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Modelling 3D Scanned Data to Visualise and Analyse the Built Environment for Regeneration

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ABSTRACT

The renovation and refurbishment market is rapidly expanding in the construction industry. The regeneration and transformation of cities from the industrial age (unsustainable) to the knowledge age (sustainable) is essentially a "whole life cycle" process consisting of: planning, development, operation, reuse, and renewal. Advanced digital mapping technologies are enablers for effective e-planning, consultation, and communication of users' views during the planning, design, construction, and life cycle process of the built environment. Those technologies can be used to enhance productivity gains by promoting a free-flow of information between departments, divisions, offices, and sites, and between themselves, their contractors, and partners. Such is the case with the 3D laser scanner, which enables digital documentation of buildings, sites, and physical objects for reconstruction, and restoration. It also facilitates the creation of educational resources within the built environment, as well as the reconstruction of the built environment. The use of a 3D scanner in combination with a 3D printer provides the transformation of digital data from the captured CAD model back to a physical model in an appropriate scale - reverse prototyping. The use of these technologies act as key enablers of the creation of new approaches to the "Whole Life Cycle" process within the built and human environment for the 21st century. This paper describes the research for building data integration in the INTELCITIES project undertaken by a European consortium of researchers and practitioners under the Framework 6 research programme to develop a prototype system for the e-City Platform in order to pool the advanced knowledge and experiences of electronic government, planning systems, and citizen participation from across Europe (www.intelcitiesproject.com). The scope includes capturing the digital data of existing buildings using 3D laser scanning equipment and illustrating of how digitised building data can be integrated with other types of city data, using nD modelling, to support integrated intelligent city systems for enhancing the refurbishment process in the built environment.

KEYWORDS

3D Laser Scanner
Intelcities
Data Integration
Building Modelling
Prototyping
Object Recognition

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INTRODUCTION

Cities are transforming themselves from industrial to post-industrial. This regeneration is seen as a "Whole life cycle" process of construction consisting of: Planning, Development, Operation, and Reuse. In regards to cultural heritage, intervention within the areas of historical and architectural importance, where one finds groupings of monumental and cultural heritage, is a complex task that implies a great responsibility, since inappropriate restoration can result in irreversible damage (Yamada and Takase, 2004). Therefore, it is fundamental to have both detailed information and the tools and technologies to allow for an effective manipulation and operation of data generated during the complete life cycle of an historical landscape.

Virtual 3D models of monuments and structures that have largely disappeared offer great potential. The use of 3D digitization and modelling in documenting heritage sites has increased significantly over the past few years. This is mainly due to advances in laser scanning techniques, 3D modelling software; image-based modelling techniques, computer power, and virtual reality (Balletti, et al, 2004), (Arayici and Hamilton, 2005). The difficulty in visualising 2D plans of building elements and components brings about errors in interpreting design specifications in terms of accuracy, and completeness. Besides, accessibility is another major problem encountered by surveyors. A number of strategies has been set out to improve efficiency and the quality of design within the built environment. Capturing and modelling the 3D information of the built environment is still a big challenge. A number of techniques and technologies are now in use. These include Electronic Distance Measurement (EDM), Global Positioning System (GPS) and photogrammetric application, and remote sensing applications. However, the 3D laser scanner comes with a stronger advantage compared to the above applications, as it is not limited to the surveying field. A key objective is to develop existing systems, such as Geographical Information Systems (GIS), Virtual Reality (VR) tools, and decision support systems for buildings, and to employ city planning for use in urban regeneration and integrating all with the laser scanner to attain the benefits of working in a holistic environment. The new integrated system will facilitate a holistic approach to problems and thus have a much greater functionality than the individual sub systems.

In the next section, the 3D laser scanning technology, its features, advantages, and disadvantages will be explained.

3D LASER SCANNER TECHNOLOGY

Recently, new instruments were introduced in the field of surveying that are able to acquire portions of land and objects of various shapes and sizes. These instruments, based on laser technology, are commonly known as terrestrial laser scanners. While laser scanner instruments based on the triangulation principle and high degrees of precision have been widely used since the 1980s, TOF (Time of Flight) instruments have been developed for metric survey applications only in the last five years (Bornaz and Rinaudo, 2004, Boehler and Marbs, 2002).

These types of laser scanners can be considered highly automated total stations. They are usually made up of a laser, which has been optimised for high speed surveying, and a set of mechanisms that allows the laser beam to be directed in space at a range that varies according to the instrument that is being used. For each acquired point, a distance is measured on a known direction: X, Y, and Z coordinates of a point can be computed for each recorded distance direction. Laser scanners allow millions of points to be recorded in a few minutes. Because of their practicality and versatility, these kinds of instruments are today widely used in the field of architectural, archaeological, and environmental surveying (Valanis & Tsakiri, 2004).

This innovation is significant because it has the potential to solve problems that have always been associated with the design and construction of existing buildings with reuse goals. For example, it can provide faster, better quality, and more precise analysis and feature detection for building surveys. Besides, in the built environment, the use of the 3D laser scanner enables digital documentation of buildings, sites, and physical objects for reconstruction and restoration. It also enables the creation of educational resources within the built environment, including cultural heritage. Furthermore, it can provide reverse engineering in construction when existing buildings are redeveloped. Producing building design and Computer Aided Design (CAD) models and VR models from an existing building by means of the laser scanner will facilitate the communication between stakeholders through 3D visualization and facilitate an analysis of the latest conditions of the buildings. Besides, it has also the potential to accurately record inaccessible and potentially hazardous areas. Consequently, it facilitates "virtual refurbishment" of buildings and allows the existing structure and proposed new services to be seen in an effective manner (Ahmed, et al, 2004).

In the research undertaken for the INTELCITIES project, laser scanner technology was brainstormed in a SCRI workshop in October 2004, in a Construct IT workshop in November 2004, and in three interviews with two architects from Japan and Spain and one building surveyor from the UK. The following potential beneficiaries is described.

As a result, this study has potential benefits and practical applications to the construction industry. It can provide better support for the evaluation and visualisation of building maintenance works so that informed policies can be effectively targeted. These interviews can be supported by other research activities, such as the use of 3D laser scanners to mark the construction schedule and as-built progress (Shih and Wang, 2004). The advantages and disadvantages of this technology are shown in the table below (Arayici, et al, 2004).

Table 1: Advantages and disadvantages of 3D laser scanning technology

3D Laser Scanning	
Advantages	Disadvantages
Applicable to all 2D and 3D surfaces	Some systems do not work in sun or rain
Rapid 3D data collection	Large 3D data sets require post-processing to produce a useable output
Very effective due to large volumes of data collected at a predictable precision	Difficulty in extracting the edges examples from indistinct data clouds
Ideal for all 3D modelling and visualisation purposes	Output requires manipulation to achieve acceptable recording quality
3D position and surface reflectance generated can be viewed as an image	No common data exchange format currently in use
Rapidly developing survey technology	Difficult to stay up-to-date with developments
Extensive world-wide research and development currently undertaken	Hardware expensive and sophisticated software required to process data

Figure 1: Potential use and benefits of laser scanner in the built environment

	Planning	Design	Construction	Maintenance
Building Services - Electricity - Air Conditioning - Health & Hygiene		• As a communication tool (Professional)	• As a communication tool (Professional) • As a general check tool of finish (Professional)	
Interior & Workplace	• As a presentation or advertisement for real estate • As an easy modeling method to explain the structure • As a tool of explanation for concrete imaging (client/supplier)	• As an easy measurement tool (level of design)	• As a communication tool of the spot (Professional)	• As a presentation tool for the layperson • As a modeling tool of space planning
Building - New Construction - Renewal - Conservation	• As an easy measurement tool (level of first diagnosis) • As an easy modeling method to explain the structure • As a tool to conserve the date of withdrawal	• As a study modeling (Building Design) • As a communication tool to form consensus	• As an alternative of model rooms	• As a deterioration measurement tool (level of first diagnosis)
Site	• As an easy measurement tool (site)			
City - Wide Area - Region - Community	• As a tool to experience landscape • As a tool to examine landscape from various perspectives	• As a study modeling (Urban Planning Design) • As a communication tool to form consensus • As a communication tool (Professional)	• As a communication tool (Professional)	• As a tool to conserve the data of the memories, renewal, and history of city

INTELCITIES PROJECT

The INTELCITIES (Intelligent Cities) Project is a research and development project that aims to help achieve the EU policy goal of a knowledge society. The INTELCITIES project brings together the combined experience and expertise of key players from across Europe, focusing on e-Government, e-Planning and e-Inclusion, e-Land Use Information Management, e-Regeneration, Integration and Interoperability, Virtual Urban Planning, etc. (www.intelcitiesproject.com).

