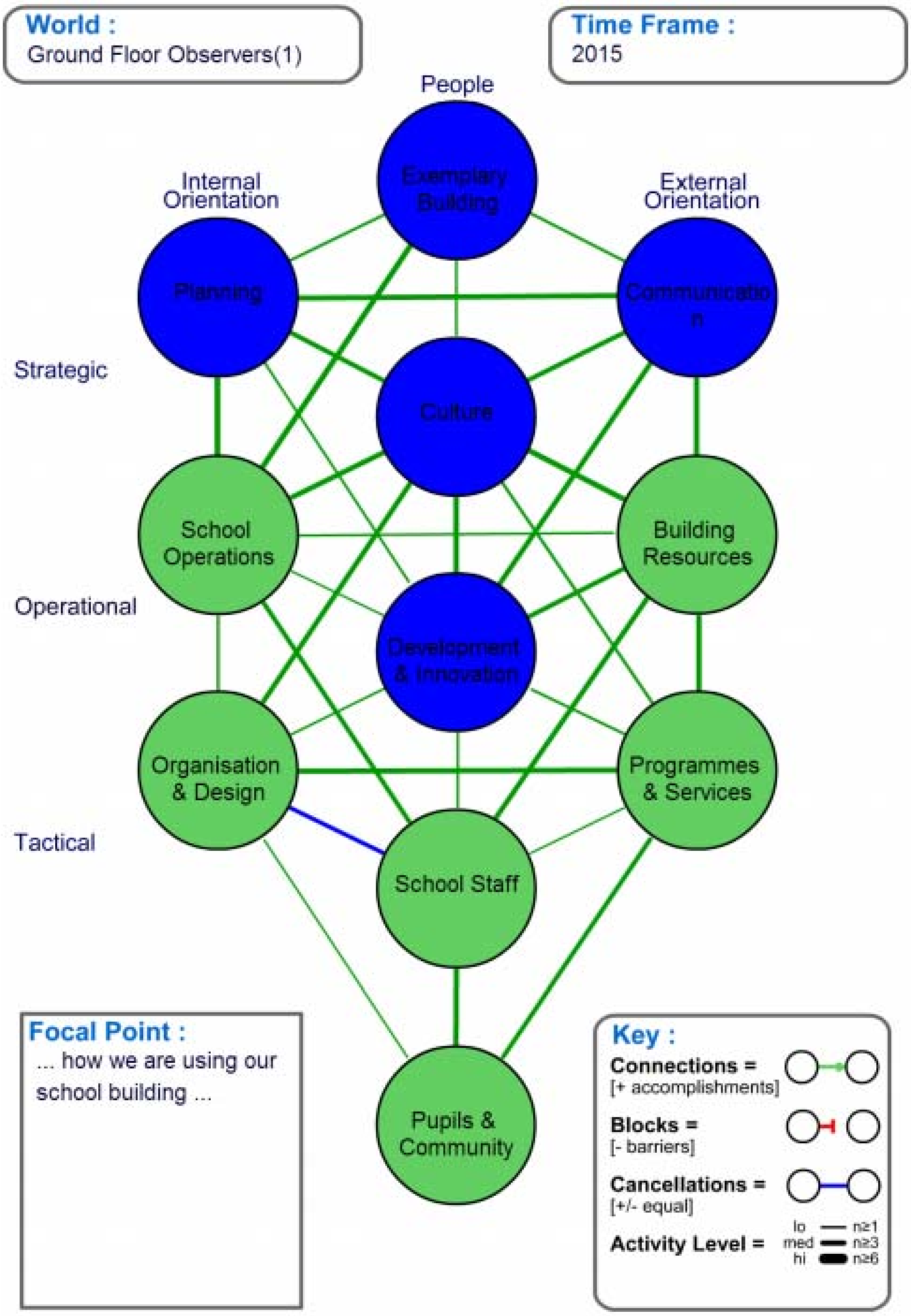
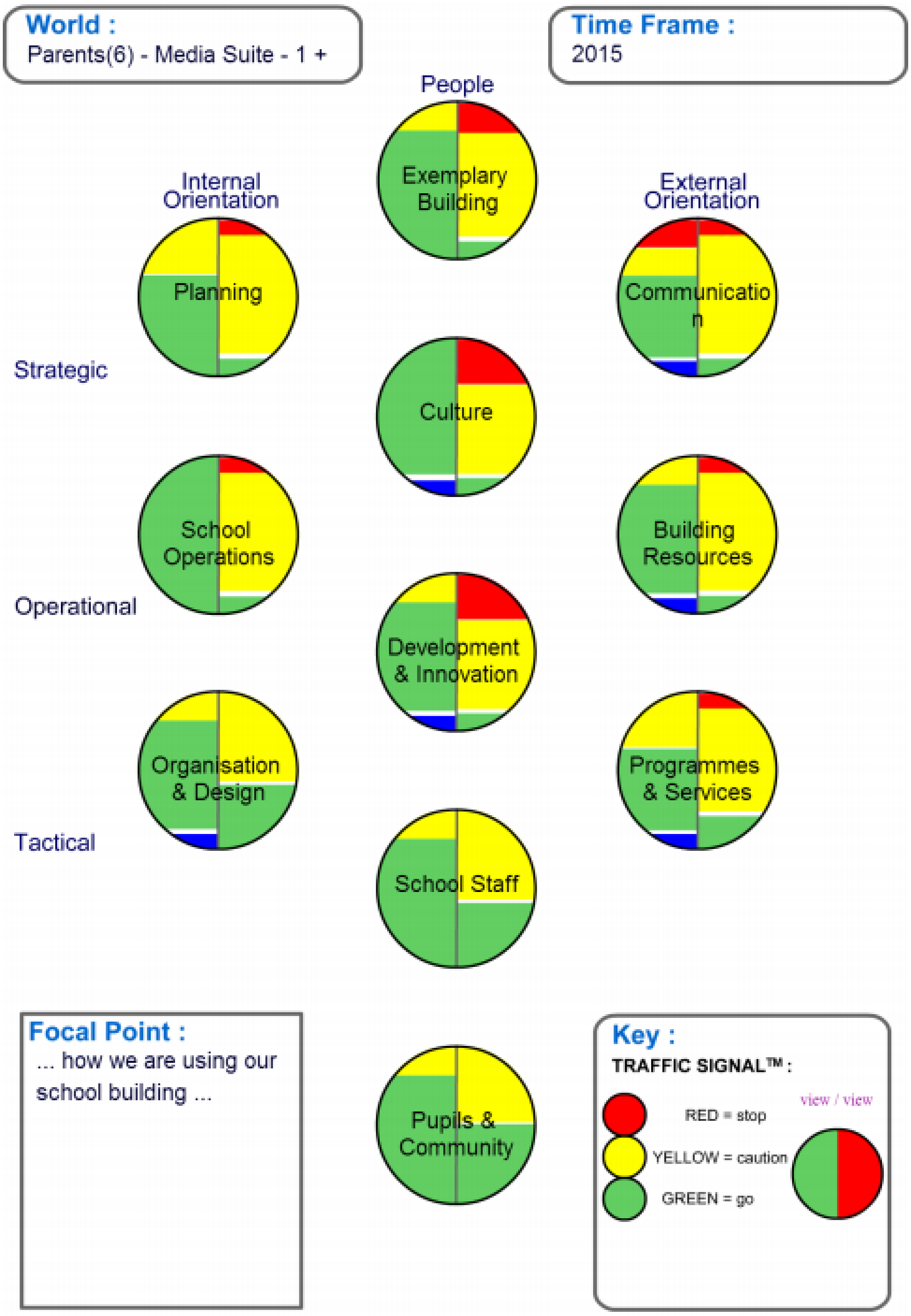
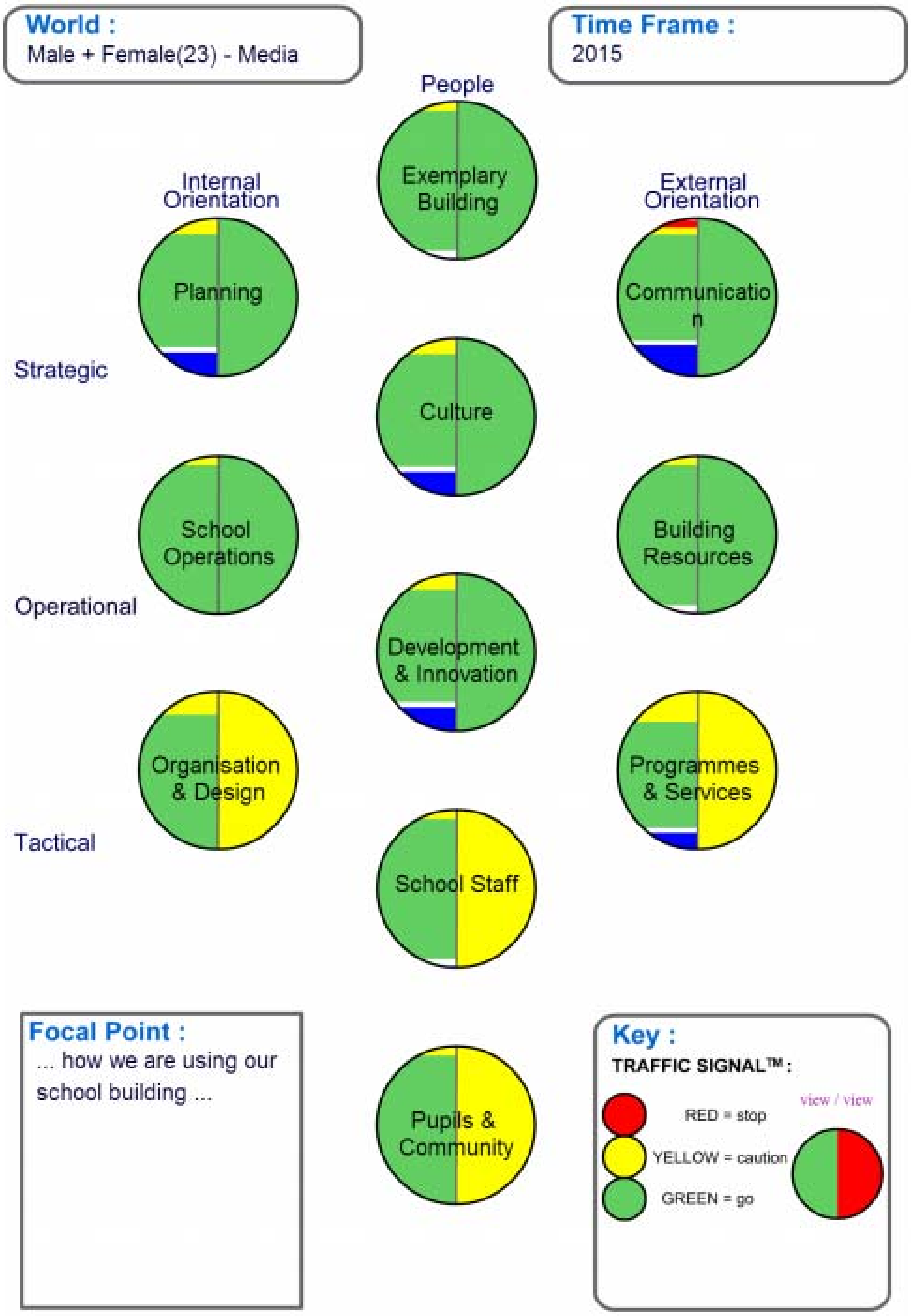
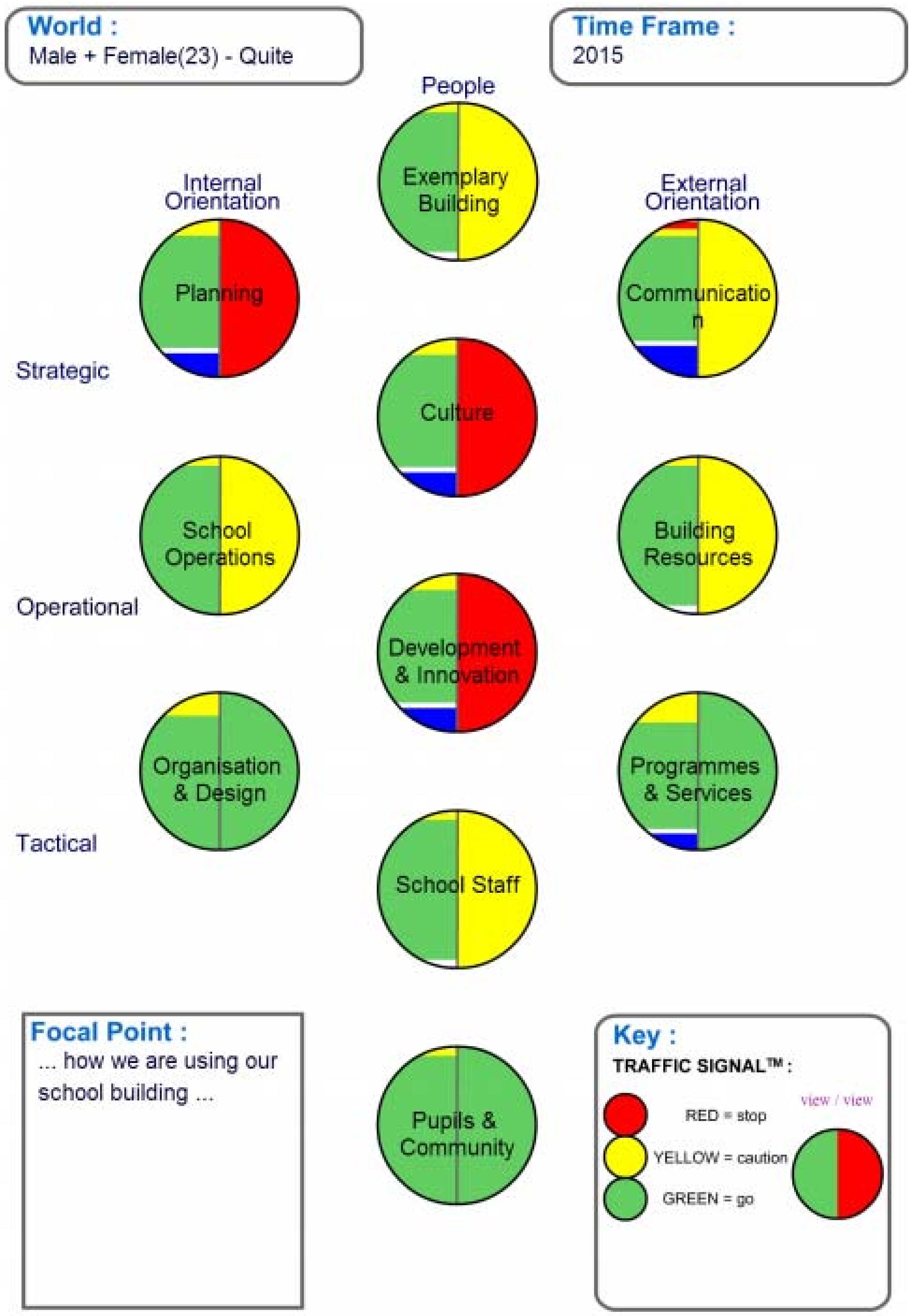

