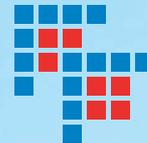


nD Modelling Roadmap A Vision for nD-Enabled Construction



salford centre for research & innovation
in the built & human environment



Centre for
Construction Innovation
North West



CCi//3d VISUALISATION



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Foreword

nD modelling is a research topic that has started to gain momentum and interest worldwide. The goal of this report has been to produce a strategic plan, or 'road map', of how nD modelling can help the design and construction industries to improve their performance. The issues surrounding nD are not just technological, but are also cultural, educational and process related. This road map is the result of an international effort to create a blueprint of the research and technology milestones that are necessary to achieve improved construction practice. This report initially summarises the findings of the 2nd international nD modelling workshop before bringing together the findings of five workshops – attended by over 150 experts from industry, universities and government research laboratories – to address the technology barriers, research needs and priorities of the ARC industry. We wish to thank all those that have contributed to the workshops for their valuable support and input, without which this report could not have been written.

This document must be viewed as evolutionary in nature. The nD modelling road map is an update of the 2003 'Developing a Vision of nD-Enabled Construction' report that summarised the results of the first four workshops. The findings of all the workshops were clustered into themes and are presented as repertory grids in the final road map. Whilst this report highlights both the barriers and opportunities of implementing nD modelling in the construction industry, the road map presents a research agenda for the global uptake of nD modelling. It shows that the concentration of effort should be placed on the education and training activities to heighten the level of industry's awareness of nD modelling, with the technology itself being of a lower importance. Although the use of building electronic product models is not widespread in the industry at the present time, its need is seen to be self evident.

While this document represents an impressive compilation of critical research needs, the workshops were necessarily limited in the time and breadth of participation by both industry and academe. It is inevitable that it will not incorporate all viewpoints and all the valuable ideas may not be included. However, this document does provide an important snapshot in time of the industrial and research community needs. It will evolve as additional information becomes available and we are keen to receive your contributions towards the development of our future programmes. Please join us in working forward to making nD modelling the future of construction.

Finally, we would like to acknowledge the support of the sponsors of the 2nd international workshop: the Engineering and Physical Sciences Research Council (EPSRC), the Centre for Construction Innovation (CCI) and the Salford Centre for Research and Innovation (SCRI).



Professor Richard Baldwin
*Formerly Managing Director, Alfred McAlpine Special Projects, UK
Visiting Professor, University of Salford*



Professor Ghassan Aouad
*Head of School of Construction & Project Management
Project Investigator: 3D to nD modelling research project*

Acknowledgements and contributions

This report would not have been able to be produced without the invaluable contribution from the attendees of the 2 academic, 1 national, and 2 international workshops:

Academic workshops

December 2001 and September 2002

Attended by 18 members of the project team (see inside back sleeve for members list)

National workshop

9th October 2002, Hilton Hotel, Milton Keynes, UK

Attended by 64 participants from the following 39 organisations:

Architecture Fab	Laing Construction
ARK e-management Ltd	Lancaster University
BAA Plc	Leeds Metropolitan University
Balfour Beatty Civic Engineering	Loughborough University
BHR Group	Loxley Associates Ltd
Bilfinger Berger UK Ltd	Open University Business School
BIW Technologies Ltd	Pickavance Consulting Ltd
Brookfield Consultancy	Public Construction & Property Ltd
Centre for Construction Innovation	Ruddle Wilkinson Architects
CIRIA	Shepherd Construction Ltd
CITE	Spie - Batignolles
Citex Professional Services	Taylor Woodro
Construction Products Association	Teamwork 2002
Construct IT	University of Cranfield
Costain Group Plc	University of Nottingham
CSIRO	University of Salford
Currie & Brown	Wates Group
Emcor Rail Ltd	Wilmot Dixon
EPSRC	
Ernst & Young	
Jeff Wix Consulting Ltd	

1st International workshop

30th January – 1st February 2003, Mottram Hall Hotel, Prestbury, UK

Attended by 52 participants from 28 organisations, representing 10 countries (Australia, Canada, Chile, Finland, Germany, Greece, Hungary, Malta, United Kingdom and the USA):

Vian Ahmed, University of Wolverhampton, UK

Mustafa Alshawi, University of Salford, UK

Chimay Anumba, Loughborough University, UK

Ghassan Aouad, University of Salford, UK

Yusuf Arayici, University of Salford, UK

*Matthew Bacon, ARK e-management
(visiting professor, University of Salford, UK)*

*Richard Baldwin, Independent consultant
(visiting professor, University of Salford, UK)*

Nick Bakis, University of Salford, UK

Peter Barrett, University of Salford, UK

Vladimir Bazjanac, Lawrence Berkeley National Laboratory, USA

Martin Betts, University of Salford, UK

Peter Brandon, University of Salford, UK

Eric Chang, STV & Polytechnic University of New York, USA

Mark Clayton, Texas A&M University, USA

*Rick Coble, CEC-RJC Consulting, USA
(visiting professor, University of Salford)*

Tyson Coble, CEC-RJC Consulting, USA

Rachel Cooper, University of Salford, UK

Nash Dawood, University of Teeside, UK

Andrew Davies, EPSRC, UK

Robin Drogemuller, CSIRO, Australia

*Martin Fischer, Stanford University, USA
(visiting professor, University of Salford, UK)*