This paper focuses on certain tasks related to the laser scanner research in the e-Regeneration work package of the project. These tasks are:

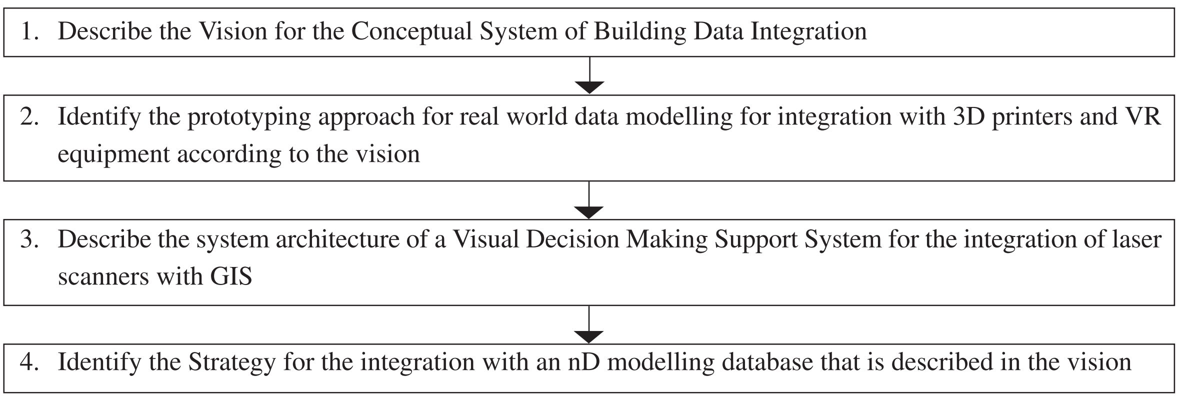
- Building data capture: Captures the digital data of existing buildings using 3D laser scanning equipment. Shows how this data can be used as an information base to enhance the refurbishment process.
- Building data integration: Build the concept nD modelling system and relate to other data structures, including relational databases, to illustrate how data can be integrated to support intelligent city systems.

In the next section, the research methodology for how to achieve the above tasks will be explained. Figure 2 illustrates the research methodology of the rest of the paper, based on which is considered the vision for the use of 3D laser scanners and their integration with various systems to enhance the refurbishment process.

RESEARCH METHODOLOGY

This section describes the various stages adopted for the elaboration and evaluation process of the building data integration system based on the research undertaken in the INTELCITIES project. The research strategy is a case study using a prototyping research approach. The case studies of the project are the Jactin House building under refurbishment in East Manchester and the Peel Building on the campus of the University of Salford. The goal of the research methodology is to describe a systematic mechanism to achieve the tasks as cited in the previous section. The evaluation process was carried out in four stages, as illustrated in Figure 2. According to the figure, at the first stage, the vision for a conceptual system of building data integration is described. The concept covers the integration of laser scanner technology with other technologies and systems, such as virtual reality (VR), GIS, CAD, the nD modelling database, and so on. At the second stage, the integration of the laser scanner technology with CAD systems, VR toolkits, and 3D printers is further elaborated on for modelling real world data, such as buildings, by means of a prototyping technique. At the third stage, the concept of a visual decision making support system through the integration of a laser scanner with GIS is elaborated on. Last, the research findings and progress on integration with nD modelling database are presented, which explains the nD modelling database, pattern matching, and

Figure 2: The research methodology that describes the structure of the paper



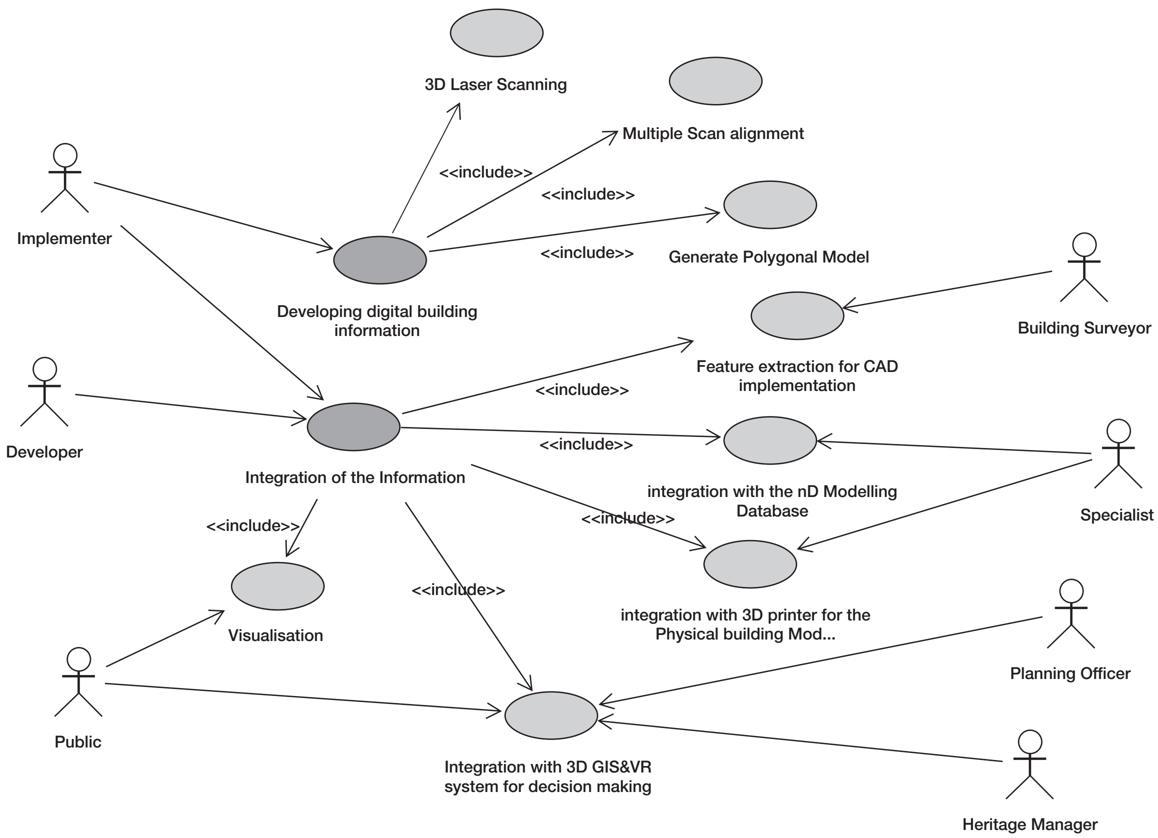
object recognition approaches for data modelling from point cloud data to object-oriented information. This section describes the approaches adopted for this process.

The Vision of Conceptual System of Building Data Integration

The scope for the conceptual system of building data integration in the INTELCITIES project is depicted in Figure 3 below. It includes the integration of laser scanner technology with various systems, such as CAD systems for 2D and 3D CAD plans, and the use of the virtual environment tools, such as workbench, a VR projection system, a video conferencing system for visualisation and communications, along with a 3D printing system for prototyping, a GIS for a visual decision making support system, and the nD modelling repository for storing the Industry Foundation Classes (IFC) building information. These are produced with a laser scanning system in a database that embraces information in various formats for future use during the refurbishment process.

The use case diagram in Figure 3 illustrates the building data integration system. The use cases were used for the conceptual modelling of what the system should do from the user's point of view. It also indicates a number of actors who will be engaged in system. While the implementer captures the building data and develops VR models of the buildings, the developer will integrate the VR models of the laser scanned data with various systems to make it ready for a variety of users for building refurbishment and planning. For example, members of the public can visualise the model, and the building surveyor can put the CAD models of the building up for refurbishment, while the planning officer and heritage manager use 3DGIS (3 Dimensional GIS) for context and environmental analysis and specialist produce physical models from digital models and IFC data for the nD (n Dimensional) modelling database.