World :
Ground Floor Observers(1)
Time Frame :
2015
People
Internal Orientation
External Orientation
Exemplary Building
Planning
Communication
Culture
Strategic
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Pupils & Community
Focal Point :
... how we are using our school building ...
Key :
Connections =
[+ accomplishments]
Blocks =
[- barriers]
Cancellations =
[+/- equal]
Activity Level =
lo n≥1
med n≥3
hi n≥6

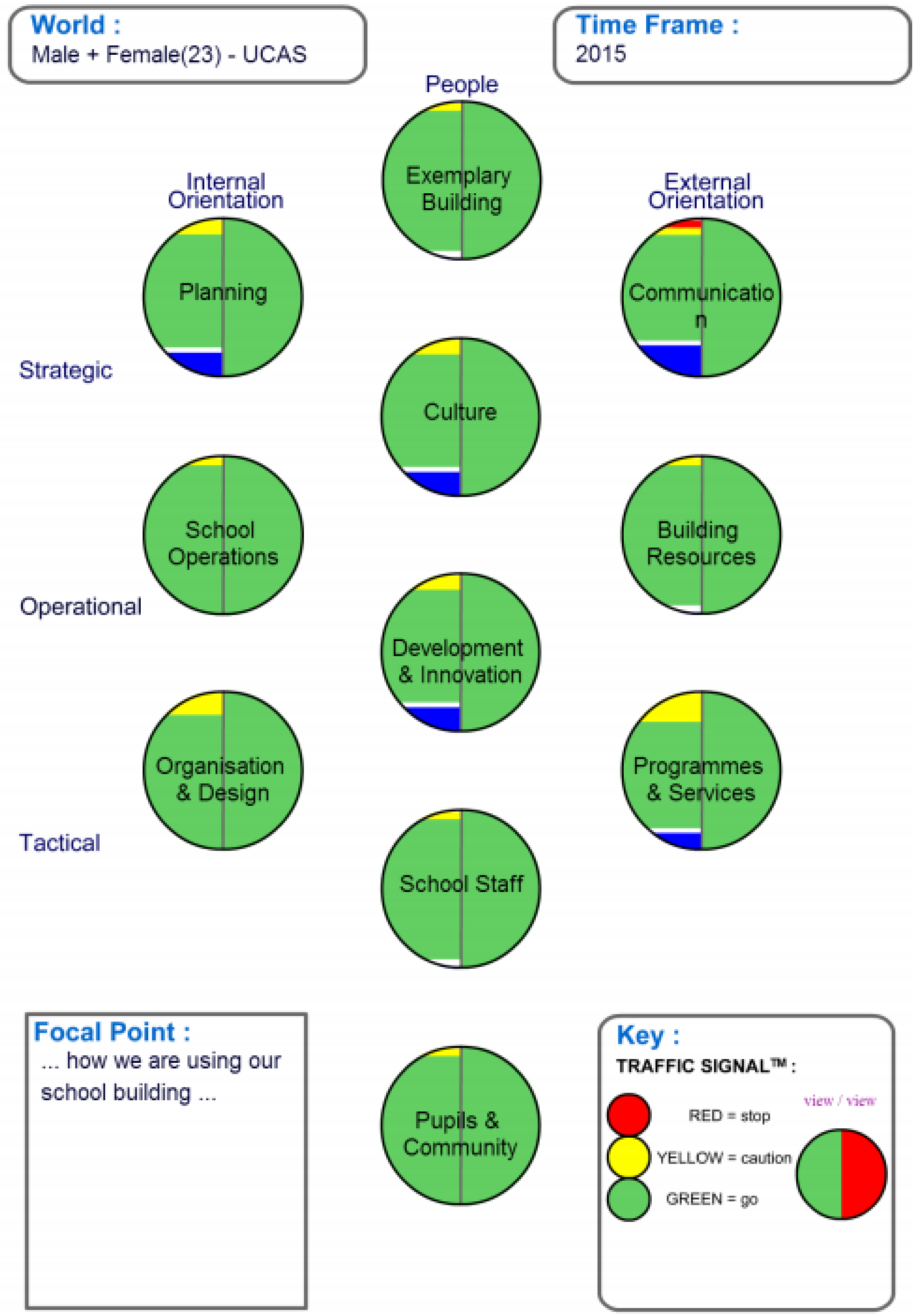
Table 7

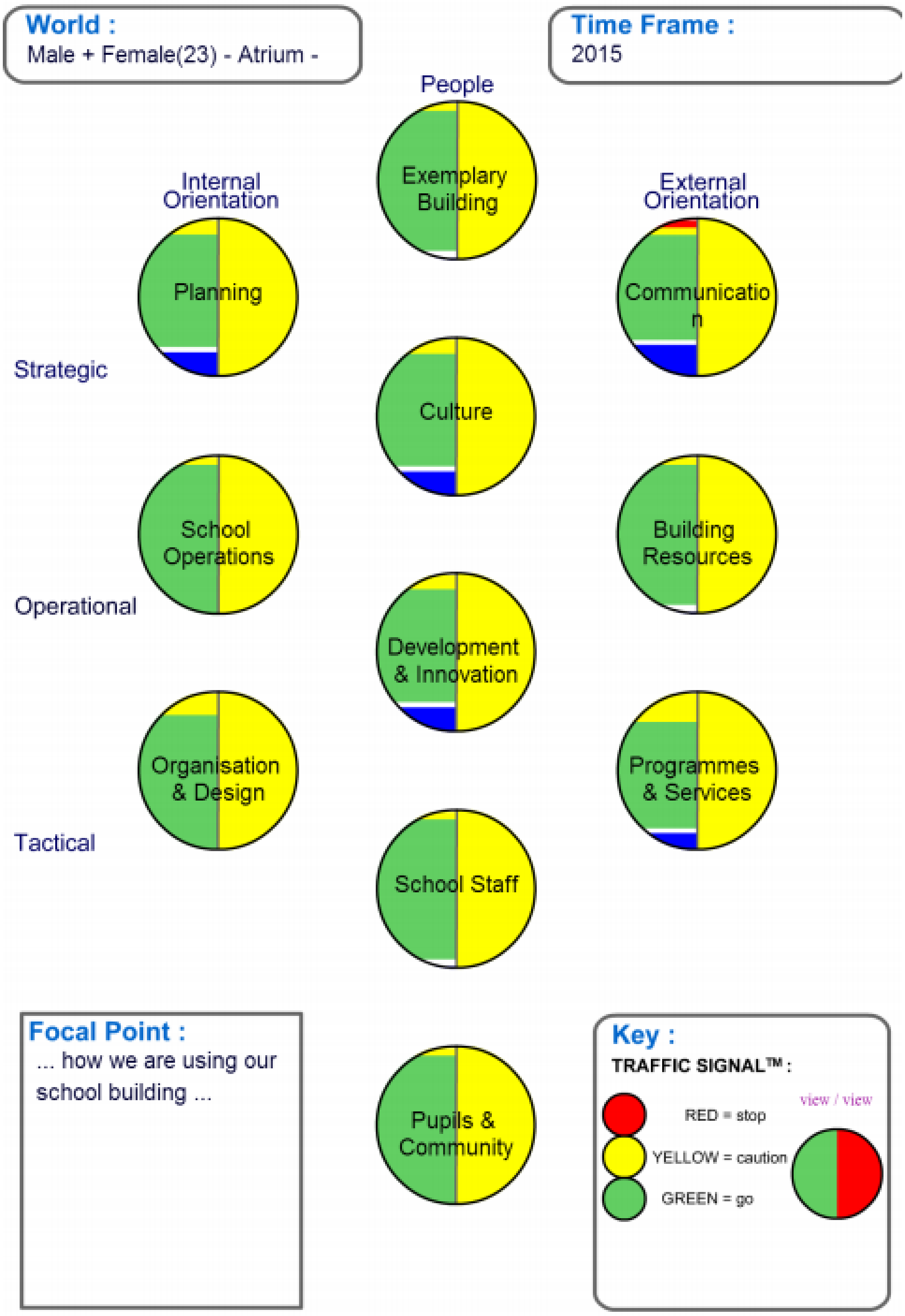
Combined Hemisphere Maps

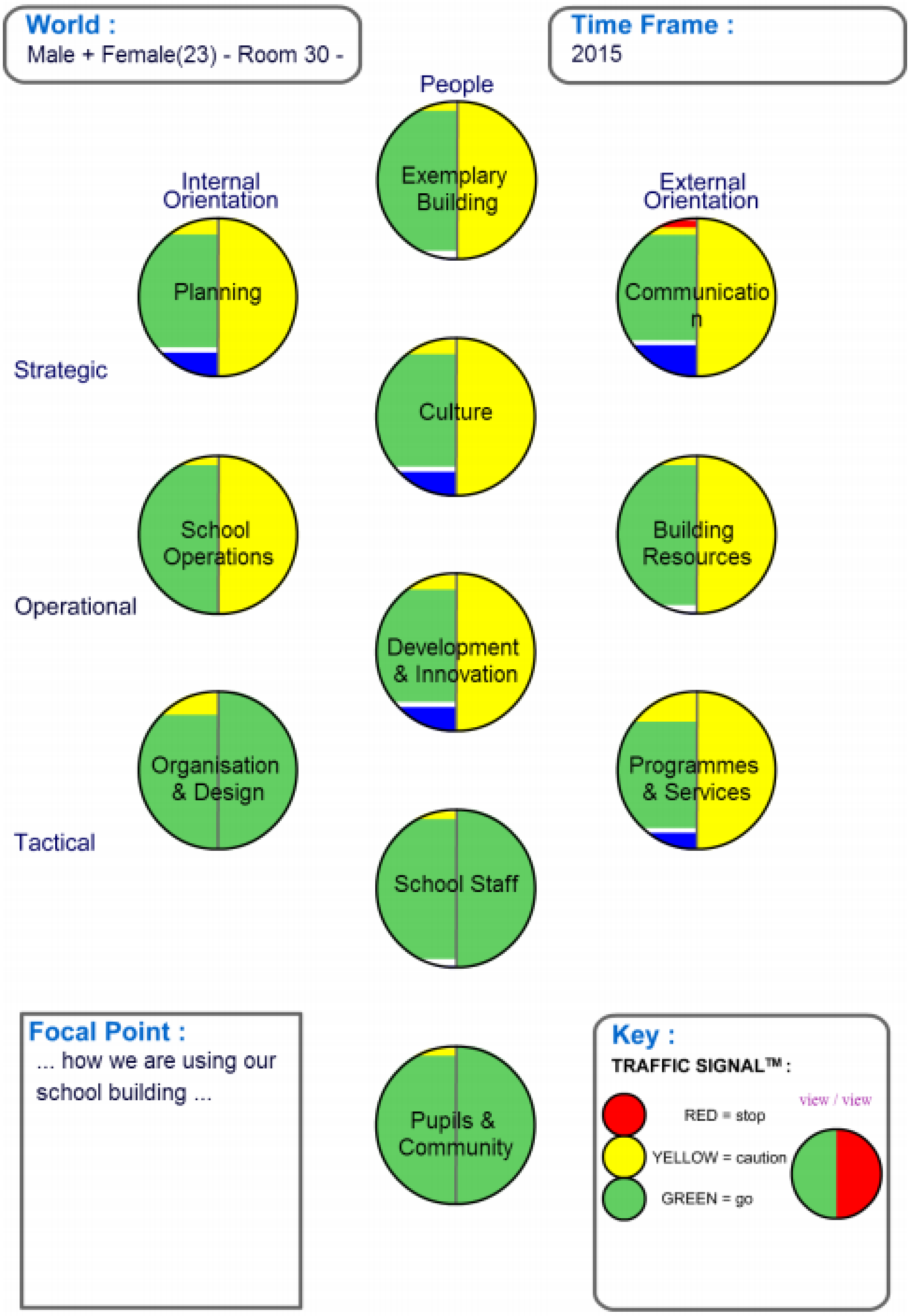

World :
Parents(6) - Media Suite - 1 +
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
TRAFFIC SIGNAL™ :
view / view
RED = stop
YELLOW = caution
GREEN = go


World :
Male + Female(23) - Media
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
TRAFFIC SIGNAL™ :
view / view
RED = stop
YELLOW = caution
GREEN = go


World :
Male + Female(23) - Quite
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
TRAFFIC SIGNAL™ :
RED = stop
YELLOW = caution
GREEN = go
view / view


World :
Male + Female(23) - UCAS
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
TRAFFIC SIGNAL™ :
RED = stop
YELLOW = caution
GREEN = go
view / view