Andy Fleming, University of Salford, UK

Thomas Froese, University of British Columbia, Canada

Charlie Fu, University of Salford, UK

Dennis Fukai, University of Florida, USA

Hilaire Graham, University of Plymouth, UK

Zuhair Haddad, Consolidated Contractors Company, Greece

Andy Hamilton, University of Salford, UK

Mike Kagioglou, University of Salford, UK

Auli Karjalainen, Senate Properties, Finland

Arto Kiviniemi, VTT Building and Transport, Finland

Irene Koh, University of Salford, UK

Carsten Kuhne, Gib Greiner, Germany

Jarmo Laitinen, JT Innovators Ltd, Finland

Y W Lam, University of Salford, UK

Angela Lee, University of Salford, UK

Lamine Mahdjoubi, University of Wolverhampton, UK

Sophie Maluski, University of Salford, UK

Amanda Jane Marshall-Ponting, University of Salford, UK

John Mitchell, Graphisoft R&D, Hungary

Leonardo Rischmoller, Bechtel Corporation Inc, Chile

Raimer Scherer, Tech University, Germany

Joseph Spiteri, University of Malta, Malta

Joseph Tah, South Bank University, UK

Ali Murat Tanyer, University of Salford, UK

Walid Tizani, University of Nottingham, UK

Jason Underwood, Construct IT, UK

Alastair Watson, University of Leeds, UK

Jeffery Wix, ARC3 Ltd, UK

Song Wu, University of Salford, UK

Xiaonan Zhang, University of Salford, UK

2nd International workshop

13-14th September 2004, Centre of Construction Innovation, Manchester, UK

Attended by 45 participants from 27 organisations, representing 12 countries (Australia, Canada, Chile, China, Denmark, Finland, The Netherlands, Norway, Malta, Qatar, Singapore and the United Kingdom):



Carl Abbott

Constructing Excellence/ Centre of Construction Innovation, UK

Carl is the Constructing Excellence Regional Director of Innovation for the North West of England. Working primarily with the University of Salford and the Centre for Construction Innovation (CCI) he is responsible for technology and knowledge transfer from the university sector to industry in the Northwest. Carl initially qualified as an electronics design engineer with British Aerospace and was a lecturer in electronics specialising in Computer Aided Engineering. He changed career when he joined the University of Salford in 1999 to research IT in construction at Construct IT.



Vian Ahmed

*School of Construction & Property Management
University of Salford, UK*

Dr Ahmed joined Salford from the School of Engineering and Built Environment, University of Wolverhampton in January 2004. She obtained her first degree in Civil Engineering from the University of Hertfordshire, followed by a MSc in Construction and a PhD in CAL in construction from Loughborough University (in which she worked and studied for a number of years), and previously worked for Corus in the Construction IT research unit.



Ghassan Aouad

*School of Construction and Property Management
University of Salford, UK*

Professor Aouad is Head of the only 6* rated School of Construction and Property Management in the UK, and director of the £3M EPSRC IMRC Centre (Salford Centre for Research and Innovation in the Built and Human Environment: SCRi). He leads the prestigious £443k EPSRC platform grant (from 3D to nD modelling). Professor Aouad's research interests are in: modelling and visualisation, development of information standards, process mapping and improvement, and virtual organisations.



Matthew Bacon

*Director of ARK e-management Ltd, UK
Visiting Professor, University of Salford, UK*

Professor Bacon is a founding director of ARK e-management Ltd, a company providing management consultancy and technology development services. ARK (Assets Resources and Knowledge) believes that new management practices are required if businesses are to effectively exploit the power of the Internet, and that the effective management of digital information is a key requirement in this regard. Currently, ARK's largest customer is Siemens who are deploying the suite within the UK.



Richard Baldwin

Visiting Professor, University of Salford, UK

Professor Baldwin has thirty-six years experience in the international electromechanical, food and beverage process engineering industries, and the domestic construction services sector. Responsibilities have included engineering centres, manufacturing facilities and contracting, including joint ventures in the UK and overseas, embracing all aspects of strategic planning, research and development, quality of management and deployment of professional people across a wide range of technologies and commercial sectors including project finance and the Private Finance Initiative. Professor Baldwin is currently undertakes a number of non-executive roles in private industry, government and academic related bodies.



Dino Bouchlaghem

*Department of Civil and Building Engineering
Loughborough University, UK*

Dino is a Professor of Architectural Engineering in the Department of Civil and Building Engineering, part of a 5* rated research group. His research interests are in the areas of collaborative visualisation, e-learning, information technology, briefing, design management, and product and process modelling. He is the coordinator of the CIB International Task Group in Architectural Engineering (TG49) and editor-in-chief of the International Journal of Architectural Engineering and Design Management.

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Peter Bosma

TNO Building & Construction Research, The Netherlands

Peter has worked in the area of standardisation and ICT in building and construction for the past 4 years: structuring information (flows), software architecture, 3D/4D/nD models. Peter is best known nationally for its work concerning VISI, and internationally for its work on ISO STEP/ IFC (Industry Foundation Classes) and the development of the IFC Engine Series software. His background is in the applied mathematics through developing and implementing complex optimisation algorithms.



Peter Brandon

*Director of Strategic Programmes
University of Salford, UK*

Professor Brandon's research interests range from construction economics, construction management, information/ knowledge based systems and sustainable construction. He has published widely in all four fields and has produced several 'world's first' software products. He has played a significant role in UK Construction Research Policy including Chairman of the UK Science Engineering Research Council Panel for Construction, Chairman of the UK Research Assessment Exercise for the Built Environment (1996 and 2001), Member of the Government UK Technology Foresight Panel, Member of the Construction Research and Innovative Strategy Panel and Chairman of the University Research Group for the Built Environment. He founded the 'CONSTRUCT IT' National Network for Construction Information Technology in the UK. He has also organised and chaired several international symposia and provided over 150 papers in more than 30 countries.



Lars Christensen

Selvaag, Norway

Lars Christensen is a civil and structural engineer from the Norwegian University of Science and Technology (NUST). He has been working both with engineering and ICT in the ARC industry for almost 20 years. His focus has been on ICT system development, but he has also been working on more academic/ theoretical projects. His experience spans from engineering companies, pre-cast concrete producers, industrial homebuilders, software companies and ship classification societies to research at NUSTS and Stanford University. Currently he is a strong evangelist for improved decision-making in construction projects by introducing low-friction information logistics enabled by the international standard IFC. Since 1999 he has been working with technology development and re-industrialization in Selvaag, a privately held homebuilding company in Norway.