Figure 3: Use case diagram for the conceptual modelling



According to the use case model above, when the concept of a building data integration system is implemented, a variety of actors can benefit from the system. For instance, in regards to cultural heritage, many historical sites are slowly deteriorating due to exposure to the elements. Although remedial efforts can reduce the rate of destruction, a digital model of the site will preserve it indefinitely. Models of historical artefacts also allow scientists to study the objects in new ways. For example, archaeologists can measure artefacts in non-contact fashion, which is useful if an object is fragile. Also, digital models allow objects to be studied remotely, saving time and travel expenses and enabling more archaeologists to study them. Besides, the heritage manager and planning officer can utilise the system by using the building information captured by means of a laser scanner in the decision making process and verifying the coherence between cultural heritage and city planning interventions. Often the materials, constructive pathologies, and systems are insufficient or deficient for archiving and the sharing of information in the documentation of historic buildings, sites, and objects for refurbishment.

In regards to deformation and inspection, bridges, for example, need to be surveyed periodically to determine whether significant settling or other movement has occurred. A 3D model of the site allows engineers to make the same measurements with the equivalent accuracy in a fraction of the time.

With regards to reverse and rapid prototyping, modelling from reality can be used to reverse engineer real objects, for which a CAD model may not be available or has never existed. The process of modelling from reality imports the real world objects into the computer environment, creating a digital model that can be edited with a CAD program and then creating a physical model of the same object. This will be useful for the communication between the stakeholders in the refurbishment process, in particular the client and architect, and for the publicity of the real object or building under refurbishment.

Regarding architecture and construction, architects frequently need to determine the "as built" plans of building or other structures, such as industrial plants, bridges, and tunnels. A 3D model of a site can be used to verify that it was constructed according to specifications. When preparing for a renovation or a plant upgrade, the original architectural plans might be inaccurate, if they exist at all. A 3D model allows an architect to plan a renovation and test out various construction options.

In regards to engineering, the process of modelling from reality offers an efficient alternative for engineers and surveyors. For example, engineers can use the information that is converted into IFC in the building life cycle for regeneration.

The following section describes the integration of laser scanner technology into 3D printer and Virtual Environment tools.

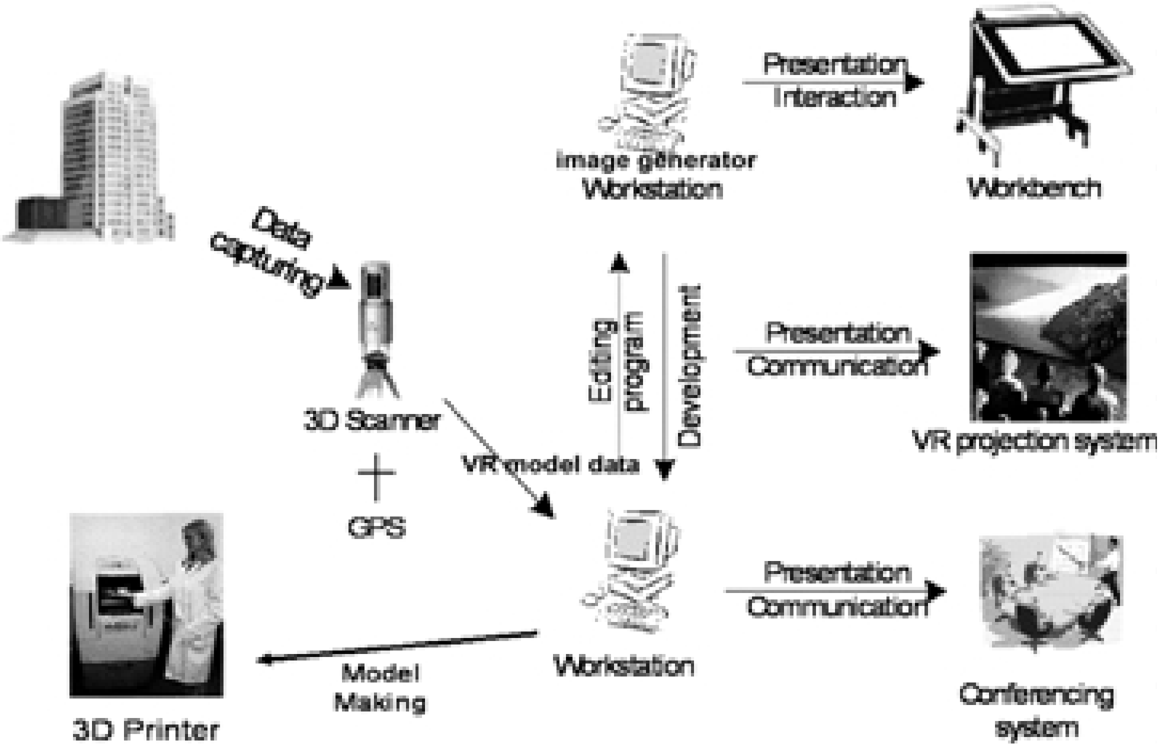
Real world data modelling

The main purpose of the conceptual model described above is to help one think about real world problems. The same dimensions of integration in the conceptual model can be implemented by using the BUHU (Research Institute of Built and Human Environment) equipment.

The spatial data can be obtained by using a 3D scanner. By post-processing the captured spatial data, outputs for different purposes can be obtained, such as CAD modeling, physical modeling by prototyping, and visualization on different platforms. It is depicted in Figure 4. The use of these technologies is a key enabler in the creation of an integrated system to capture, process, and display 3D information.

For example, these technologies can be used for civil engineering and environmental analysis. It permits the user to acquire irregular point clouds of land areas, rivers, and infrastructure in a fast

Figure 4: Integration of spatial data with 3D printer and the virtual environments



and cheap way. The use of raw laser scanner data requires orientation and filtering procedures to generate a 3D model of the surveyed object. It is possible to automatically derive a set of geometric information from this 3D model that is useful for a variety of particular engineering and environmental applications, such as dense Digital Terrain Model (DTM) generation, sections and profiles, contour maps, volumes, and so on (Bornaz, et al, 2002).

Integration of spatial data can also provide faster, better quality, and more precise analysis and feature detection for building surveys (Arayici, et al, 2004). One of the major problems that building surveyors have encountered is inaccessibility. That is to say, on some occasions, they have to measure the details of building and relevant architectural details on the walls for example, particularly when developing elevation plans. In these circumstances, building surveyors are required to estimate the measurements of these details, which is very much likely to involve a variety of errors regarding the accuracy and the actual design of a building due to a wrong assumption or judgement.

The use of a 3D laser scanner has the potential to benefit building surveyors and their clients in terms of accuracy, speed, and productivity in plan preparation, and then to extend the range of services offered through modelling applications. The output of feasibility studies would improve immeasurably through modelling in areas, such as those concerning disabled access and fire safety. With current demand for whole life costing, asset management planning, and database application, building surveyors are called upon to link information in CAD files to database files. The possibility of linking this information to 3D models would suggest all sorts of additional benefits. For example, producing a computer model of historical building with 3D laser scanner technology can only take a week, and this includes scanning the interior and exterior of a building in two days and post-processing the point cloud data in three days. For this work, only two people would be required to both complete the initial scans and post-process the raw data. Consequently, this technology is significantly faster and more effective than any other surveying application in use. However, the post-processing part may continue depending on the end product sought. For example, if it is aimed at rapid prototyping, another two weeks of work will be necessary to complete it.

Rapid Prototyping

The term rapid prototyping refers to a class of technologies that automatically construct physical models from Computer Aided Design (CAD) data. These "three dimensional printers" allow designers to quickly create tangible prototypes of their designs, rather than just two dimensional pictures. Such models have numerous uses. They make excellent visual aids for communicating ideas with co-workers or clients. In addition, prototypes can be used for design testing. There are research activities in rapid prototyping for the reverse engineering and design of buildings in particular historic buildings. For example, Alves and Bartolo (2006) proposed integrated computational tools for virtual and physical automatic construction using the human vision approach and 2D photos for 3D computer modelling. However, in this paper rapid prototyping is conducted in accordance with the ground-based 3D laser scanner data.