World :
Male + Female(23) - Atrium -
Time Frame :
2015
People
Exemplary Building
Internal Orientation
External Orientation
Planning
Communicatio n
Strategic
Culture
School Operations
Building Resources
Operational
Development & Innovation
Organisation & Design
Programmes & Services
Tactical
School Staff
Focal Point :
... how we are using our school building ...
Pupils & Community
Key :
TRAFFIC SIGNAL™ :
RED = stop
YELLOW = caution
GREEN = go
view / view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Male + Female(23) - Room 30 -
Time Frame :
2015
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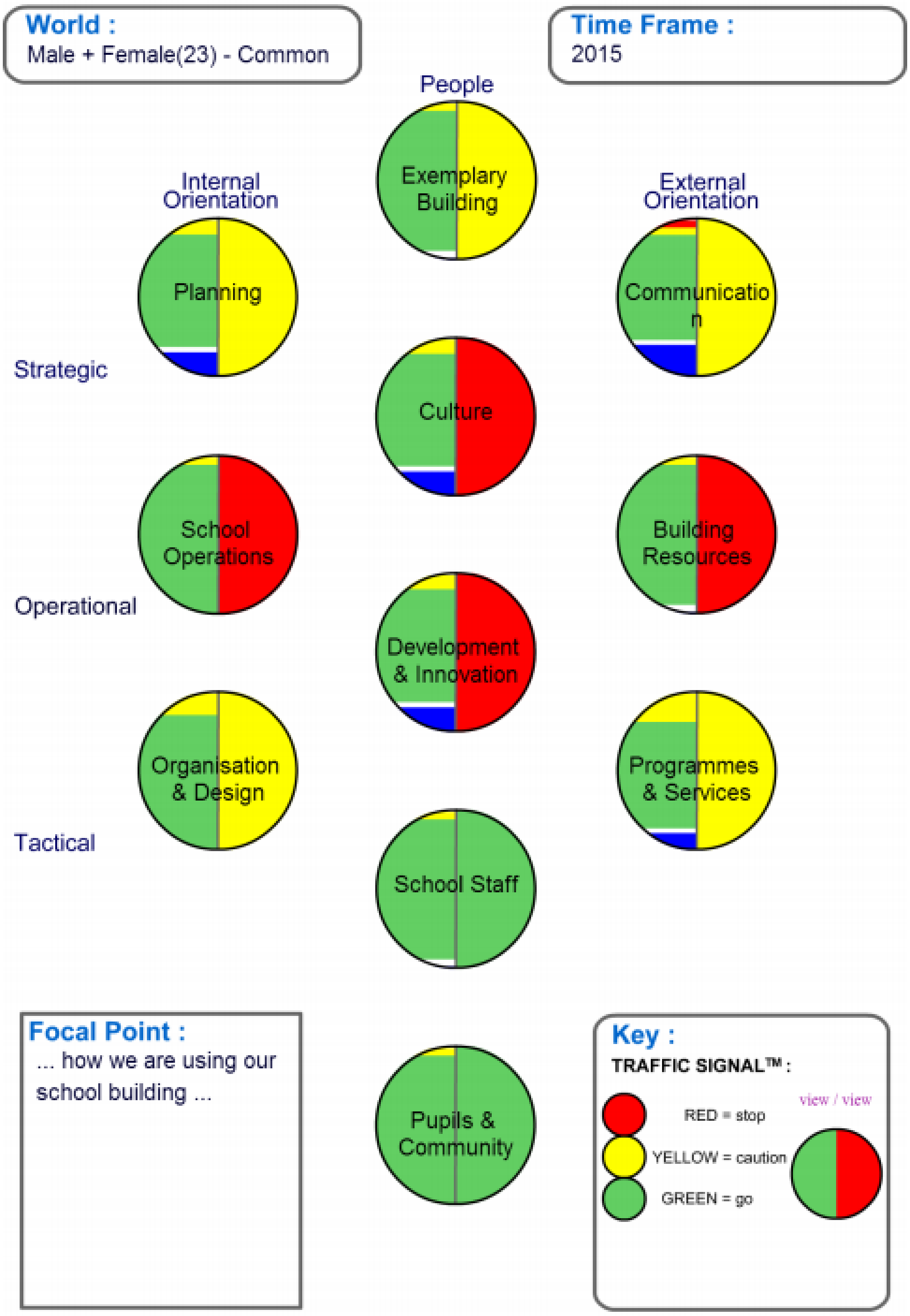
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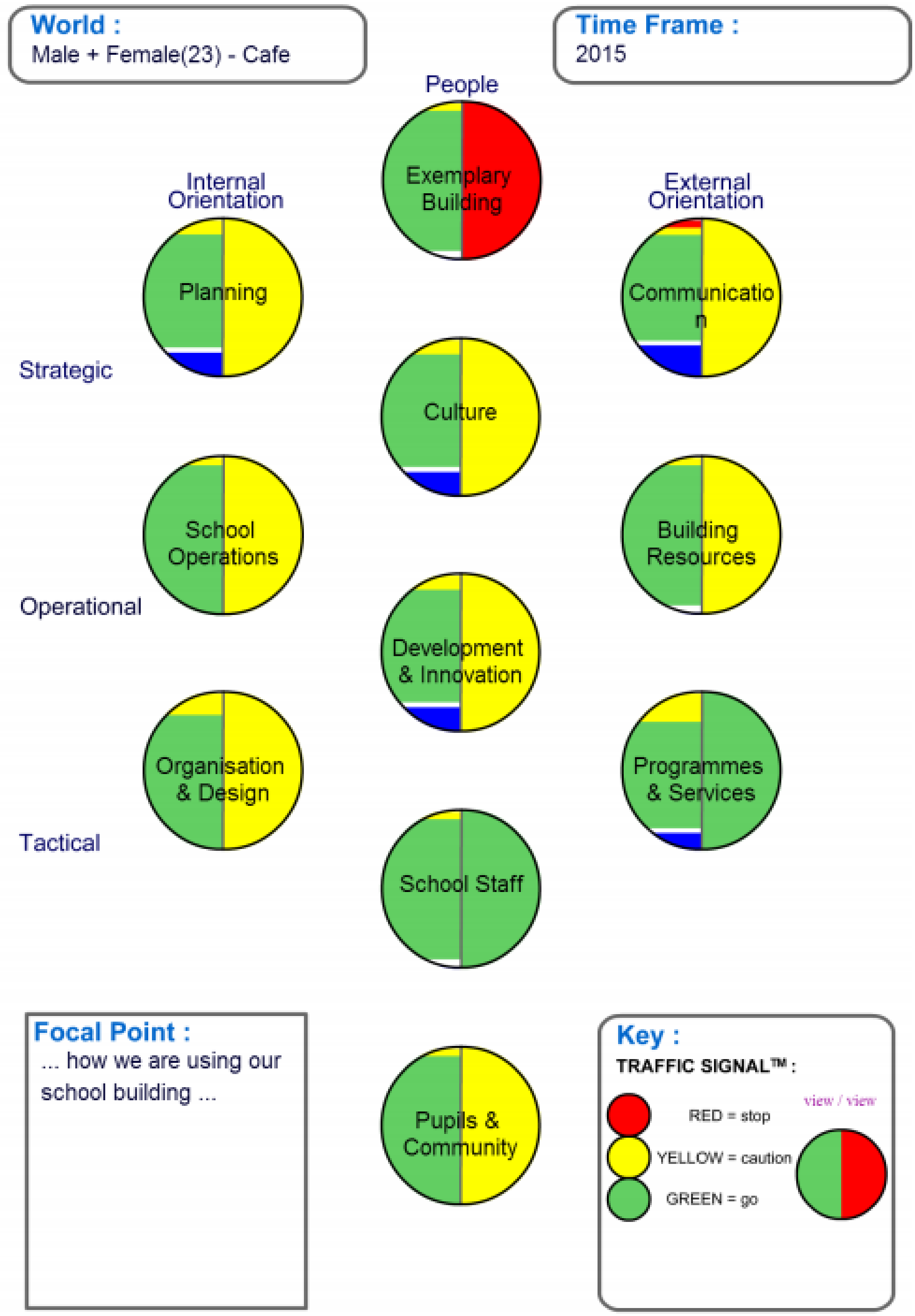
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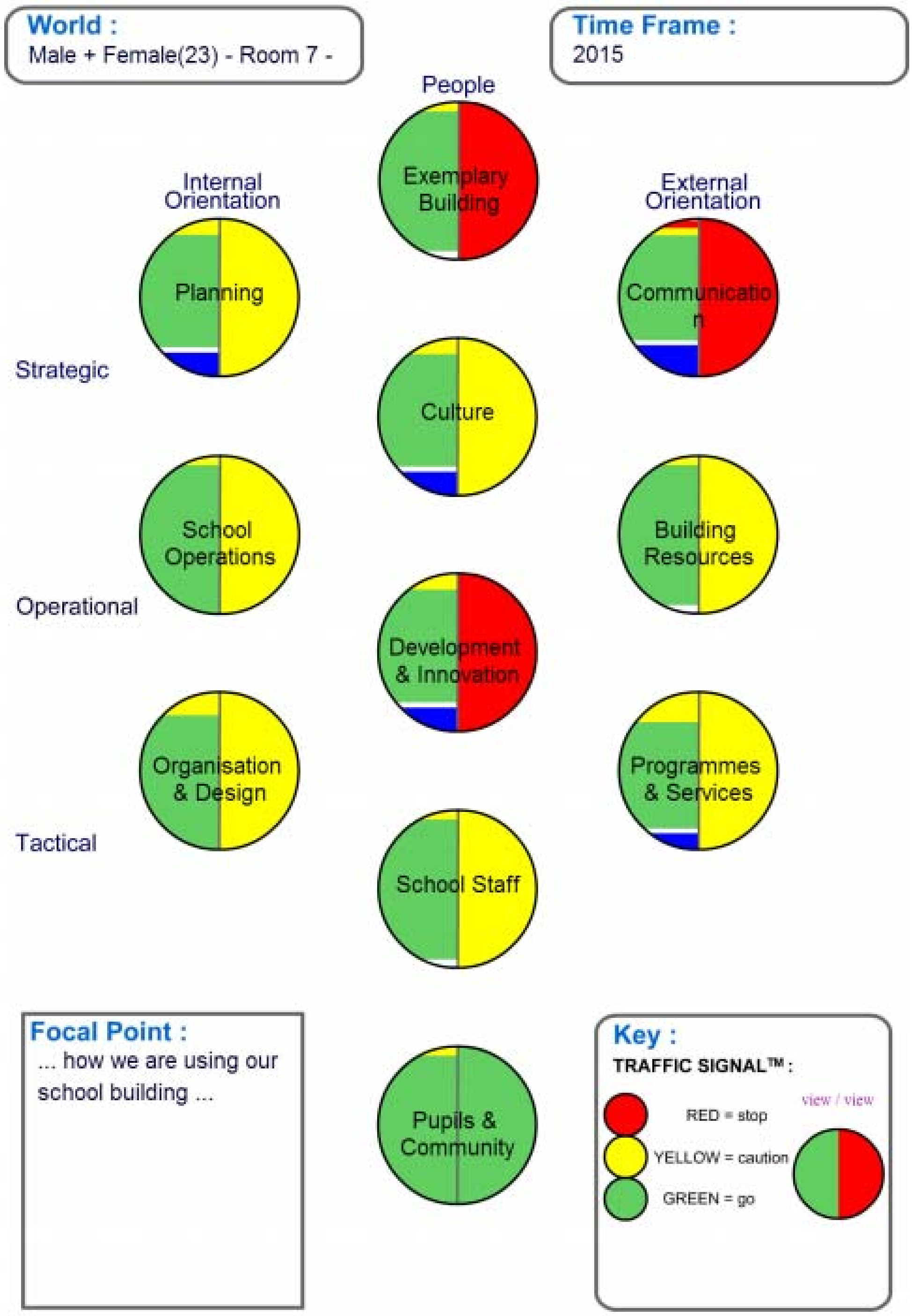
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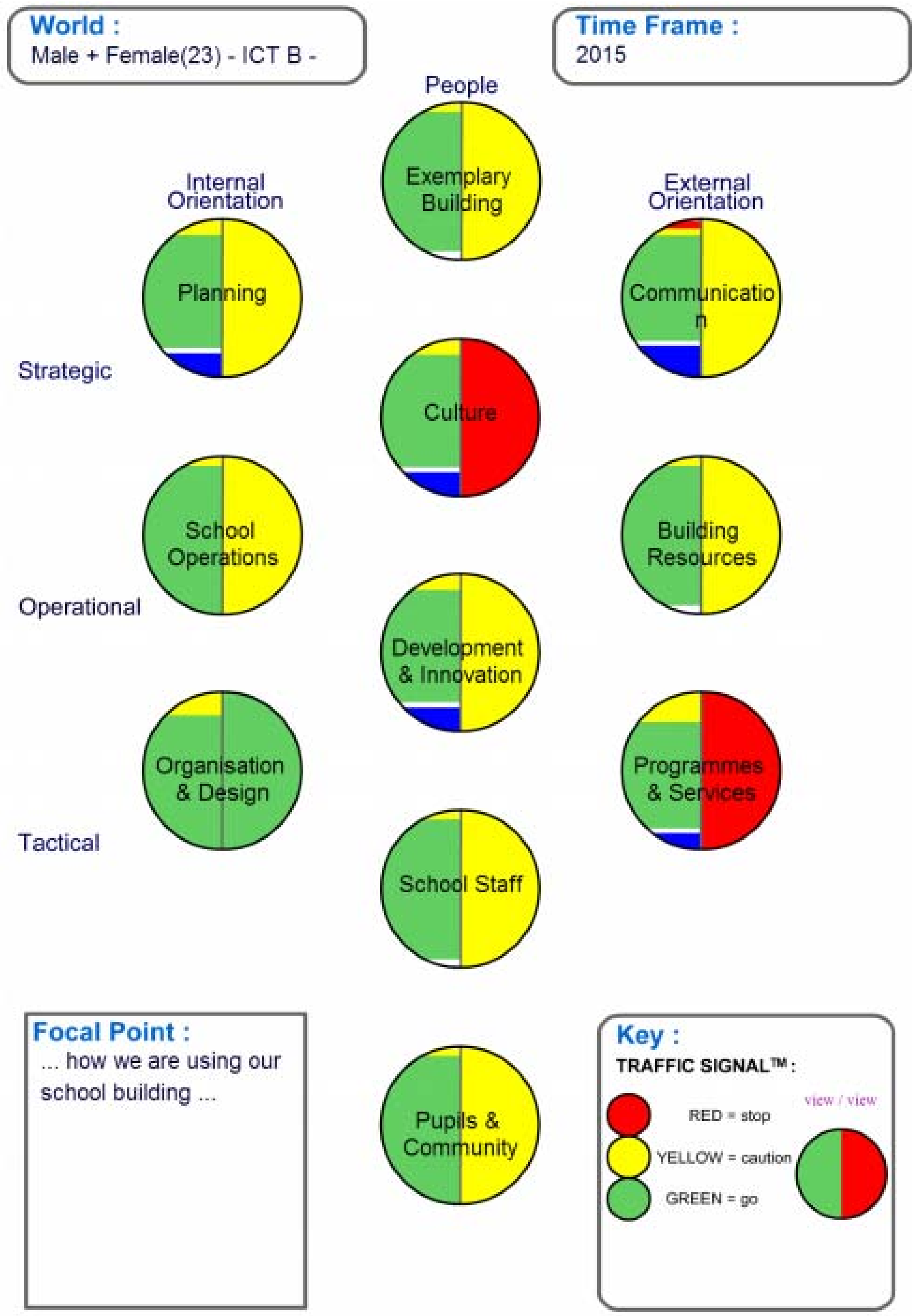
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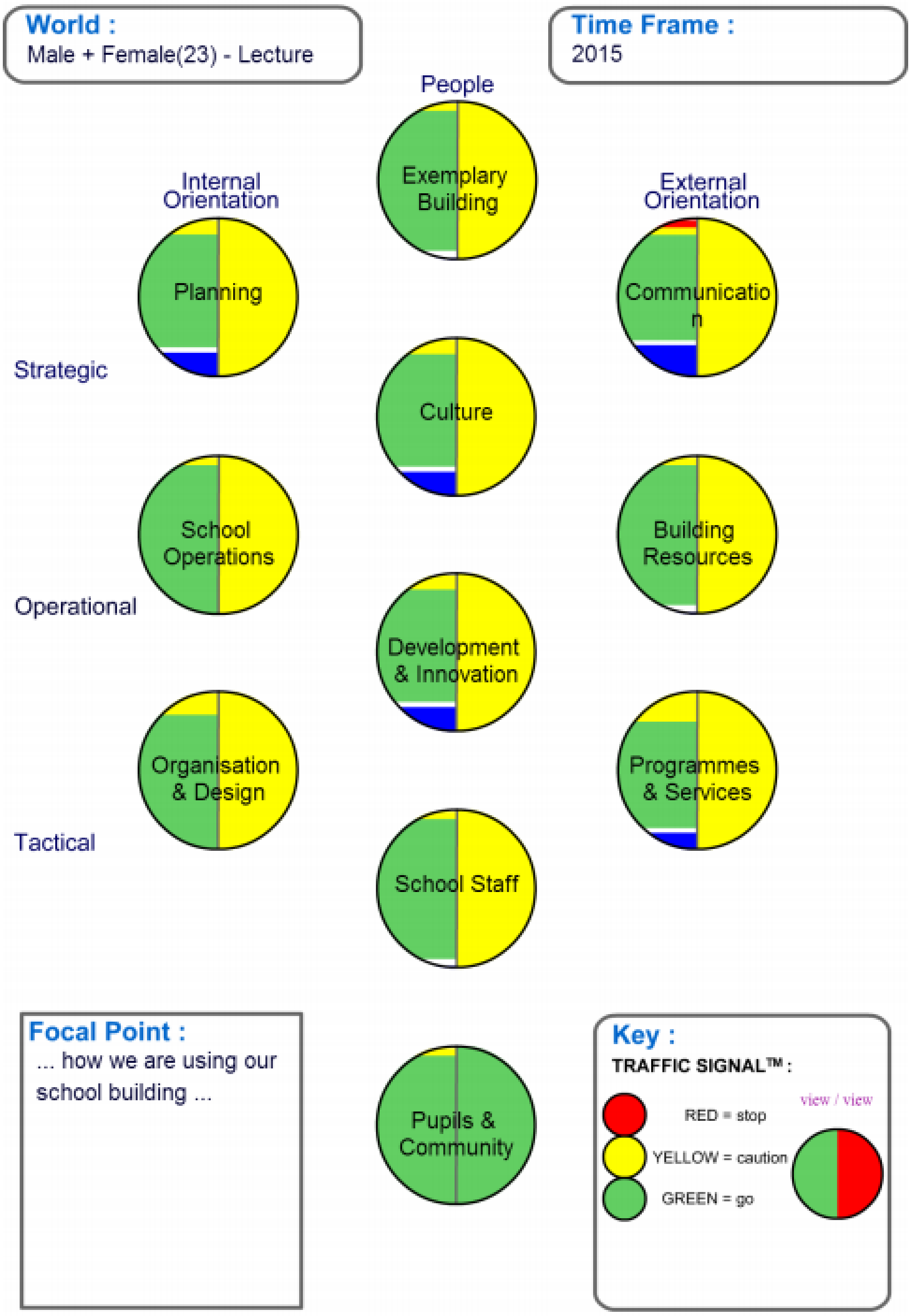
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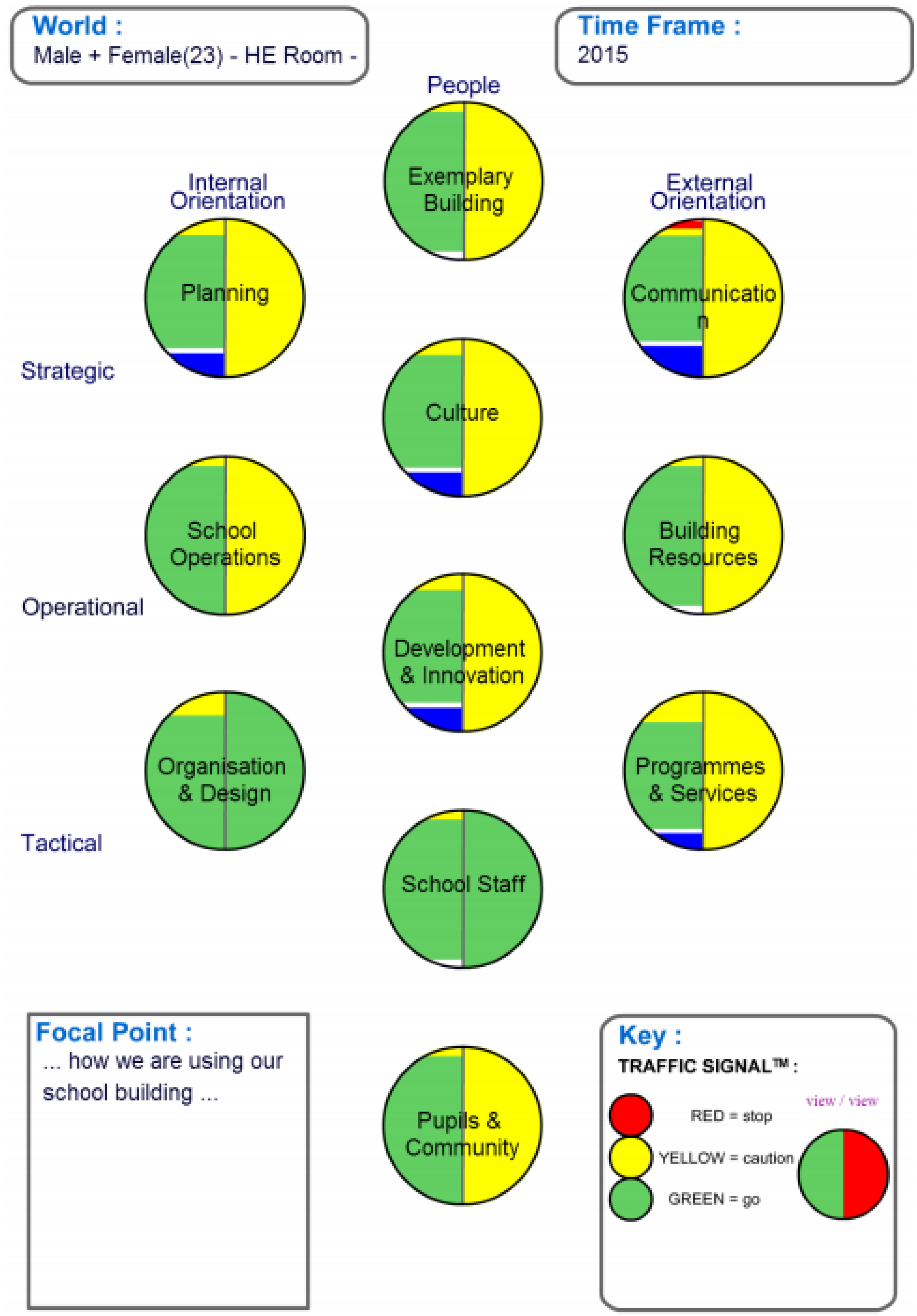