Grahame Cooper

*Salford Centre for Research and Innovation
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Dr Ian Cooper

*Eclipse Research Consultants, UK
Visiting Professor, University of Salford, UK*

Dr Cooper has worked extensively in the areas of procurement, management and operation of the built environment in the UK. He has a firm relationship with the University of Salford; he was a founding co-director of the Centre for Sustainable Urban and Regional Futures; was a facilitator for the BEQUEST ‘concerted action’ (1998-2001) whose purpose was to build a common language and framework for the assessment of urban sustainability; he played similar role on the INTELCTITY thematic network whose purpose was joint scenario planning between the EU’s ICT and Sustainable Urban Development research communities; and is now a partner on INTELCITIES, a EU Framework 6 project delivering an electronic platform for on-line civic services, working with 20 major European Cities.



Rachel Cooper

*Co-director of Salford Centre for Research and Innovation
Director of the Adelphi Research Institute for Creative Arts and Sciences
University of Salford, UK*

Rachel is a Professor of Design Management, and undertakes research in the areas of design management; new product development; design in the built environment; design against crime; and socially responsible design. All her projects have been in collaboration with industry, working both nationally and internationally. Currently, Professor Cooper is Principal Investigator of ‘Vivacity 2020’, a five year study of urban sustainability for the 24-hour city. Professor Cooper was Founding Chair of the European Academy of Design, and is also Founding Editor of The Design Journal. She is currently a member of the Strategic Advisory Team for Environment and Infrastructure division of EPSRC and is Panel Convenor for the Postgraduate Awards in Visual Arts and Media for the Arts and Humanities Research Board (AHRB), where she is also currently serving on the Management Board. Professor Cooper has written over 100 papers and six books.



Steve Curwell

*School of Construction & Property Management
University of Salford, UK*

Steve is a Professor of Sustainable Urban Development (SUD) and a leading European researcher in this area through his key role in 14 EU and UK national research projects to a total value of circa €15M over the last 15 years. Professor Curwell has led exploration of innovative ways of inclusive, consensus-based research over the complex problems of SUD and urban regeneration linking IT and new ways of e-working, and is currently scientific and technical director of the €16M IntelCities Integrated E.U. Project.



Nash Dawood

*Construction Management & IT
University of Teeside, UK*

Professor Dawood’s research lies within the field of project and construction management, including the application of VR in the construction process, risk management, intelligent decision support systems, cost forecasting and control business processes. This has resulted in over 100 published papers in refereed international journals and conferences, and research grants from the British Council, Industry, Engineering Academy, EPSRC, DETR and Peter Berg Foundation.

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Andrew Davies
*Associate Programme Manager
EPSRC, UK*

Dr. Davies is responsible for the peer review of construction related research proposals submitted to EPSRC and is the principal contact for the construction related Innovative Manufacturing Research Centres at the Universities of Salford and Reading. Prior to joining the EPSRC, he was involved in research as a materials chemist, during which time he received a PhD from the University of London via the Royal Institution of Great Britain, and gained postdoctoral experience at the University of Cambridge.



Robin Drogemuller
*Principal Research Scientist and Team Leader
CSIRO & Co-operative Research Centre for Construction Innovation, Australia*

Robin holds qualifications in architecture, mathematics and computing, and worked as an architect and construction manager in both temperate and tropical Australia before entering academia at the Northern Territory University and then James Cook University of North Queensland. At CSIRO, Robin leads a team of 12 people in the area of IT support to design and manufacturing with a major focus on ARC applications. This group has developed and is continuing to develop commercial software to support construction innovation.



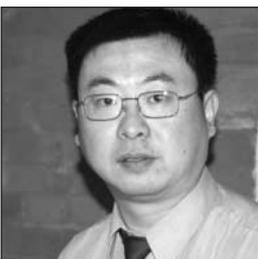
Kjetil Espedokken
Selvaag Gruppen, Norway

Kjetil is a system developer in Selvaag, his main responsibility is model development and integration of enterprise wide solutions in areas like knowledge engineering, knowledge based systems and process and product development. He is also involved with international standards development for data exchange (IFC) and is an observer to the Model Support Group of the IAI.



Thomas Froese
*Associate Professor in the Department of Civil Engineering
University of British Columbia, Vancouver, Canada*

Professor Froese's research focus concentrates on computer applications and information technology to support construction management, particularly information models and standards of construction process data for computer-integrated construction. Professor Froese originally studied Civil Engineering at U.B.C. before obtaining his Ph.D. from Stanford University in 1992.



Charlie Changfeng Fu
University of Salford, UK

Charlie gained an MSc in Architecture and a Diploma in Computer Science; worked as a research assistant in computer programming for five years at the Martin Centre, Cambridge University; and as an architect for over three years before joining Salford. His research interests include 3D computer modelling, visualisation and virtual reality technologies in architecture, urban design and planning. He is at present writing up his PhD thesis in the Practice of E-participation in Urban Planning and Design.



Andy Hamilton

*School of Construction & Property Management
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Andy has been a lecturer at Salford since 1992. His research interests lie within Urban and Environmental Information Systems. He is currently involved in two EU projects: Intelcites (12M Euros) and Virtual Environmental Planning Systems (4M Euros), and previously worked on the Intelcity and BEQUEST projects.



Tarek Hassan

*Department of Civil & Building Engineering
Loughborough University, UK*

Dr Hassan is a Senior Lecturer and Director of the European Union Research Group at Loughborough University. His academic experience is complimented by 10 years of industrial experience with several international construction organisations. Dr Hassan has been leading and partner in 10 projects funded by the European Commission under the IST (Information Society Technologies) programme. His research interests include Advanced Information and Communication Technologies (ICT), applications of e-commerce, virtual enterprises business relationships, legal aspects in ICT environments, information modelling and simulation, design management, management information systems, strategic management and dynamic brief development.