Although several rapid prototyping techniques exist, all employ the same basic five-step process. These steps are as follows:

1) *Create a CAD model of the design:* First, the object to be built is modelled using a Computer Aided Design (CAD) software package, such as Microstation, which is used together with Polywork point cloud modeller in order to create a CAD model from the laser scanned data of real objects, such as buildings.

   First, a model is lined up against the reference for the coordinate system of Polywork software and co-planar surfaces with different distances and depths are defined according to the model's facade. Some planes are parallels to the model and others perpendicular. Next, vertices on the corresponding surfaces are selected and projected to the co-planar surfaces previously defined. With this process of projection of points onto the co-planar surfaces, the edges are also defined. Then, the mesh model is optimised to rectify the imperfection in the triangulation that existed in the initial model. Cross-sections are inserted into the co-planar surfaces to obtain the feature lines of the model. Last, the cross-sections are exported in dxf and then imported into Microstation. The result in Microstation is a regular 3D CAD model of the building.

2) *Convert the CAD model to STL format:* To establish consistency, the STL (Stereolithography) format has been adopted as the standard of the rapid prototyping industry. This format represents a three-dimensional surface as an assembly of planar triangles. The STL file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Because STL files use planar elements, they cannot represent curved surfaces precisely. Increasing the number of triangles improves the approximation, but at the cost of bigger file size. Large, complicated files require more time to pre-process and build, so a designer must balance accuracy with manageability to produce a useful STL file. Since the .stl format is universal, this process is identical to all of the rapid prototyping techniques.

3) *Slice the STL file into thin cross-sectional layers:* In the third step, a pre-processing program prepares the STL file to be built. Several programs are available, and most allow the user to adjust the size, location, and orientation of the model. The pre-processing software slices the STL model into a number of layers from 0.001 mm to 0.07 mm thick, depending on the build technique. The

program may also generate an auxiliary structure to support the model during the construction. Supports are useful for delicate features, such as overhangs, internal cavities, and thin-walled sections.

4) *Construct the model one layer on top another:* The fourth step is the actual construction of the part. Using one of several techniques, rapid prototyping machines build one layer at a time from polymers or powdered metal.

5) *Clean and finish the model:* The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment.

Figures 5 to 10 show the Jactin House example, which is the case study building in East Manchester, for VR models produced from the building data captured by the 3D Laser scanner and CAD models extracted from the VR models.

Figure 5: 12 scans were conducted around Jactin house; the picture below is one of the scans

Figure 6: The individual scans are processed to create the VR model below

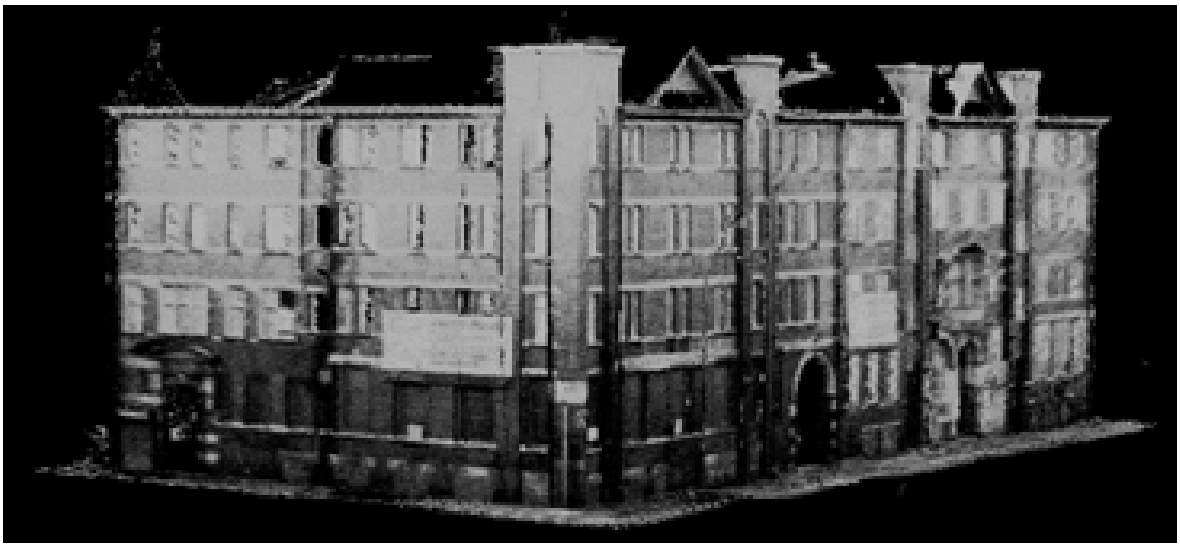


Figure 7:** **Using co-planar surfaces and creating sharp edges from curves in the model in Figure 6, the CAD model below is developed using Polyworks modeller and Microstation software

Figure 8: Polygonal models for printing can be generated from the CAD model above

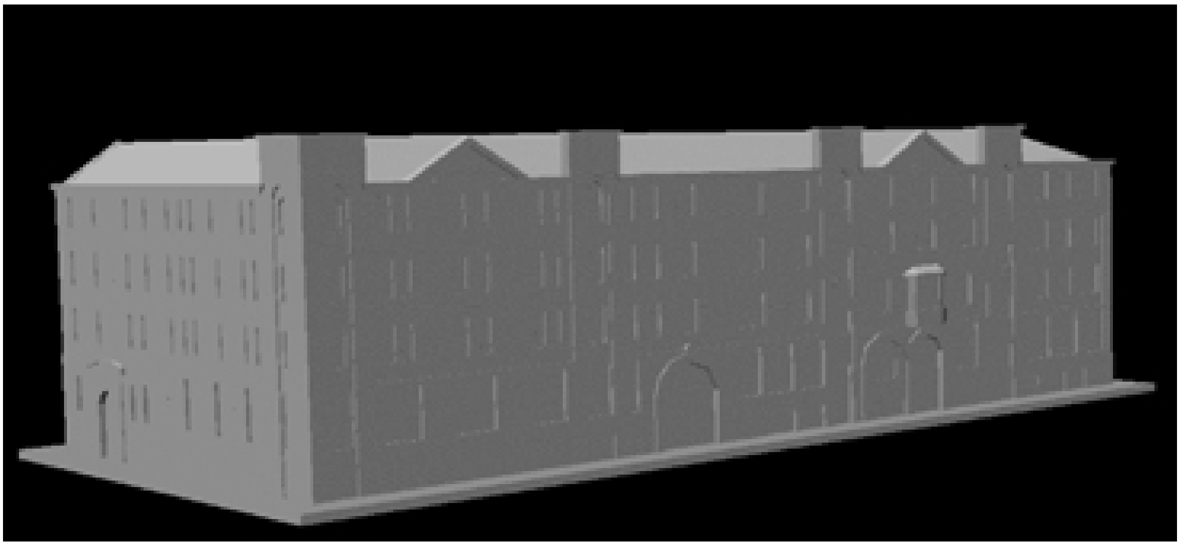


Figure 9: The images below are samples of the Jactin House model

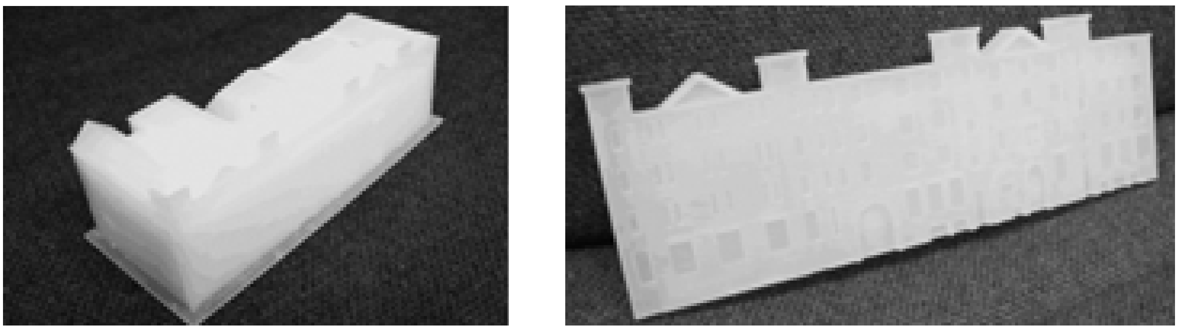


Figure 10: Peel building data captured by the laser scanner is textured and presented

The sequence of figures from Figure 5 to Figure 10 also illustrates the process of data from real world to digital modelling and to physical modelling, which is one of the dimensions of integration between the laser scanner and the 3D printer depicted in the conceptual model of building data integration system in Figure 3.