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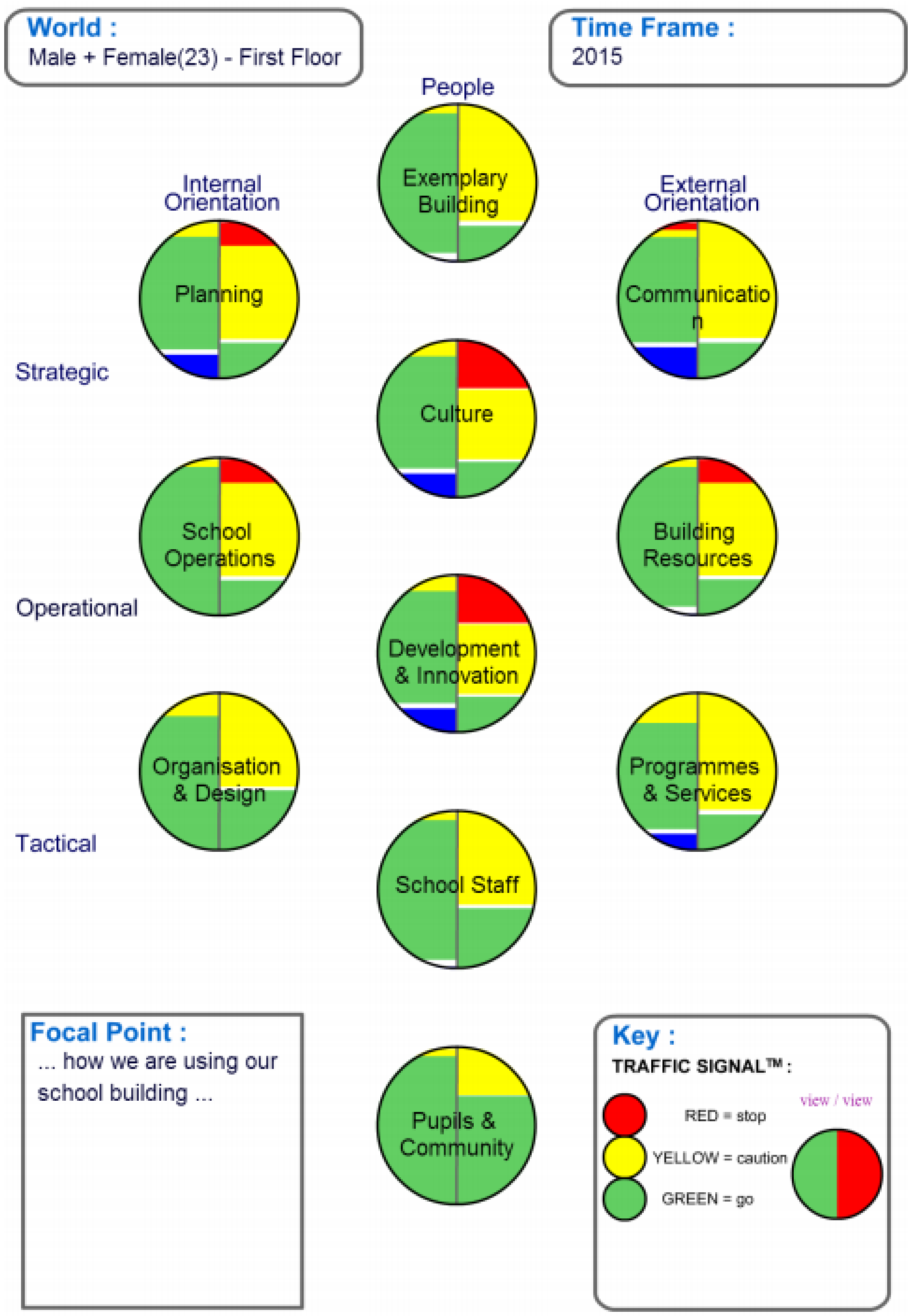
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Time Frame :
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Building Resources
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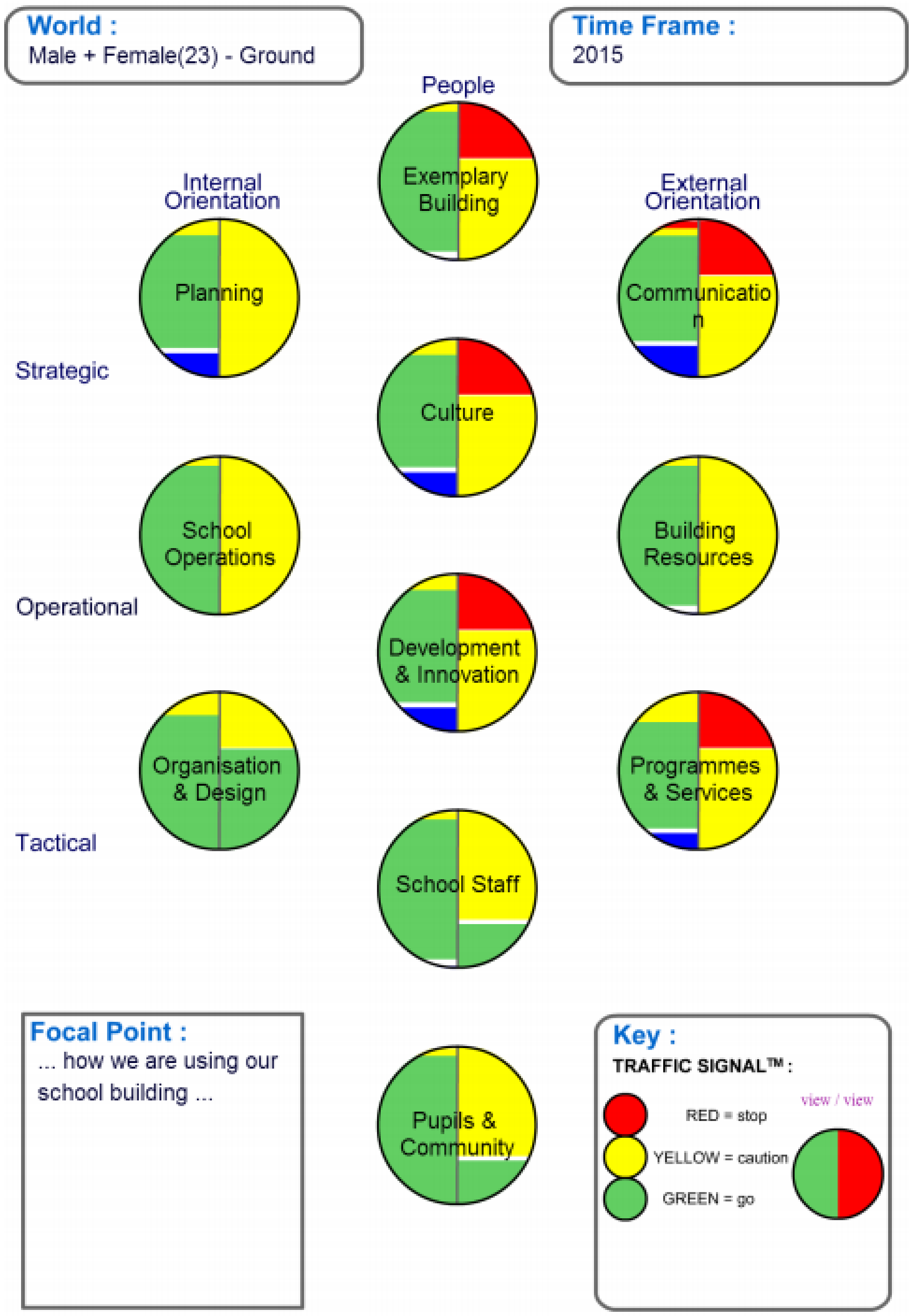
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Male + Female(23) - Ground
Time Frame :
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Building Resources
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Appendix 2 - Stakeholder Briefing Document