Mike Kagioglou

*Manager of the Salford Centre for Research and Innovation (SCRI)
University of Salford, UK*

Dr Kagioglou comes from a manufacturing background and for the last seven years he has been undertaking research in the built and human environment. He has worked in a number of research projects including the 'Process Protocol' and more recently he was the lead author of a training module on 'process management' that is published by CIRIA on the 'training the trainers' series. He has published widely and his current research looks at the modelling and visualisation of hybrid concrete structures, process and project management, IP telephony communications, delivery of healthcare from a built environment perspective and enabling mass customisation capabilities for construction supply chains.



Kalle Kähkönen

VTT Building & Transport, Finland

Dr Kähkönen works as a chief research scientist at the VTT Technical Research Centre of Finland. He holds degrees from two universities: MSc (Civil Engineering) from the Helsinki University of Technology and Ph.D. from the University of Reading (UK). He has carried out research and development in numerous areas also covering the implementation of research results in companies as consultancy. Broadly speaking, Dr Kähkönen's main interests are in advanced technology and solutions for modern project management and project business.

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Jan Karlshøj
Rambøll, Denmark

Dr. Karlshøj has a Master of Science and Ph.D in data modelling for the construction industry. He has been working at consulting engineer companies for 12 years, where he has been giving tasks within the structural domain and a number of ICT development related tasks. He is working as a Chief Consultant at Rambøll. Dr. Karlshøj has been active in a number of national ICT development projects for the construction industry, and has the project lead in the '3D visualisation and simulation' project under the national IT implementation programme: Digital Construction. He has had a long interest in IFC, and has held several positions within the International Alliance for Interoperability.



Jarmo Laitinen
JT Innovators Ltd, Finland
Acting Professor, Tampere University of Technology, Finland

Professor Laitinen (MSc, Eur.Ing) has a background in structural design, production processes and their technologies. He has wide expertise of European RTD-programmes and knowledge of many different R&D methodologies. Dr. Laitinen has participated in and co-ordinated several EC-research projects, and has evaluated for the EC 4th and 5th Framework programmes. He is the chairman of the steering committee of the national VERA programme launched by Tekes (IT enabled business networking in construction), member Nordic IAI chapter, and has coordinated the IST-1999-60002-GLOBEMEN (IMS) project.



Angela Lee
University of Salford, UK

Dr. Lee works on various CIB/ EU related projects including Revaluing Construction and PeBBu, and on the EPSRC funded 3D to nD Modelling project. She is the Assistant Editor of the International Journal of Construction Procurement. Her research interests include performance measurement, performance-based building, process modelling, process management, nD modelling and requirements capture. She has published extensively in both journal and construction papers in these fields. Dr Lee completed a BA (Hons) in Architecture at the University of Sheffield, and her PhD at the University of Salford.



Jun Lee
University of Salford, UK

Jun trained as an architect in Korea and was awarded an MSc in Architecture in 2002. He is currently a doctoral candidate at the University of Salford. His PhD aims to develop an integrated building information modelling that will aid visualisation of the interaction between various design criteria, with particular concentration on security and health & safety issues in construction.



Amanda Jane Marshall-Ponting
University of Salford, UK

Amanda obtained a BSc (Hons) in Applied Psychology from John Moores University in 1998, and an MRes in Informatics at Manchester University. Her introduction to Salford University came through involvement with the BEQUEST network, an EU concerted action concerned with Sustainable Urban Development. She has been involved with a number of Salford projects including VULCAN (Virtual Urban Laboratories for computer aided network), Intelcity and From 3D to nD Modelling; the latter project is being used as the main PhD case study to develop her interests in multi-disciplinary collaboration, organisational working and information systems.



Dave Moyes
Building Design Partnership, UK



Khalid Naji
University of Qatar, Qatar

Dr. Naji holds a Ph.D. degree in Civil Engineering (1997) from the University of Florida in the area of Public Works Planning & Management. He received his M.Sc. degree in Civil Engineering from the University of Texas at Austin in 1993, and his B.Sc. degree in Civil Engineering from the University of Qatar in 1990. Dr. Naji's area of interest is computer applications in construction engineering, project planning & scheduling and applications of virtual reality in construction engineering. Currently Dr. Naji is the Head of the Civil Engineering Department at the University of Qatar since the year 2000.



Brendan Patchell
Bucknall Austin, UK

Brendan, a quantity surveyor by profession, produced a 3D cost model in 1982 that was used to produce capital cost estimates. He also developed systems analysis, rates databases and relationships between fundamental dimensions. The 4D cost model (4DCM) was developed in 1999 to address the need of owner/ occupier and PFI consortiums to calculate total project costs and running maintenance and replacement costs.



Leonardo Rischmoller
Bechtel Corporation, Chile

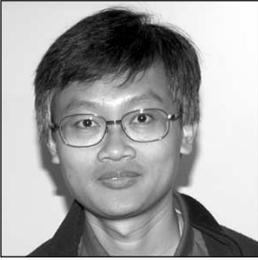
Leonardo is currently in the process of completing his PhD in Construction Technology at the Universidad Católica de Chile. At Bechtel, he has been developing technology, methods and procedures by which to conduct 4D planning; he pioneered the first 4D application on a live project that rendered significant and demonstrable savings in man-hours and materials, giving solid credence to his assertion that 4D technology is viable and cost-effective. Prior to this, he worked on several small to medium-sized construction projects.



Geoffrey Q. P. Shen
Hong Kong Polytechnic University, China

Professor Shen, PhD, is an active researcher in value management and related fields, supported by construction IT. He has managed a large number of research projects with total funding over HK\$10 million, and has produced more than 200 publications including journal and conference papers, books, and reports. He also teaches extensively in these fields at both postgraduate and degree levels. Professionally, he is a member of the Institute of Value Management in the UK and a founding council member of the Hong Kong Institute of Value Management (HKIVM). He has been serving the HKIVM as the Secretary, Councillor, Editor, and Member of the Executive Committee since its formation. As a certified Value Management Facilitator (List A), he has professionally facilitated a number of value management and partnering workshops for large client organisations in both the public and private sectors.