As illustrated in Figure 4, the system can collect data from the real world and manipulate it for integration. For example; the geometric information can be obtained using a 3D scanner. By editing and integrating the data, a model of the object (building/urban area) could be created to be used in the decision-making process. The model can be presented in different ways, for example, as a physical model or VR projection system for reverse and forward prototyping, which is shown in Figures 5, 6, 7, 8, and 9. An example of visualization in the VR projection system is illustrated in Figure 10.

This implementation depicted in Figure 10 is the dimension of integration of the laser scanner with the VR environment tools shown in the concept model of building data integration system in Figures 3 and 4.

In the next section, another dimension of the integration of a laser scanner with GIS will be discussed for a Visual Decision Making Support System in regeneration.

An Approach for a Visual Decision Making Support System

The aim of this section is to describe a framework that includes a geospatial database, such as the nD modelling database, the 3D laser scanner, and a series of analytical tools that will enable various stakeholders in the regeneration process to make decisions relating to building maintenance works (Ahmed, et al, 2004). This framework is depicted in Figure 12, and includes:

1) The development and population of a geo-spatial project database with the digital data of existing buildings captured with laser scanning equipment.

2) The analysis of complex building information maintenance options within a knowledge repository environment, in which digital building data that was captured by the laser

scanner is retrieved with a 3D GIS system for the analysis.

3) The visualisation of project information through a range of different interconnected graphic windows. The laser scanner VR model can be visualised on different platforms.

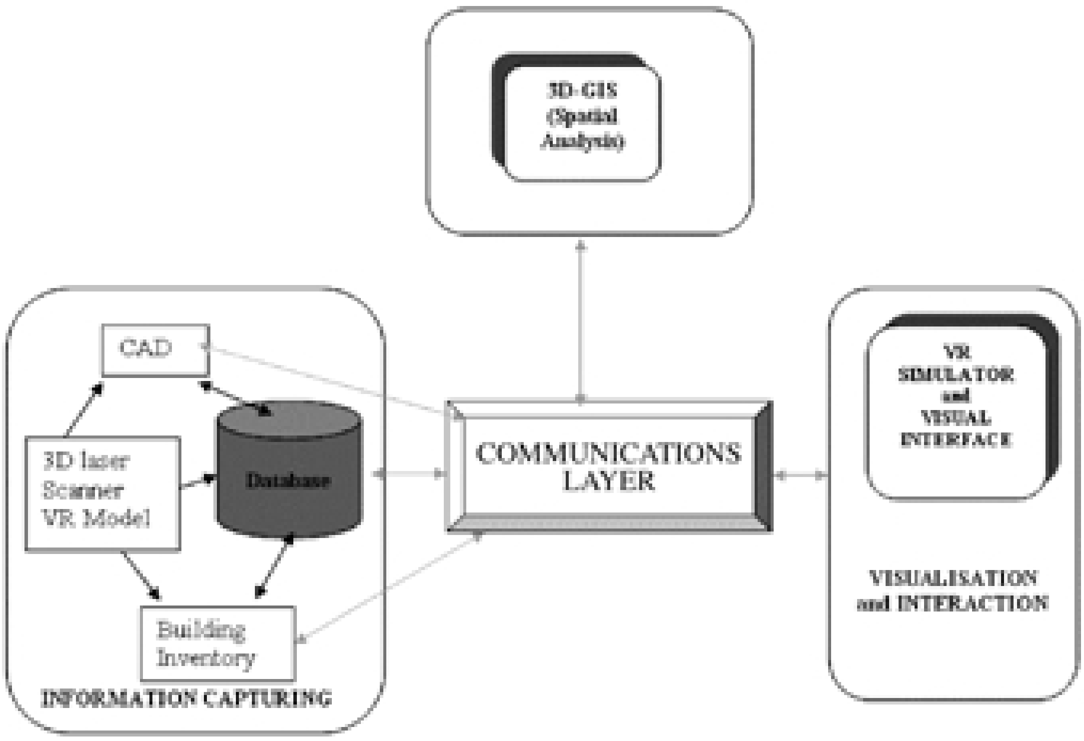
The geospatial database describes the geometries of both the building frame and its components. Simple open geometric descriptions are used, but each entry will also be associated with the data on inventory information, such as name, supplier, date installed, replaced, number of replacements, etc (Ahmed, et al, 2004).

The system will enable the capture of geo-spatial data using a laser scanner. This data will be processed and building frame and components will be determined in a CAD environment. Inventory information relating to each frame and component will also be captured within the relational structure of the database. Such information will be accessible in real-time with some of the attributes (e.g. component supplier information) made available through the communication layer.

GIS software will be used to generate and analyse thematic developments relating to the building properties and associated refurbishment management strategies. Such software will retrieve the building information from the database through the communications layer, which provides users situated in various locations with access to the database.

The VR environment will be created in a Virtual Reality Modelling Language (VRML) interface. The systems are developed based on the sharing of construction information via a central object orientated project database. Typically, the CAD application allows a user to create and manipulate the components of a facility. The components are stored as instances of classes in an object-oriented database. These instances are read by the VRML interface in order to create a 3D view of the facility, which gives the user a

Figure 11: Structure of a visual decision making support system



better environment for navigation and walkthrough. Therefore, the results of the spatial analysis obtained within the 3-D GIS environment can be evaluated in real-time with the options of viewing building refurbishment alternatives (Mahdjoubi and Ahmed, 2004).

In the next section, the research methodology for the actual development and implementation of the conceptual system of building data integration will be described.

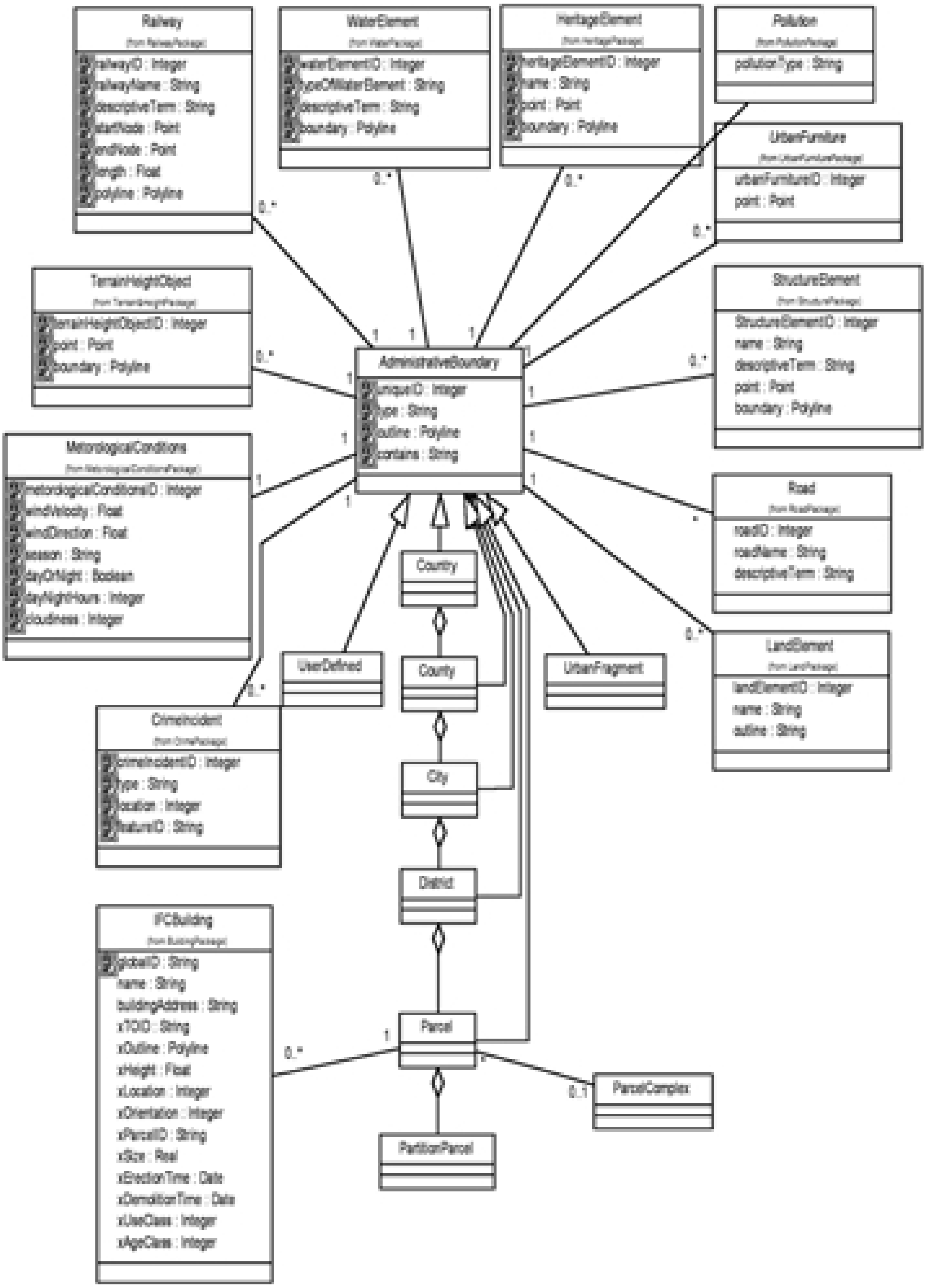
Integration with the nD modelling Repository