PhD Research Project

Engineering Better Social Outcomes through Requirements Management & Integrated Asset Data Processing

LND School

Background

Leaders in the public and private sectors now realise that the approach to development currently being pursued by society is not sustainable in the long term. The social problems that are arising from this lack of sustainability are becoming obvious and are creating concern in the mind of the public at large. H M Government are quoted as saying “we need to respond in many ways to make better use of our finite resources and to deliver the best possible opportunities for our population to lead fulfilling useful lives”.

If successfully applied an integrated approach to social and human aspects can ensure the welfare of end users can be dramatically enhanced. Best practice supports the acceptance and adoption of the asset by ensuring end users’ expectations and perceptions are met. Experience from schemes that have failed to address these issues are characterised by failure to plan, manage, design, integrate and execute with other designers and stakeholders.

The Government’s stated objective in the Construction Industrial Strategy is to deliver a national infrastructure to service public and private consumers. The impact of national infrastructure not performing has gross implications on society and our ability to perform basic day to day tasks as well as to maintain a competitive national economy. As technology develops and matures, finite resources diminish our historic approach needs to evolve. The digital revolution has come at a very timely moment in history with growing awareness of our impact on the planet, realisation that our continued use of finite resources will have consequences and the impact of those consequences on society.

Research Approach

The approach required to achieve a PhD is to identify a new area of knowledge. This is achieved through the identification of a new area of thinking and through research and inspection and the development of a method to prove the validity of the new learning. The learning I am interested in exploring is to "better understand the relationship between the built environment and the communities and people that inhabit them". To do this I have studied three key areas and identified a methodology to bring them together in a manner that can demonstrably provide useful assistance to both building users as well as built environment professionals,

1. The use of modern 3 Dimensional Object building models to gather "Building Physics" data
2. The understanding of how individuals and communities operate and interact
3. The relationship between the community and the built asset

The measurement of any human interaction is by nature subjective and qualitative. The human response to any situation is based on many variable and perceptions. The measures from a building are the opposite, they are quantitative and measurable, for instance temperature, light and CO2 levels. This research has led me to build a Test Bench system which gathers data both from the community and the buildings they inhabit and to perform some useful analytics on the data to identify how the community and building can deliver a happier more productive environment.

The analytics contain mathematics to enable quantitative and qualitative data to be compared and further analytics to understand the real feelings the community has rather than the perceived view. This is accomplished through the use of "double loop" reasoning. The end result is then presented to the user in a form they can understand and act upon.

Research Proposal

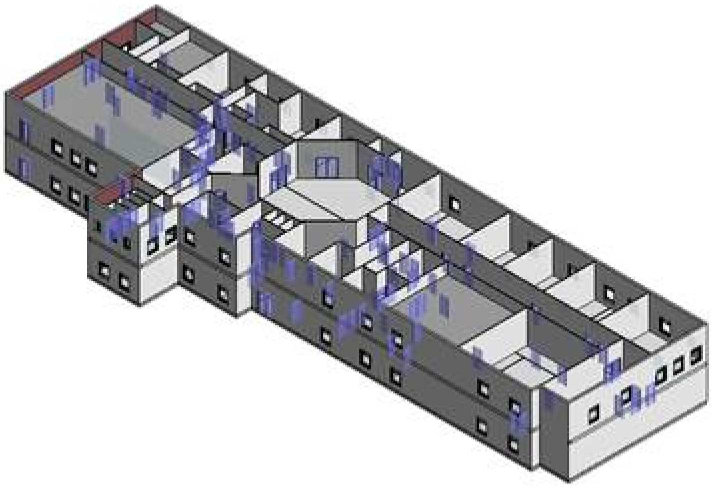
To develop a digital approach to creating a built environment which has a positive impact on the wellbeing of people and communities"

Ethics

Clearly any research into a sensitive facility such as a school must have clear ethical and procedural governance. The proposal here is data will be collected about the building fabric and physical form through the use of new and existing measurement sensors. Data will also be gathered from each part of the school community. This data will be gathered on line in the form of a questionnaire, which will be pre-approved by the schools appointed governance officer. All data gathered will be anonymous at all times, the data will be gathered on line with a simple web based list of questions, which are sent to individual named e-mail addresses only. Once processed all base data will be destroyed. Once the process is complete the results will be used anonymously by the researcher to present the outcomes and will be provided to the school for interest and review. The methodology other than that contained in the final dissertation report will be restricted to those individuals who request access and have signed a non-disclosure agreement.

The Process

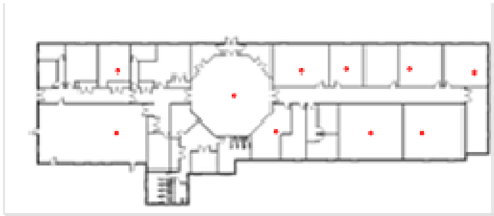
A 3D Building information model will be developed of the parts of the school under analysis. An early demonstration model has been prepared for information purposes. The image below indicates the new Sixth Form block, which may form a useful scope for the data analysis.



The context of the model is shown in the Google Earth image, where the modelled block is indicated. The 2D floor plans indicate the potential locations for environmental sensors which will require further discussion, as will the data required to be captured by existing metering systems.

Ground Floor

First Floor



The social perception community will be discussed in detail at a future date but by way of indication the following community members would be ideally consulted in the questionnaire process.

- Six Form Students
- Volunteers
- Outside School Club Users
- First Floor
- Ground Floor
- Advisors
- Prefects
- Head Teacher
- Departmental Heads
- Librarian
- FM Staff
- PTA Member
- Governor
- Teaching Staff
- Community Member
- Parents

Results

The results and the outcomes of the exercise will be provided as a written report and the final thesis will be publicly available.

The school will be free to use the data as they wish for educational purposes or to inform a wider study with larger parts of the school and a bigger sample set.

Appendix 3 - Respondent Briefing

Dear

You are invited to take part in a piece of research at XXX School, which aims to identify a new area of knowledge. Please read the information below which will inform you of the background of the research, our involvement and an ethical position. If you decide you would like to participate in this research, please reply to the address below and you will be sent a secure link to take part.

Title: Engineering Better Social Outcomes through Requirements Management and Integrated Asset Data Processing

Aim: To develop a digital approach to creating a built environment which has a positive impact on the wellbeing of people and communities.

The aim of the Government Strategy for Construction is to ensure all public buildings serve the public and meet their expectations and needs. The historical methods used in the construction industry need to develop as our finite resources diminish and population increases and to continue with current methods would both impact the planets resources and have consequences for our society as a whole. Advances in technology mean that improving public welfare through the way we build is not a distant future, but can become a reality within the next decade, with the help of the right research and knowledge.

Mark Bew is a parent of XXX and is currently doing a PhD exploring the built environment and how we can shape it to bring out better social wellbeing through digital technology. This is a brand new area of knowledge that is likely to be adopted by the Government in their future construction strategy. Mark's aim is to "better understand the relationship between the built environment and the communities and people that inhabit them" through studying three key areas and identifying methodology to bring them together. These are:

1. The use of modern 3 Dimensional "Building Information Models" to gather "Building Information" data
2. The understanding of how individuals and communities operate and interact with buildings
3. The relationship between the community and the building

How We Are Involved

XXX has agreed to be a part of this ground-breaking research and allow Mark and his team to collect data at the school. This will consist of sensors to collect physical data including temperature, light, noise and CO_2 levels from the sixth form block, using small sensors places in pre-approved places around the building. There will also be an online social outcomes questionnaire which all parts of the school community will be invited to fill out. This will gather views and reactions to the new sixth form building and once correlated with the sensor measurements, will provide valuable information about how our new building affects the wellbeing of its users.

Ethical Information

The sensors used in the building will not pick up any personal data about individuals in the building. This includes identities, images or conversations. The pre-approved social outcomes questionnaire will be anonymous and will be opt-in only. A link will be sent via email to carefully selected participants who have agreed to participate. Once the base data is collected and processed, all identifying information will be destroyed. The researcher will use this anonymised data to present the outcomes for the school's interest and review.

If you have any further questions regarding the study or would like to take part, please contact Mark Bew at M.D.Bew@edu.salford.ac.uk

Regards

Appendix 4 – Electronic Results Archive

Due to the large volume of data developed during the process of delivering this research only a sample is shown in this document the remainder are available upon request. This data store includes

- COBie Demand Matrix
- Process Map
- Analysis Reports
- Links to SOFI system
- Transcripts of conversations with Phillip Cousins and Diane Downs
- ERD for Toolkit

Appendix 5 – Detailed Specification - LND Experiment Contract

Section 1

1. General Information

1.1 Project:

Expansion of 6th Form Block

1.2 Project Scope:

(1) Construction of sufficient additional new build accommodation to facilitate the expansion.
(2) Works required to satisfy the conditions and reserved matters associated with the successful planning application.
(3) External works associated with items (1) & (2) above.

1.3 Contact Details:

Client Main Contact: JB, Estate Management Officer

1.4 Client and End User:

The Client for these projects is LND

The end users are the school plus Head Teacher.

1.5 Design Development

The design has been developed up to feasibility stage. During the detailed design development and submission of planning application the contractor may wish to make changes to the design. Any design development and / or design changes should be discussed with the Client and the Project Manager. Contact should be made initially to the Employers Agent.

In order to consider any design developments, the client will need to understand the potential impact on the final product, the planning process and any cost implications.
The Client will discuss any design developments with the end user as necessary.

[Note: if the contractor is holding design team meetings then it may facilitate the consideration or certain changes by having the client present for all or part of these meetings]

1.6 Programme (general)

The school will be expanding from September 2013 and will be admitting the first year of sixth form children from the expansion on this date, i.e. the school will have an additional 30 pupils. Therefore, the client would, ideally like the construction completed by September 2013 but as a minimum the client will need to be able to admit an additional 30 pupils at this school from September 2013.

1.7 Room Data Sheets

A set of room data sheets is included as an appendix to this brief. This brief should be read and used in conjunction with these room data sheets.

1.8 Department for Education (DfE) Guidance

Contractors may find it useful to refer to the published DfE guidance in relation to design form school buildings. The following are a list (not exhaustive) of guides that may assist:

- *BB102 - Designing for children and young people with special educational needs or disabilities in mainstream and special schools*
- *BB100 Designing and Managing Against The Risk of Fire in Schools*
- *BB99 – Briefing Framework for Primary School Projects (incorporate the area guidelines)*
- *BB93 – School Acoustics*
- *BB90 – Lighting Design in Schools*
- *BB87 – Guidelines for Environmental Design*

[Note: where there is any variance between the requirements in this brief / the Employer's Requirements (ERs) and the Building Bulletin the brief and ERs take precedence]

1.9 Building Regulations

When design guidelines are not allowed for within the above the proposal should comply with relevant and current building regulations and at minimum adhere to approved documents A – P.

Building Regulations 2000, Approved Document L2A (2006) under clauses 83 –85 requires building designers and professionals to produce a Building Log book based on guidance in CIBSE TM 31 "Building Log Toolkit", demonstrating new or changed or modified building services. The log book is generally written by designers and specialist authors developed in conjunction with the building user. The log book is a requirement for compliance with the Building Regulations.