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Wawan Solihin

novaCITYNETS Pte Ltd, Singapore

Wawan has been active in the area of nD modelling; programmes include CORENET ePlanCheck project and IAI in Singapore. His key research interest is in the area of downstream implementation of the nD model, e.g. code-checking and simulation; shaping the direction of code-checking implementation with concerns on the adoption and readiness of the end-users; and focusing on creating applications and making sure that the nD model can be used for real and useful applications that will benefit the end-users, with flexibility and resiliency towards 'imperfect' data.



Joseph Spiteri

University of Malta, Malta

Dr. Spiteri's expertise is largely in the field of architectural, engineering and management services, with particular concentration on accessibility. He is a qualified access auditor. He gained an MSc from Edinburgh University, and a PhD from the University of Leeds.



Joseph Tah

*School of Construction & Property Management
University of Salford, UK*

Joe is Professor of Construction Management. His research interests are in the areas of project and risk management, integrated design and construction, supply chain management, and the globalisation of the construction industry. He has undertaken extensive research and developed expertise in the application of knowledge-based systems, object-oriented programming, relational and object database management, computer-aided design, product and process modelling, and artificial intelligence techniques to the provision of advanced decision support within integrated computer systems for construction management using open distributed computing standards.



Paul Tiley

*School of Construction & Property Management
University of Salford, UK*

Paul has been involved in the building and construction industry for nearly 30 years, starting as a building cadet with Queensland State Works Department in 1975, through to private building and project management consultant practices. In 1995, he joined the CSIRO's Building, Construction and Engineering Division as a Construction Systems Researcher, and has recently joined Salford to investigate the theory of project and production management, as it relates to the construction industry.



Walid Tizani

*Senior Lecturer, School of Civil Engineering
University of Nottingham, UK*

Dr Tizani's main research areas are the application of novel information technologies to structures and the performance of steel connections. His experience includes the application of knowledge based systems and object orientated technology in the provision of advice and decision support for structural design; virtual reality in the design of structural steelwork; construction-led and integrated design; the economic appraisal of structural steelwork; collaborative design; blind-bolt connection to tubular hollow sections. Dr. Tizani lectures in Steel Structures, IT for Engineers, and Engineering Communication.



James Tucker
Wates Construction, UK



Jason Underwood
*Manager of Construct IT
University of Salford, UK*

Dr. Underwood's background is in Civil Engineering, graduating from John Moores University in 1991. Since being awarded a Ph.D. in Construction IT (researching into the integration of design and construction through the effective usage of IT) he has been involved in a number of UK and EU funded research projects, specialising in the field of Concurrent Engineering and Integrated Collaborative Construction, publishing extensively. In addition, he has worked in the software industry developing expert/ knowledge-based systems for the M&E sector. He is currently Manager of Construct IT For Business, an international industry-led collaborative network comprising leading edge construction organisations whose aim is to improve industry performance through the innovative application of IT and act as a catalyst for academic and industrial collaboration.



Hongxia Wang
University of Salford, UK

Hongxia gained a BSc. in Computer Science from the National University of Defence Technology (China) and a MSc. in Computer Application from Shijiazhuang Mechanical Engineering Institute (China). She worked as a computing science lecturer in China for nine years, and as a programmer (part-time) in UMIST for one year. Her research interests include data modelling, information management and database, 3D visualisation etc. Currently, she is undertaking a PhD at the University of Salford (nD urban information model) and is a part-time research assistant for the Intelcities Project.



Alastair Watson
*Senior Lecturer in Computer-Aided Engineering, School of Civil Engineering
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Dr. Watson is a chartered Civil Engineer and moved from industry to academia in 1984. His early research includes developing the now established concept of 'calculation processing' and extensive work on knowledge-based systems, led to the establishment of the Computer-Aided Engineering (CAE) group and involvement in a sequence of major collaborative research projects: such as CIMsteel, CI-PM, ProCure, CIMclad to name a few. The outputs from these extensive research activities have included two important informatics standards for the construction industry: CIS/2 (structural steelwork) and DocLink (document management). Dr Watson has published widely and has an international reputation arising from his leading work on the application of product models within the construction industry.

nD Modelling Road map: A Vision for nD-Enabled Construction



Jeffrey Wix
Building Services Engineer
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Jeff has been active in research and development of IT for building construction since 1980. In 1988 he developed low cost CAD for construction and building services applications. He returned to research consultancy in 1993 and is active in developing next generation software applications, information sharing capabilities between software and strategies for information development within major organisations. Current key work involves developing information models for and supporting development of a rule-based regulation checking system, creating new forms of cost and environmental impact representation, re-engineering O&M instruction delivery using XML/XSD and defining shared data links between the GIS and building construction worlds. He is engaged in standards development for data exchange and dictionary frameworks within ISO, CEN and BSI. He is a member of the Model Support Group of the IAI and is Technical Coordinator for the UK Chapter, and led development of the IFC 2x information model.



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Chris is a trained performance coach (Industrial Society) and Value Manager (Leeds University) as well as a Chartered Architect; he worked in private practice until 1995. He is a founder member of Be (INCR) Innovation Network of Construction Research, and is an occasional contributor to the cross-sectorial Synchrony knowledge management network and the International Cultural Learning Association (Interclass). Currently he is working with Constructing Excellence and nCRISP executives to develop a long term vision and strategy for UK construction. Within Wates, he works within the Group Strategic Process team that is accountable for developing business strategy, cross project & market stream business improvement and integration of process across specialist disciplines. He is currently researching the integration of various business improvement processes that have originated outside the construction and development industry. He is involved in two Pii projects 'prOSPpa' and 'Integrated Team Collaboration using Object Modelling.'



Song Wu
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Dr Wu is a research fellow on the 3D to nD Modelling project and previously worked on the Process Protocol II project at the University of Salford. He was a Quantity Surveyor in Singapore and China for 3 years. He was awarded an MSc in Information Technology in Construction and a PhD at the University of Salford. Dr Wu's research interests include product and process modelling, construction IT and knowledge management.