The building data captured by the laser scanner is processed to generate information that will be stored in the nD modelling database in IFCs (Industry Foundation Classes). The information stored in the database will be available for the decision making process and be reused in the refurbishment process in the future. To make progress in modelling, conversion issues of 3D scanned data need to be solved. There are certain barriers related to laser scanner data. For example, there are no standard formats for the distribution of scanned data. This leads to issues relating to compatibility, the exchange of information, and data archiving. These barriers can be overcome through data conversion from scanned data to standard data formats such as IFC (IFC2x2, 2005). Once this conversion is achieved, it is time to store this information characterised by IFC schema in the nD modelling database.

In this section, the integration concept with the nD modelling database will be elaborated on. The nD modelling database is a multi-dimensional data storey to keep information for various systems in the building life cycle. The aim of the database development is to design, build, and evaluate the components of an interactive virtual urban planning environment as part of the e-City platform. The nD modelling database is the base of this interactive virtual urban planning environment (Hamilton, et al, 2005).

Figure 12 shows the n-dimensional conceptual urban data model. Entities such as 'road, railway, pollution, and IFC Building' have been described. The core of the conceptual data model is the abstract entity of 'administrative boundary'. An administrative boundary is defined as the limit of responsibility area. A 'country' could be the largest administrative area. Countries are composed of counties, cities, districts, and parcels. A parcel can also be divided into smaller units called 'partition parcels'. The attributes of the administrative boundary are all inherited by these sub classes. The 'administrative boundary' classes, such as countries, counties, cities, districts, and parcels, have relations with geographical entities, such as roads, railways, water elements, heritage elements, etc. A parcel may have a building on it. IFCs were used to model the building related data. An administrative boundary may also attract crime and pollution. A city, a parcel, or a user-defined boundary unit may be selected for the air, noise pollution simulations (Tanyer, et al, 2005a, 2005b).

Figure 12: Conceptual urban data model (Source: Tanyer, et al, 2005)

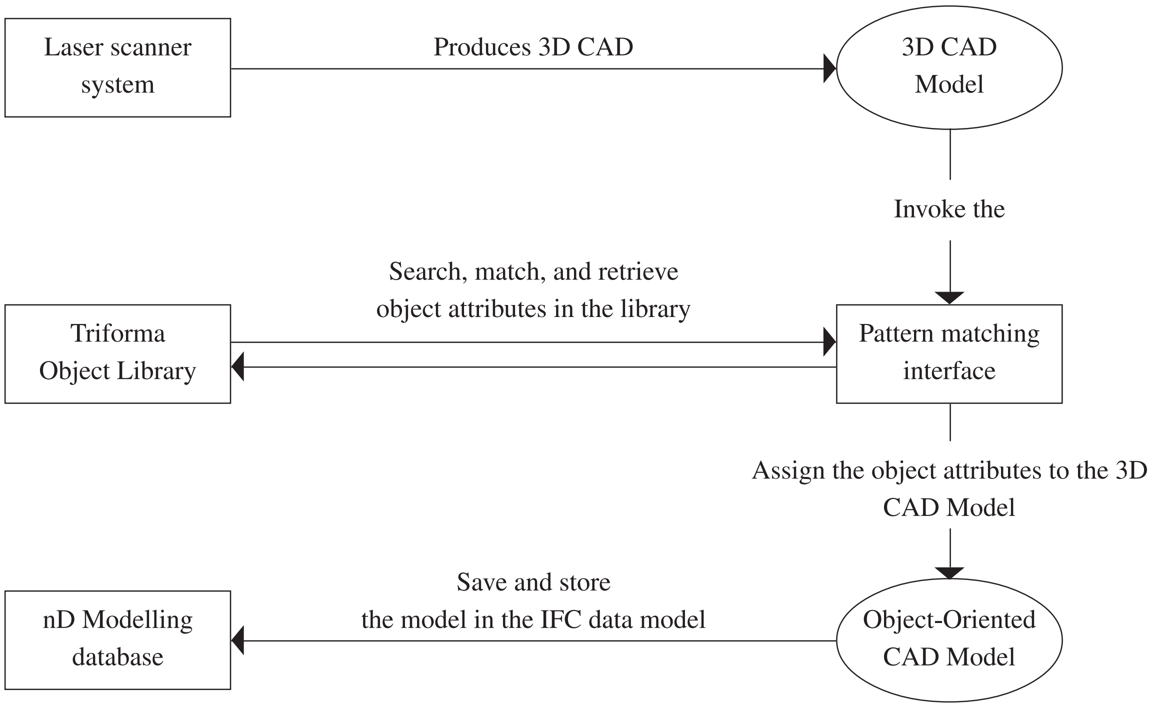


From 3D Scanned Data to nD Modelled Data
The research to date about object recognition from the laser scanned data has focused on a pattern matching approach. Pattern Matching addresses issues of searching and matching strings and more complicated patterns, such as trees, regular expressions, graphs, point sets, and arrays (Johnson, 2002). The diagram below shows the pattern matching approach in the INTELCITIES project for object recognition from the laser scanned data.

3D CAD models using semi-automated techniques were extracted from the polygonal mesh model developed in the laser scanner system. The extracted CAD model is presentable in any commercial CAD software. According to Figure 13, the pattern matching interface being designed will invoke the 3D CAD model to its display screen. Highlighting any building frame in the model will enable the pattern matcher to define geometric features as criteria for matching processes such as shape, sides, width, height, thickness, line type, line thickness, line colour, and so on. Besides the automatic feature recognition, users can also input further criteria into the matching process. However, this process is being completed manually in Microstation Triforma for now because the pattern matching algorithm definition is still under investigation. The IFC building model of Jactin House is presented in Figure 14.

Microstation triforma employs a single building model concept. All information about a building is recorded in a 3D model. Traditionally, a given door in a building would be drawn in at least three or four places (plan, building elevation, building section, interior elevation, etc). In the single building model, it is constructed once and these various drawings are later extracted automatically. The single building model requires building objects, which are defined, edited, and stored in the triforma library.

Figure 13: Data Conversion approach for laser scanned building data



The pattern matcher will access the triforma library with the criteria to do "search and match". Two different types of matching can be done: 1) the exact pattern matching, and 2) the approximate pattern matching. Exact pattern matching consists of finding the exact pattern. In the case of approximate pattern matching, it is a generalisation of the pattern sought and a determined number of differences between the pattern sought and the objects found in the library is allowed.

There will be three types of pattern form: simple, constrained, and variable. All three forms can be accommodated by the pattern matcher interface. However, the pattern matcher will handle them differently to improve efficiency. Simple patterns are simple matches on values. The pattern describes which values must be included in the search. For example, the pattern matcher tries to match an instance of a square (a frame) and it finds square-1, square-2, square-3, and square-4, which are all the squares in the example database.