The contractor is required to apply to the local authority for Building Regulations Approval either through the authority's own inspectors or an external Approved Inspector, licensed by The Construction Industry Council. This must be a Full Plans Application. A copy of the approval must be submitted to the Employer prior to commencement of construction works. The contractor is responsible for paying all associated costs, for achieving approval and for the Approved Inspector. The contractor must arrange all visits with any Inspectors in advance of commencing on site to ensure inspections are undertaken on time at the pertinent stages of construction to not hinder the programme.

The contractor is to provide, on completion of the works, a copy of the Completion Certificate, issued by the TDC Chief Building Inspector or a Final Certificate if an Approved Inspector is employed, certifying that the works have been completed satisfactorily. The Original is to be bound into the O&M manual on completion of the contract.

1.10 Planning Issues

Xxx District Council as the Local Planning Authority will need to be consulted. Contractors will need to obtain full planning permission by submitting a successful full planning application. The contractor should allow sufficient time in his programme for this activity.

The contractor will be responsible for complying with the conditions as laid out in the planning approval. Where the contractor requires the assistance of the client and end user to comply with a condition such assistance will be provided in a timely manner.

Where a condition needs to be complied with before construction commences the contractor is to ensure that these conditions are discharged in a timely manner.

1.11 Environmental Planning BREEAM

The client requires that these schemes achieve the BREEAM rating required to obtain planning permission. A BREEAM rating of excellent is required for this project.
Contractors should adopt sustainable design and construction methods. The proposals should also achieve the carbon emissions reduction as required within the planning application. (Refer to Sustainable Design and Construction Supplementary Planning Document).

1.12 CDM Regulations

The contractor must work in accordance with the current CDM regulations and in conjunction with the clients CDM-coordinator.

Those representatives from the main contracting party who visit and/or work on the site outside of any self-contained site compounds must hold an up to date CRB check, all subcontracting parties should be accompanied by a CRB checked member of the main contracting party. Contractors must be willing to provide details of CRB checks held so that schools can verify the information if necessary.

A health and safety file must be issued at practical completion; one hard copy for site and two CD-ROM electronic copies including (current Auto Cad LT - DWG system and PDF format) all drawn as built information.

1.13 Secure by Design

The proposal will need to be designed with the security of both the building users and the premises themselves and have both manual and automatic security provisions. The design should be compliant to the Secured by Design principles and achieved any approvals required by the planning conditions.

1.14 British Standards

All materials, goods and appliances for the works, unless otherwise stated, shall comply as a minimum with the latest relevant British Standard Specifications, British Board of Agreement Certificates, BRE Digests, NHBC/Zurich, and Local Authority requirements. Where any materials, goods or appliances are covered by more than one of the above standards and/or recommendations, the higher shall be selected.

All workmanship shall, as a minimum, be in accordance with the recommendations of the latest relevant British Standard Codes of Practice and/or trade suppliers, manufacturers' representative bodies, Codes of Practice and recommendations of the NHBC/Zurich, BRE Digests and Local Authorities and good common practice.

The contractor shall use its best endeavours to minimise the extent of construction waste and will be required to employ a Site Waste Management plan.

1.15 Statutory Undertakings

Where necessary the contractor is to obtain all statutory consents and instruct all statutory undertakings for connections to gas, water, electricity, highways, telecommunications and other necessary, for the works, before commencing works and bear all associated costs. Contractors will be required to liaise with statutory undertakers in earnest to limit delays to programme.

Section 2

2. Building Information

Although we are setting out general requirements associated with the provision of the new accommodation as a client and end users we are keen that where a contractor believes there may be a better way to provide something that such options are brought to our attention and we will be keen to give these proposals due consideration and accept where appropriate. This includes changes to internal design, choice of finishes / materials etc.

2.1 Room Schedules

Room schedules or room data sheets are based on the generic schedule below in table 9.1. The specification reflects the new accommodation proposed within the new Sixth form block.

Table 0.1 - Room Specification (Data) Sheet

Specified Item	Description
Project name	LND
Room Name	Group Rooms – Generic
Room Ref	001
Size of Rooms	
Room Occupancy	
Ceilings	Either suspended or painted plasterboard. (Above ceiling void easily accessible for future maintenance and adaptation of services. (Moisture resistant)
Walls	Paint or other easily cleanable finish, should be easily re-paintable
Floors	Combination of anti-static carpet and non-slip vinyl (or equivalent) surface
Joinery	Timber or equivalent, skirting's, architraves and window boards, painted finish.
Fittings	1 * standard double cupboard sink unit, including stainless steel single drainer and separate hot and cold taps. Units to be of high quality standard kitchen units. Selection of cupboard front to be agreed from ranges selected with the school, with robust cupboard hinges
Fixtures	Blinds to all external windows
Windows	Double glazed, solar reflective, lockable, restricted openings (Maximum glazed area to maximise natural light)
Doors	Internal flush faced, solid, top and bottom, anti-shatter glass vision panels,

	finger guards, lockable door. External doors predominantly anti shatter glazed, threshold with a level transition from inside to out, lockable and openable from the inside without a key
Ironmongery	3 No hinges, push plate, pull handle, kick plate, metal barrel latch, deadlock, escutcheons (no snib). Keys to be on a master key system for whole block. Door closer, vision panel, room sign holder system
Storerooms	
Whiteboards	Supplier by client
Pin Boards	5 Pin boards 1200 * 900 Locations to be selected by school
Notes	Client / end user to order loose furniture
Temperature Summer (Min)	19
Temperature Summer (Max)	21
Temperature Winter (Min)	19
Temperature Winter (Max)	21
Ventilation VOC (Max)	1000
Ventilation VOC (Min)	450
Humidity (Max)	45
Humidity (Min)	55
Heating	
Noise Level (Max)	60
Air Conditioning	
Water Services (Cold)	
Water Services (Hot)	Tepid water supply to sink unit
Water Services (Drinking)	Drinking water supply to sink unit
Special Items	
Sprinkler	As specified by Building Control
Lighting (Luminaire Type)	
Type of Lamp	
Minimum Lux	300 Lux Min, limiting glare rating 19, minimum colour rendering 80 and uniformity ration 0.8
Power Outlets 240v (Non IT)	8 No DSO ideally 2 on each wall within each room
Power Outlets 240v (IT)	5 No DSO
Power Outlets 240v	
Power Outlets 120v	N/A
Other	Audio visual connection for interactive whiteboard
Data Outlets (RJ45)	4 No Data Outlets
Telephone	1 RJ45 for telephone connection

Fire Alarm	
Emergency Lighting	Yes, as specified by Building Control
Smoke Detector	
Security System	

All room areas should be treated as a base figure. However, it is unlikely that school will be able to fund room sizes significantly larger than the figures quoted and as far as possible these figures should be adhered to.

A tolerance of up to + 2.5% may be used in sizing rooms.

2.2 Basic Teaching accommodation – Class bases

The following general comments apply to all classrooms.

Room shapes should be designed so that they are practical for use by a 6th form school. Square or rectangular shapes are acceptable where all the walls are of similar lengths (i.e. no long thin rooms). Other shape rooms will be considered only if it can be demonstrated that these are operable efficiently. In general terms acute angles should be avoided as these create space areas that are difficult to use efficiently or flexibly. A teacher in a classroom should have sight of the whole room from any point in the classroom. The whole room should be viewable from room's entrance doorway.

Each room should have coat-hanging space that can either be in the adjacent circulation space or in the classroom adjacent to the entrance door however not obstructing means of escape.

Each classroom will require store area either a lockable walk-in cupboard (2m²) or provided by fitted units or loose furniture. This will be confirmed for individual schools in the specific details.

2.3 Group Rooms

Groups are teaching spaces meant for use with less than a full class of children. Room shapes should be designed so that they are practical for use by a 6th form school. Square or rectangular shapes are acceptable where all the walls are of similar lengths (i.e. no long thin rooms).

2.4 Storage

Storage within classrooms, See 2.2

Store rooms

Store rooms around the school are to provide space for the storage for curriculum materials, consumables etc. Generally, there should be some fixed spur shelving within these spaces to facilitate the safe use of the space. Generally, for smaller stores shelving should be on one wall but for larger areas additional shelving should be provided to other walls.

Cleaners Store

These areas are for the safe storage of chemicals and other materials used for cleaning, therefore this area needs to be secure and compliant with relevant regulations for safe storage of these materials.

In addition, this store should contain a water supply and sink suitable for cleaning staff to fill and empty buckets and rinse out mops etc.

2.5 Wheelchair User Accessible WCs

Where wheelchair user accessible toilets are required these should be a unisex facility. These toilets should be designed with an adult height WC and comply with Part M of the Building Regulations.

2.6 Pupil Toilets

Pupil toilets will need to be provided as separate girls and boys toilets.

Within the girls toilets there is a need for WC facilities separated into individual cubicles with associated communal hand wash facilities. The flush mechanism for the WCs should be push button or similar, ideally with hidden cisterns with access for maintenance. Sinks to be provided as individual hand basins. Fixtures and fittings as described in the room data sheets are required. Unless otherwise stated contractors should look to maximise the number of WCs within the toilet area.

Within the boys toilets there is a need for both WC facilities separated into individual cubicles and individual bowel type urinals along with the associated communal hand wash facilities. The number of WCs and urinals should be more or less equal [note: where a toilet area is small and two or less toilets can be provided then these should both be WCs]. The flush mechanism for the WCs should be push button or similar, ideally with hidden cisterns with access for maintenance. Sinks to be provided as individual hand basins. Fixtures and fittings as described in the room data sheets are required. Unless otherwise stated contractors should look to maximise the number of WCs within the toilet area.

2.7 Staff Toilets

Within the staff toilets there is a need for WC facilities separated into individual cubicles with associated communal hand wash facilities. Sinks to be provided as individual hand basins. Fixtures and fittings as described in the room data sheets are required. Unless otherwise stated contractors should look to maximise the number of WCs within the toilet area.

2.8 Circulation

Circulation space should be as far as possible wide enough for two wheelchairs to pass and suitable for the number of pupils and staff who will be using it routinely. As far as possible these areas should be well naturally lit and naturally ventilated. If coat storage is to be included in circulation space then consideration should be given to provide storage space under the coat hooks for packed lunches etc. subject to the corridor being wide enough.

2.9 Plant room

Plant room space will be for; boilers, or electrical switch gear or gas intake. Dependant on use these areas will need to be appropriately sized, designed and fitted out. All these areas must be secure but with good access for maintenance.

2.10 ICT Room

An ICT room will require fixed benching to all walls where pupils will operate PCs. If it is not possible to provide 30 pupil workstations around the wall there should be provision for power and ICT network *connection available in the centre of the room via floor boxes. In addition, the pupil workstations there will need to be provision for a workstation for a member of staff and printer and scanner.*

2.11 Lifts

A suitable DDA platform lift may be required, capacity to be confirmed.

2.12 ICT & Phone Provision

The contractor will need to facilitate the installation of both ICT and Telephone cables by the client / end user's preferred providers. This will mean that all of the cable routes / trunking will need to be provided by the contractor with access being available prior to practical completion for the installation of the cables. Where interactive whiteboards, projectors etc. are to be installed the contractor will ensure that the structure is strong enough to support the equipment.

Information about weight loadings of ICT equipment will be provided by the client / end user in a timely manner when requested.

2.13 Security
The completed building should be secure both during the school day and out of hours. Details of locks and other physical security measures are to be discussed and confirmed with the client.

Where the new building is to be protected by an intruder alarm/cctv/access control system and fire alarm which will need to be connected to the existing school's systems. The responsibility for the integration/connection rests with the contractor and where appropriate the client / end user will provide information about the existing installation.