1.0 2nd International nD Modelling Workshop: An Introduction

This report aims to develop the nD modelling road map as part of the 3D to nD modelling project at the University of Salford (£0.443 million EPSRC Platform Grant funded). It reports primarily on the results of the 2nd International nD modelling workshop, but also draws its results from a number of research team workshops (academic), a Construct IT national workshop (industrial), and 2 international workshops (both industrial and academic) that took place over a period of 3 years

- The first academic workshop sought to gain consensus amongst the 20+ strong group of multi-disciplinary research team of the boundaries of the vision; applied or blue-sky, short or long-term industry implementation? An electronic voting tool was used to ascertain the consensus of the participants in their own grappling of what they perceived the nD model would be .
- The second academic workshop set about defining the need and scope of nD modelling using a case study exemplar. Research topics, such as data quality/ availability and decision-making mechanisms, were identified
- At the national workshop, the findings of the academic workshops were presented to enable a consensus with both industry and academia across the UK. Those attending included contractors, clients, suppliers and architects, ranging from 1 person to large multi-national organisations. The spectrum of participants was to reduce any inherent exclusion of industry players in the vision development, and to gain interest and acceptance of the work. The positioning of IT in the industry was established
- The 1st international workshop, held at Mottram Hall February 2003, brought together world-leading experts (both from the industrial and academic communities) within the field of nD modelling (see Figure 1). There were 52 participants from 32 collaborating organisations, from 10 countries. The workshop developed a business process and IT vision for how integrated environments would allow future nD-enabled construction to be undertaken

A summary of all 4 workshops is published in 'Developing a Vision of nD-Enabled Construction' (Lee et al, 2003).



Figure 1: 1st international nD modelling workshop participants

The aim of the 2nd international nD modelling workshop was to build upon the findings of the preceding event, concentrating on tackling the strategic and operational issues confronted by the widespread application of nD-enabled construction, and defining the future research agenda. This report firstly summarises the work undertaken on the nD modelling project thus far and the findings of the 2nd workshop, which was held on the 13-14th September 2004. The workshop brought together 45 participants from 27 organisations and representing 12 countries: Australia, Canada, Chile, China, Denmark, Finland, The Netherlands, Norway, Malta, Qatar, Singapore and the United Kingdom. Whilst this report highlights the barriers and opportunities of implementing nD modelling in the construction industry, the findings of all the workshops are formulated to develop a road map of the future research agenda for global nD uptake.

The research papers and additional funding generated thus far from the 3D to nD project can be found in Appendix A and B respectively. A number of research papers were presented as part of the 2nd international nD modelling workshop, some of which can be found in Appendix C. Finally, further details of 2nd international workshop sponsors can be found in Appendix D.

1.2 nD modelling

The terms 'nD modelling' and 'nD CAD' are gaining increased usage in the field of information communication technologies (ICTs) and building design; the concept gaining a heightened profile via the £0.5 million funded 3D to nD modelling project at the University of Salford. An nD model is an extension of the building information model by incorporating all the design information required at each stage of the lifecycle of a building facility (Lee et al, 2003). Thus, a building information model (BIM) is a computer model database of building design information, which may also contain information about the building's construction, management, operations and maintenance (Graphisoft, 2003). From this database, different views of the information can be generated automatically, views that correspond to traditional design documents such as plans, sections, elevations and schedules. As the documents are derived from the same database, they are all coordinated and accurate – any design changes made in the model will automatically be reflected in the resulting drawings, ensuring a complete and consistent set of documentation (Graphisoft, 2003). This report summarises the two international nD modelling workshops, presents the current development of the 3D to nD modelling project, lays out the nD modelling opportunities and barriers for implementation, and concludes by proposing a future road map for nD modelling and where this concept should move forward.

2D and 3D modelling in the construction industry takes its precedence from the laws governing the positioning and dimensions of a point or object in physics whereby a three number vector represents a point in space, the x and y axes describing the planar state and the z axis depicting the height (Lee et al, 2003). 3D modelling in construction goes beyond the object's geometric dimensions and replicates visual attributes such as colour and texture. This visualisation is a common attribute of many ARC design packages, such as 3D Studio Max and ArchiCAD, which enable the simulation of reality in all its aspects or allow a rehearsal medium for strategic planning.

Combining time sequencing in visual environments with the 3D geometric model (x, y, z) is commonly referred to as 4D CAD (Rischmoller et al, 2000). Using 4D CAD, the processes of building construction can be demonstrated before any real construction activities occur (Kunz et al, 2002). This will help users to find the possible mistakes and conflicts at the early stage of a construction project, and to enable stakeholders to predict the construction schedule. Research projects around the world have taken the concept, developed it further and software prototypes and commercial packages have begun to emerge. In the USA, the Centre of Integrated Facility Engineering (CIFE) at Stanford University has implemented the concept of the 4D model on the Walt Disney Concert Hall project. In the UK, the University of Teesside's VIRCON project integrates a comprehensive core database designed with Standard Classification Methods (Uniclass) with a CAD package (AutoCAD 2000), a Project Management Package (MS Project) and Graphical User Interfaces as a 4D/ VR model to simulate construction processes of an £8 million, 3 storey development for the University's Health School (Dawood et al, 2002). Commercial packages are also now available, such as 4D Simulation from VirtualStep, Schedule Simulator from Bentley, and 4D CAD System from JGC Corporation.

nD modelling develops the concept of 4D modelling and aims to integrate an nth number of design dimensions into a holistic model, which would enable users to portray and visually project the building design over its complete lifecycle. nD modelling is based upon the building information model (BIM), a concept first introduced in the 1970s and the basis of considerable research in construction IT ever since. The idea evolved with the introduction of object oriented CAD; the 'objects' in these CAD systems (e.g. doors, walls, windows, roofs) can also store non-graphical data about the building in a logical structure. The BIM is a repository that stores all the data 'objects' with each object being described only once. Both graphical and non-graphical documents, such as drawings and specifications, schedules and other data respectively, are included. Changes to each item are made in only one place and so each project participant sees the same information in the repository. By handling project documentation in this way, communication problems that slow down projects and increase costs can be greatly reduced (Cyon Research, 2003).