In case of a constrained pattern form, it is possible to specify a constraint on a value instead of a specific value. To do so, a function to be provided will test the constraint. For example, the pattern matcher matches the frame to triangle-1, triangle-2, triangle-3, and triangle-4. The constraint (value <4) limits the value of sides to less than 4.

In respect to variable types of pattern form, patterns may also include variable references. Variables in patterns can be used to relate values. The first occurrence of a variable in a pattern causes the value in a frame to be bound to that variable. The second occurrence forces a constraint that the value will be equal to the value bound to the variable. For example, pattern (width a, height a) describes objects with widths equal to their heights.

Variables may also be used in constraints to relate values through more complex relations than simple equality. For example, pattern (width a, height {value >a}) describes objects with heights greater than width. Variables may also be used to relate values across patterns. Since each pattern refers to values in a single frame, relating values across frames requires multiple patterns (Yates, 2004). The function, multiple-pattern match, searches for frames that match a set of related patterns. The multiple-pattern match returns a list of sub-lists in which the sub-lists contain the value of the variables followed by the frames

Figure 14: The building details are defined as triforma objects

that match each pattern within the set. The variables can also be related across frames with constraints. For example, pattern (width a, height {value >a}, sides 4) describes all objects with heights greater than the width and with 4 sides.

As a result of various matching processes, object recognition can be worked out for the interested building frames in the 3D CAD model. Attributes of the objects matched in the library will be assigned to the building frame in the CAD model, which result in the building frames to be defined as building objects. Subsequently, an object-oriented (OO) CAD model will be obtained. This OO CAD model will be mapped into IFC schema to be saved and stored in the nD modelling database.

The Object Recognition Approach

To progress in the area of modelling, conversion issues of 3D scanned data need to be solved. The general problems of 3D data integration in the built environment were considered by Wang and Hamilton (2005). This section specifically addresses the problem of object recognition. This is important in realizing the visualization of 3D models of the built environment because visualization will be undertaken with the real characteristics and features of real world objects, as opposed to raw 3D models of laser scanned data, which is difficult to handle for many visualization software applications due to large file sizes. As a result, data modelling and analysis of laser scanned data can also be done more effectively and precisely. This also facilitates the use of CAD and GIS software, which will not normally support raw scanned 3D models.

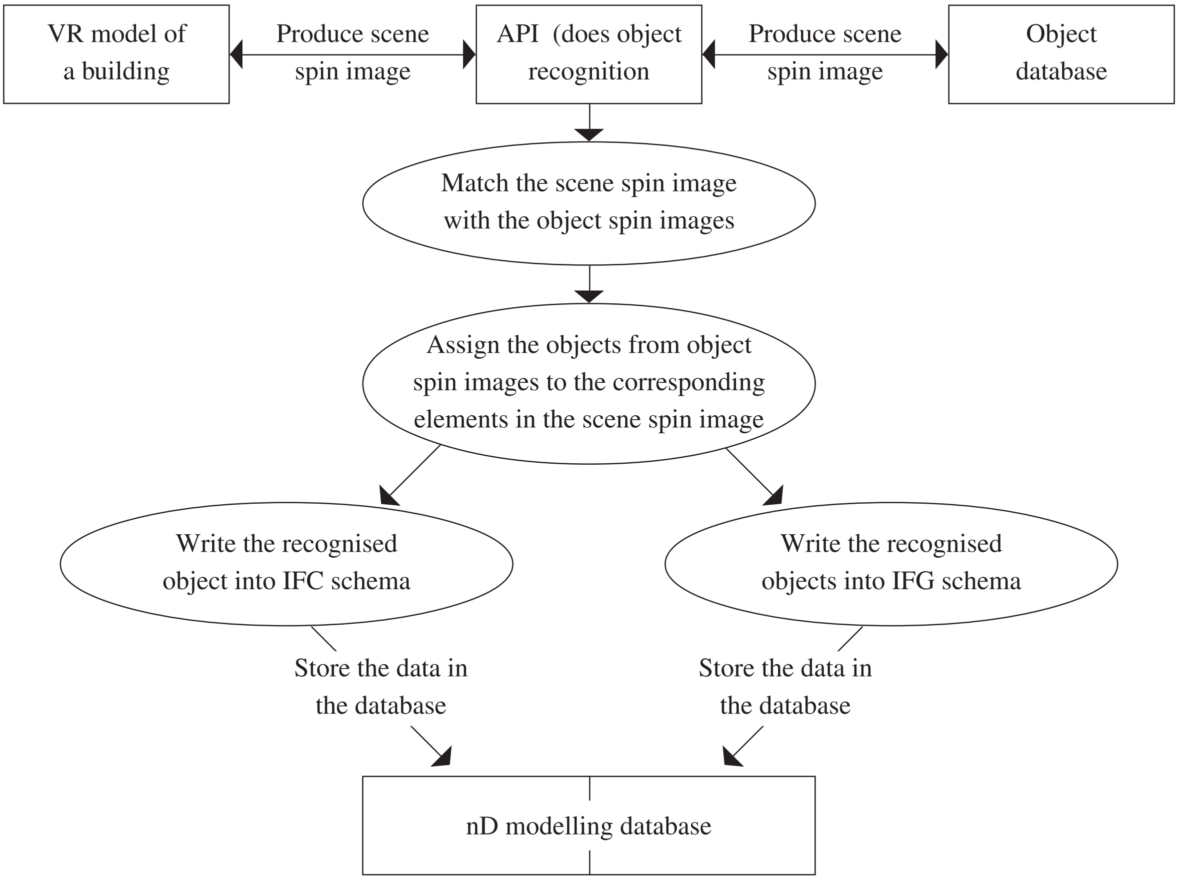
There are certain barriers. For example, there are no standard formats for the distribution of scanned data. This leads to issues relating to compatibility, the exchange of information, and data archiving. These barriers can be overcome through data conversion from scanned data to a standard data format, such as IFC (IAI, 2004) or IFG (Industry Foundation Classes for GIS). IFC is an international data standard model for information sharing and interoperability in the construction industry. On the other hand, IFG also makes it possible to communicate relevant intelligent information from various GIS standards to CAD systems using IFC (Wang and Hamilton, 2005).

In the INTELCITIES research programme, we have an approach for object recognition through the simultaneous recognition of multiple objects in the scenes of polygonal mesh models produced from the laser scanner point cloud data, which contains clutter and occlusion. Recognition is based on matching surfaces by matching points using spin image representation. Spin imaging is a data level descriptor that is used to match surfaces represented as a surface mesh (Johnson and Hebert, 1999). Figure 15 below describing the process of object recognition from the laser scan data was developed based on a spin image definition from Johnson and Hebert (1998, 1999).

Through surface matching, an object can be identified in a scene of laser scanned data by comparing a targeted surface to an object surface stored in a database. When the object surface is matched, an interrelation can be established between something known (the object) and something unknown (the scene of laser scanned data). As a result, information about the world is acquired.

Surface matching is based on matching individual surface points in order to match complete surfaces (Johnson and Hebert, 1999). By matching points, the problem of surface matching is broken down into many smaller localized problems of point matching. As a result, matching points provides a method for handling clutter and occlusion in surface matching without first segmenting the scene. Clutter points on one surface will not have matching points on the other, and occluded points on one surface will not be sought on the other (Ullman, et al, 2002).

Figure 15: Object recognition from the laser scanner system



To differentiate among points, 2D images associated with each point were constructed. Oriented points, which are 3D points with associated directions, were used to create spin images. An oriented point was defined at a surface mesh vertex using the 3D position of the vertex and surface normal at the vertex. The surface normal at a vertex was computed by fitting a plane to the points connected to the vertex by the edges at the surface mesh (Johnson and Hebert, 1998, 1999).

According to Figure 15, the polygonal model mesh was invoked by the API (Application Programming Interface) to be developed in order to create a scene spin image based on a selected scene oriented point. At the same time, the system will access the object database to create spin images for each object model in the database, and these spin images are stored in a spin image stack. Point correspondences were then established between the selected point and the points with the best matching spin images on the other surface. This procedure was repeated for many points until there were a sizeable number of set point correspondences. The point correspondences were then grouped and the outliers eliminated using geometric consistency.