2.14 External Works

These will be described elsewhere

2.15 Aesthetics

The client has an expectation of an attractive building being provided, although the client notes the limitations of both the budget and construction method.

2.16 Roof and Cladding

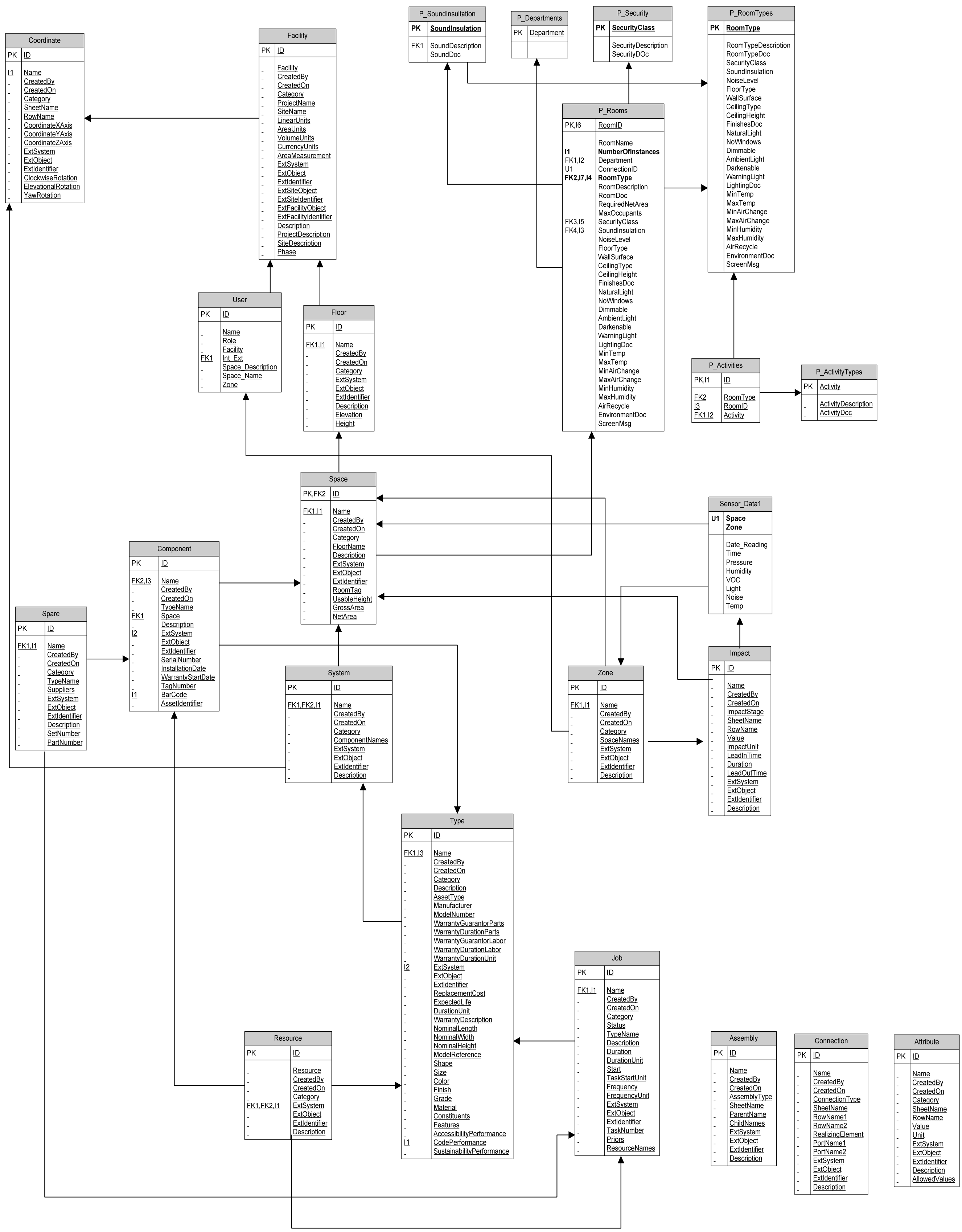
The client will expect a pitched roof and the building to be over clad in brick or other appropriate material.

Appendix 6 – Detailed Specification – Data Definitions

The following are specific data definition details building on those identified in chapter 6. The ERD is fully detailed and available in the electronic archive described in Appendix four. The COBie specified entities are defined in BS1192:4:2014. The following table defines the attributes and usage of the incorporated entities as indicated.

Entity	Description	Attribute
P_Soundinsulation	A description of the potential types of acoustics that may be specified	SoundInsulation Sound Description SoundDoc
P_Departments	A description of the departments that may occupy the space, for reporting purposes	Department
P_Security	An entity with attributes describing the security requirements	SecurityClass SecurityDescription SecurityDoc
P_RoomTypes	This entity contains all of the specific attributes which define the physical performance properties of the space	RoomType RoomTypeDescription RoomTypeDoc SecurityClass SoundInsulation NoiseLevel Floor Type Wall Surface CeilingType Ceiling Height FinishesDoc NaturalLight NoWindows Dimmable AmbientLight Darkenable WarningLight LightingDoc MinTemp MaxTemp MinAirchange MaxAirChange MinHumidity MaxHumidity AirRecycle EnvironmentDoc ScreenMag

P_Activities	Activities which may be performed in each space	RoomType RoomId Activity
P_ActivityTypes	A description and lookup of each activity type a space needs to support	Activity ActivityDescription ActivityDoc
Sensor_Data 1	Data captured by each sensor	Space Zone Data_Reading Time Pressure Humidity VOC Light Noise Temp
P_Rooms	Entity describing the room (space) to be provided	RoomName Number of instances Department ConnectionID RoomType RoomTypeDescription RoomTypeDoc SecurityClass SoundInsulation NoiseLevel Floor Type Wall Surface CeilingType Ceiling Height FinishesDoc NaturalLight NoWindows Dimmable AmbientLight Darkenable WarningLight LightingDoc MinTemp MaxTemp MinAirchange MaxAirChange MinHumidity MaxHumidity AirRecycle EnvironmentDoc ScreenMag


P_SoundInsultation
PK SoundInsulation
FK1 SoundDescription
SoundDoc
P_Departments
PK Department
P_Security
PK SecurityClass
SecurityDescription
SecurityDOc
P_RoomTypes
PK RoomType
RoomTypeDescription
RoomTypeDoc
SecurityClass
SoundInsulation
NoiseLevel
FloorType
WallSurface
CeilingType
CeilingHeight
FinishesDoc
NaturalLight
NoWindows
Dimmable
AmbientLight
Darkenable
WarningLight
LightingDoc
MinTemp
MaxTemp
MinAirChange
MaxAirChange
MinHumidity
MaxHumidity
AirRecycle
EnvironmentDoc
ScreenMsg
Coordinate
PK ID
I1 Name
CreatedBy
CreatedOn
Category
SheetName
RowName
CoordinateXAxis
CoordinateYAxis
CoordinateZAxis
ExtSystem
ExtObject
ExtIdentifier
ClockwiseRotation
ElevationalRotation
YawRotation
Facility
PK ID
Facility
CreatedBy
CreatedOn
Category
ProjectName
SiteName
LinearUnits
AreaUnits
VolumeUnits
CurrencyUnits
AreaMeasurement
ExtSystem
ExtObject
ExtIdentifier
ExtSiteObject
ExtSiteIdentifier
ExtFacilityObject
ExtFacilityIdentifier
Description
ProjectDescription
SiteDescription
Phase
P_Rooms
PK,I6 RoomID
RoomName
I1 NumberOfInstances
FK1,I2 Department
U1 ConnectionID
FK2,I7,I4 RoomType
RoomDescription
RoomDoc
RequiredNetArea
MaxOccupants
FK3,I5 SecurityClass
FK4,I3 SoundInsulation
NoiseLevel
FloorType
WallSurface
CeilingType
CeilingHeight
FinishesDoc
NaturalLight
NoWindows
Dimmable
AmbientLight
Darkenable
WarningLight
LightingDoc
MinTemp
MaxTemp
MinAirChange
MaxAirChange
MinHumidity
MaxHumidity
AirRecycle
EnvironmentDoc
ScreenMsg
User
PK ID
Name
Role
Facility
FK1 Int_Ext
Space_Description
Space_Name
Zone
Floor
PK ID
FK1,I1 Name
CreatedBy
CreatedOn
Category
ExtSystem
ExtObject
ExtIdentifier
Description
Elevation
Height
P_Activities
PK,I1 ID
FK2 RoomType
I3 RoomID
FK1,I2 Activity
P_ActivityTypes
PK Activity
ActivityDescription
ActivityDoc
Space
PK,FK2 ID
FK1,I1 Name
CreatedBy
CreatedOn
Category
FloorName
Description
ExtSystem
ExtObject
ExtIdentifier
RoomTag
UsableHeight
GrossArea
NetArea
Sensor_Data1
U1 Space
Zone
Date_Reading
Time
Pressure
Humidity
VOC
Light
Noise
Temp
Component
PK ID
FK2,I3 Name
CreatedBy
CreatedOn
TypeName
FK1 Space
Description
I2 ExtSystem
ExtObject
ExtIdentifier
SerialNumber
InstallationDate
WarrantyStartDate
TagNumber
I1 BarCode
AssetIdentifier
Spare
PK ID
FK1,I1 Name
CreatedBy
CreatedOn
Category
TypeName
Suppliers
ExtSystem
ExtObject
ExtIdentifier
Description
SetNumber
PartNumber
System
PK ID
FK1,FK2,I1 Name
CreatedBy
CreatedOn
Category
ComponentNames
ExtSystem
ExtObject
ExtIdentifier
Description
Zone
PK ID
FK1,I1 Name
CreatedBy
CreatedOn
Category
SpaceNames
ExtSystem
ExtObject
ExtIdentifier
Description
Impact
PK ID
Name
CreatedBy
CreatedOn
ImpactStage
SheetName
RowName
Value
ImpactUnit
LeadInTime
Duration
LeadOutTime
ExtSystem
ExtObject
ExtIdentifier
Description
Type
PK ID
FK1,I3 Name
CreatedBy
CreatedOn
Category
Description
AssetType
Manufacturer
ModelNumber
WarrantyGuarantorParts
WarrantyDurationParts
WarrantyGuarantorLabor
WarrantyDurationLabor
WarrantyDurationUnit
I2 ExtSystem
ExtObject
ExtIdentifier
ReplacementCost
ExpectedLife
DurationUnit
WarrantyDescription
NominalLength
NominalWidth
NominalHeight
ModelReference
Shape
Size
Color
Finish
Grade
Material
Constituents
Features
AccessibilityPerformance
I1 CodePerformance
SustainabilityPerformance
Job
PK ID
FK1,I1 Name
CreatedBy
CreatedOn
Category
Status
TypeName
Description
Duration
DurationUnit
Start
TaskStartUnit
Frequency
FrequencyUnit
ExtSystem
ExtObject
ExtIdentifier
TaskNumber
Priors
ResourceNames
Resource
PK ID
Resource
CreatedBy
CreatedOn
Category
FK1,FK2,I1 ExtSystem
ExtObject
ExtIdentifier
Description
Assembly
PK ID
Name
CreatedBy
CreatedOn
AssemblyType
SheetName
ParentName
ChildNames
ExtSystem
ExtObject
ExtIdentifier
Description
Connection
PK ID
Name
CreatedBy
CreatedOn
ConnectionType
SheetName
RowName1
RowName2
RealizingElement
PortName1
PortName2
ExtSystem
ExtObject
ExtIdentifier
Description
Attribute
PK ID
Name
CreatedBy
CreatedOn
Category
SheetName
RowName
Value
Unit
ExtSystem
ExtObject
ExtIdentifier
Description
AllowedValues