Leading CAD vendors such as AutoDesk, Bentley and Graphisoft have promoted BIM heavily with their own BIM solutions and demonstrated the benefits of the concept. However, as these solutions are based on different, non-compatible standards, an open and neutral data format is required to ensure data compatibility across the different applications. Industry Foundation Classes (IFC), developed by the International Alliance for Interoperability (IAI), provide such capabilities. IFCs provide a set of rules and protocols that

determine how the data representing the building in the model are defined, and the agreed specification of classes of components enables the development of a common language for construction. IFC-based objects allow project models to be shared whilst allowing each profession to define its own view of the objects contained in that model. This leads to improved efficiency in cost estimating, building services design, construction, and facility management: IFCs enable interoperability between the various ARC/FM software applications allowing software developers to use IFCs to create applications that use universal objects based on the IFC specification. Furthermore, this shared data can continue to evolve after the design phase and throughout the construction and occupation of the building.

The 3D to nD research project at the University of Salford is developing a holistic nD modelling tool using IFCs, to help improve the decision-making process and construction performance by enabling true 'what-if' analysis to be performed to demonstrate the real cost in terms of the variables of the design issues. Therefore, the trade-offs between the parameters can be clearly envisaged, which will help to:

- Predict and plan the construction process
- Determine cost options
- Maximise sustainability
- Investigate energy requirements
- Examine people's accessibility
- Determine maintenance needs
- Incorporate crime deterrent features
- Examine the building's acoustics

Traditionally, a whole host of construction specialists are involved in instigating the design of modern buildings. With so much information and from so many experts, it becomes very difficult for the client to visualise the design, any changes applied, and subsequent impacts on the time and cost of the construction project. These problems highlight the need for nD modelling. Changing and adapting the design, planning schedules and cost estimates to aid client decision-making can be laborious, time consuming and costly. Each of the design parameters that the stakeholders seek to consider will have a host of social, economic and legislative constraints that may be in conflict with one another. Furthermore, as each of these factors vary – in the amount and type of impacts they can have – they will have a direct impact on the time and cost of the construction project. The criteria for successful design therefore will include a measure of the extent to which all these factors can be co-ordinated and mutually satisfied to meet the expectations of all the parties involved.

Specialist design criteria input is usually undertaken in a sequential step-by-step fashion whereby the design undergoes a number of changes: after satisfying the legal requirements, it then proceeds to the next consultant who in turn makes a number of design recommendation changes. Design changes are made in isolation from each other in an over-the-wall manner, whereby each discrete change pays little or no regard to the next. Therefore, it is often difficult to balance the design between aesthetics, ecology and economism – a three dimensional view of design that acknowledges its social, environmental and economic roles – in order to satisfy the needs of all the stakeholders. The sequential 'over-the-wall' approach is problematic as it allows information wastage, loss and repetition, and long lead times – changes to the design are made and passed on to the next professional for their updates (Brödner, 1996; Syan, 1994; Müller, 1987; Buggert, 1995). These problems are mainly attributed to the vast amount of information and knowledge that is required to bring about good design and construction co-ordination and communication within a traditionally fragmented supply-chain. The complexity of the problem increases with the fact that this information is produced by a number of construction professionals of different backgrounds. Therefore, without effective implementation of IT and processes to control and manage this information, the problem will only intensify as construction projects become more and more complex, and as stakeholders increasingly enquire about the performance of buildings (sustainability, accessibility, acoustic, energy, maintainability, crime etc).

2.0 nD modelling development

The nD modelling project aims to develop technology and tools to incorporate numerous design perspectives in order to systematically assess and compare the strengths and weaknesses of different design scenarios – as identified through the workshops. Thus, the tool builds upon the concept of BIM, and is IFC-based: the system architecture is proposed in Figure 2: -

- nD knowledge base: platform that provides information analysis services for the design knowledge related to the various design perspective constraints of nD modelling (i.e. accessibility requirements, crime deterrent measures, sustainability requirements etc). Information from various design handbooks and guidelines on the legislative specifications of building component will be used together with physical building data from the building information model to perform individual analysis, i.e. accessibility data model is developed to enable the sharing of the information with other design aspects through the knowledge base. (Figure 3)

- Decision support: multi-criterion decision analysis (MCDA) techniques have been adopted for the combined assessment of qualitative criteria (i.e. criteria from the Building Regulations and British Standard documents that cannot be measured against directly in their present form) and quantitative criteria (e.g. expressed in geometric dimensions, monetary units etc). Analytic Hierarchy Process (AHP) is used to assess both qualitative criteria (i.e. criteria that cannot be directly measured) and quantitative criteria (e.g. expressed in dimensions, monetary units, etc). The accessibility assessment model based on the AHP methodology is developed to support the decision making on accessible design. (Figure 4)