This surface matching can be extended to object recognition as follows. Each object in the object database is represented by a polygonal mesh. Before recognition, the spin images for all vertices on all models were created and stored. At recognition time, a scene point was selected and its spin image was generated. Next, its spin image was correlated with all the spin images from all the objects. The best matching model spin image will indicate both the best matching model and model vertex after matching many scene spin images to model spin images. The result was a simultaneous recognition and localization of the objects that existed in the scene (Stein and Hebert, 2005).

The following step is to assign and populate objects to the corresponding elements in the scene of the laser scanner VR mesh model. In the end, a new VR model is an object-populated mesh model. The following step is to write these objects at the scene into the IFC schema at building scale or IFG schema at city scale (Wang and Hamilton, 2005). IFC-enabled CAD software assists professionals when they plan a building or an area with buildings by supplying an attribute information type of window, cost and performance, directly connected to the 3D model. For larger scale integrated data, it is also necessary to extract parts of the site and building information (in IFC form) and make it available in GIS standards.

The information characterised by either the IFC schema or IFG schema will be stored in the nD modelling (Lee at al, 2003) database. The nD modelling database is a multi-dimensional data storey for keeping information for various systems at the building scale and urban scale. This is an ongoing progress, and the focus of future work will be on the algorithm definition of object recognition for data conversion from scanned data to nD modelled data.

CONCLUSION

This paper explained the research on the use of laser scanner technology for the built environment. The focus was on e-regeneration to facilitate the building refurbishment process. Therefore, building data captured by laser scanners and building data integration with various systems were addressed.

In the paper, the INTELCITIES research project was introduced. Their scope for the use of the laser scanner technology for the built environment at the building scale and urban scale was described. The research undertaken in the project for 3D laser scanner technology mainly focused on data capture, modelling, and integration. Case studies of Jactin House and the Peel Building were given as examples for CAD and VR modelling and integration with other technologies, such as the 3D printer and VR projection system. Furthermore, the potential benefits of using a 3D laser scanner were addressed. Last, an approach to object recognition for object-oriented data modelling from the 3D scanned data was discussed. The benefits of this approach were noted. For example, providing information in standard formats, such as IFC and IFG on the built environment using the laser scanner through object recognition approach, will enable one to communicate with other city and building systems, including CAD and GIS systems.

Generally speaking, the present use of laser scanners in the built environment was criticised as being too laborious and time consuming. However, the approaches explained in this paper can lead to answers for overcoming these issues, and it is envisaged that when the data conversion problems are solved according to the methods explained in this paper, the use of laser scanner VR models can be developed quickly, which will make it feasible for intelligent visualizations to be produced for a wide range of applications.

REFERENCES

Ahmed V, Arayici Y, Hamilton A and Aouad G (2004), Virtual Building Maintenance: Enhancing Building Maintenance Using 3D-GIS and 3D Laser Scanner (VR) Technology, *Proceeding of European Conference on Product and Process Modelling in the Building and Construction Industry (ECPPM)*, 8-10 September 2004, Istanbul, Turkey, 29-34.

Alves NM and Bartolo PJ (2006), Integrated computational tools for virtual and physical automatic construction, *Journal of Automation in Construction*, 15:3, 257-271.

Arayici Y and Hamilton A (2005), Modelling 3D Scanned Data to Visualise the Built Environment, *Proceedings of 9th International Conference on Information Visualisation, IEEE Computer Society*, 6-8 July 2005, London, 509-514.

Arayici Y, Hamilton A, Gamito P and Albergaria G (2004), The Scope in the INTELCITIES Project for the Use of the 3D Laser Scanner, *Proceeding of ECT2004: The Fourth International Conference on Engineering Computational Technology*, 7-9 September 2004, Lisbon, Portugal.

Balletti C, Guerra F, Vernier P, Studnicka N, Riegl J and Orlandini S (2004), Practical Comparative Evaluation of An Integrated Hybrid Sensor Based On Photogrammetry and Laser Scanning for Architectural Representation, *XXth ISPRS Congress*, 12-23 July 2004 Istanbul, Turkey, 536-541.

Boehler W and Marbs A (2002), 3D Scanning Instruments, *Proceeding of the CIPA WG 6 International Workshop on Scanning For Cultural Heritage Recording*, 1-2 September 2002, Corfu, Greece.

Bornaz L, Lingua A and Rinaudo F (2002), Engineering and environmental applications of laser scanner techniques, *International Archives of Photogrammetry and Remote Sensing*. ISSN: 1682-1777. Volume XXXIV part 3A+BCD-ROM.

Bornaz L and Rinaudo F (2004), Terrestrial Laser Scanning Data Processing, *XXth ISPRS Congress,* 12-23 July 2004, Istanbul, Turkey, 514-520.

Hamilton A, Wang H, Tanyer AM, Arayici Y, Zhang X and Song Y (2005), Urban information model for city planning, *ITcon,* 10:6, 55-67.

IAI (2002), *International Alliance for Interoperability,* Available online at: http://www.iaiinternational.org, (accessed 20 June 2005).

IFC2X2 (2005), IFC2x Edition 2 Addendum 1, Available online at: http://www.iaiinternational.org/iai_international/Technical_Documents/R2x2_add1/index.html, (accessed 20 June 2005).

Johnson AE, and Hebert M (1998), Surface Matching for Object Recognition in Complex Three-Dimensional Scenes, *Image and Vision Computing*, 16, 635-651.

Johnson AE and Hebert M (1999), Using Spin Images for Efficient Object Recognition in Cluttered 3D Scenes, *IEEE Transaction on Pattern Analysis and Machine Intelligence,* 21:5, 433-449.

Johnson M (2002), A simple pattern matching algorithm for recovering empty notes and their antecedents, *Proceeding of 40th Annual Meeting of the Association for Computational Linguistics (ACL)*, July 2002, Philadelphia, 136-143.

Lee A, Marshall-Ponting AJ, Aouad G, Wu S, Koh WWI, Fu C, Cooper R, Betts M, Kagioglou M and Fisher M (2003), Developing a vision of nD-enabled construction, *Construct IT*, University of Salford, UK.

Lichti D (2004), A Resolution Measure For Terrestrial Laser Scanners, *XXth ISPRS Congress*, 12-23 July 2004 Istanbul, Turkey.

Mahdjoubi L, and Ahmed V (2004), Virtual Building Maintenance: Enhancing Building Maintenance using 3D GIS and Virtual Reality (VR) Technology' , *Conference of Designing, Managing, and Supporting Construction Projects through Innovation and IT solutions* (INCITE2004), February 2004, Langkawi, Malaysia.

Stein A and Hebert M (2005), Incorporating Background invariance into Feature-Based Object Recognition, *7th IEEE Workshop on Application of Computer Vision*, January 2005.

Shih NJ and Wang PH (2004), Point-Cloud-Based Comparison between Construction Schedule and As-Built Progress: Long-Range Three-Dimensional Laser Scanner's Approach, *Journal of Architectural Engineering,* 10:3, 98-102.

Tanyer AM, Tah JHM and Aouad G (2005a), An Integrated Database to Support Collaborative Urban Planning: The N-Dimensional Modelling Approach, *ASCE Conference on Computing in Civil Engineering*, 12-15 July 2005, Cancun, Mexico.

Tanyer AM, Tah JHM and Aouad G (2005b), Towards n-Dimensional Modelling in Urban Planning, Innovation in Architecture, *Engineering & Construction (AEC)*, 15-17 June 2005, Rotterdam, 503-512.

Ullman S, Vidal-Naguet M and Sali E (2002), Visual features of intermediate complexity and their use in classification, *Nature Neuroscience*, 5:7, 682-687.

Wang H and Hamilton A (2005), Data integration issues within nD Information Modelling for Urban Planning, *5th International Postgraduate Research Conference*, Salford, UK, 194-203.

Yamada O and Takase Y (2004), A Case Study For the Practical Use of 3D Digital Archive of Cultural Properties, *XXth ISPRS Congress*, July 2004, Istanbul, Turkey, 12-23.

Yates BR (2004), A Fast Set Intersection Algorithm For Sorted Sequences, *Proceeding of Combinatorial Pattern Matching* conference (CPM), July 2004, Istanbul.