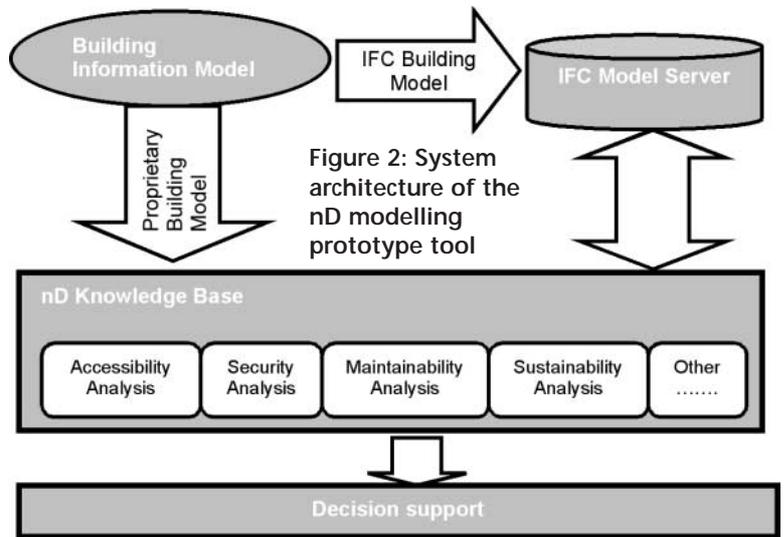
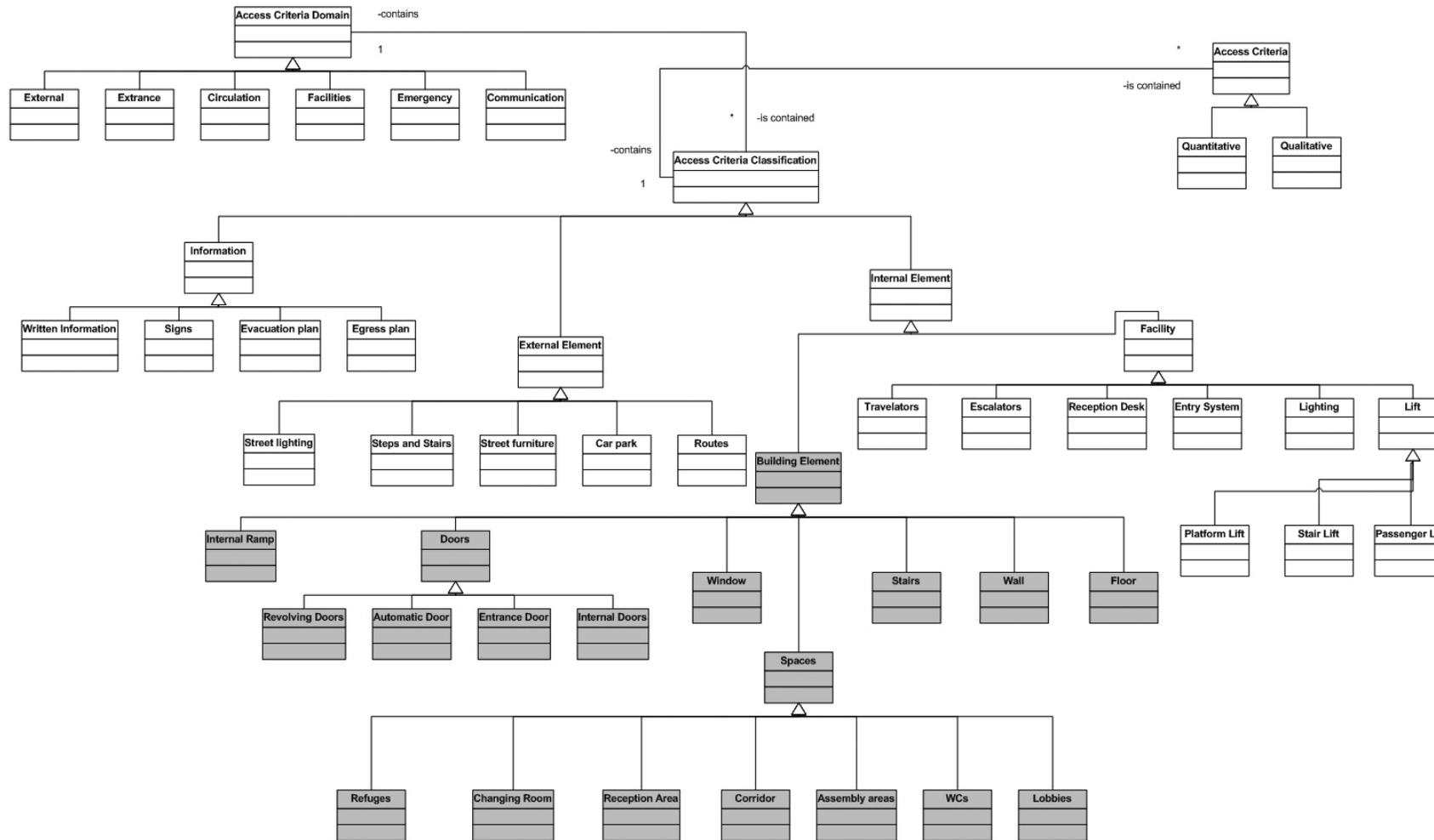


Figure 3: Accessibility data model (section)

So far, the nD prototype tools incorporate whole-lifecycle costing (using data generated by Salford's Life-Cycle Costing research project), acoustics (using the Rw weighted sound reduction index), environmental impact data (using BRE's 'Green Guide to Specification' data), crime (using the Secured by Design Scheme standards) and accessibility (using BSI:83001). Technology for space analysis is also developed to support the accessibility analysis. Figures 5 through to 7 demonstrate the prototype on a live case study – the extension of The Lowry. The Lowry is a national landmark millennium building. The Lowry is an architectural flagship with a unique and dynamic identity, designed by Michael Wilford & Partners. Opened on 28th April 2000, it brings together a wide variety of performing and visual arts under one roof. The Lowry houses two theatres for performing arts (1,730 & 466 seats) presenting a full range of drama, opera, ballet, dance, musicals, children's shows, popular music, jazz, folk and comedy; gallery spaces (1,610 metres of floor space); showing the works of LS Lowry alongside contemporary exhibitions; and ArtWorks, an interactive attraction designed to encourage individual creativity. The success of the building has led to the need for an extension of the existing building. The extension of the Lowry is used only to test and validate the nD modelling prototype tool and technologies we developed, i.e IFC based space analysis, and not to assess the feasibility of the design itself: the results of the nD modelling prototype tool will not be used to inform the design of the building.

Figure 3: Accessibility data model (section)



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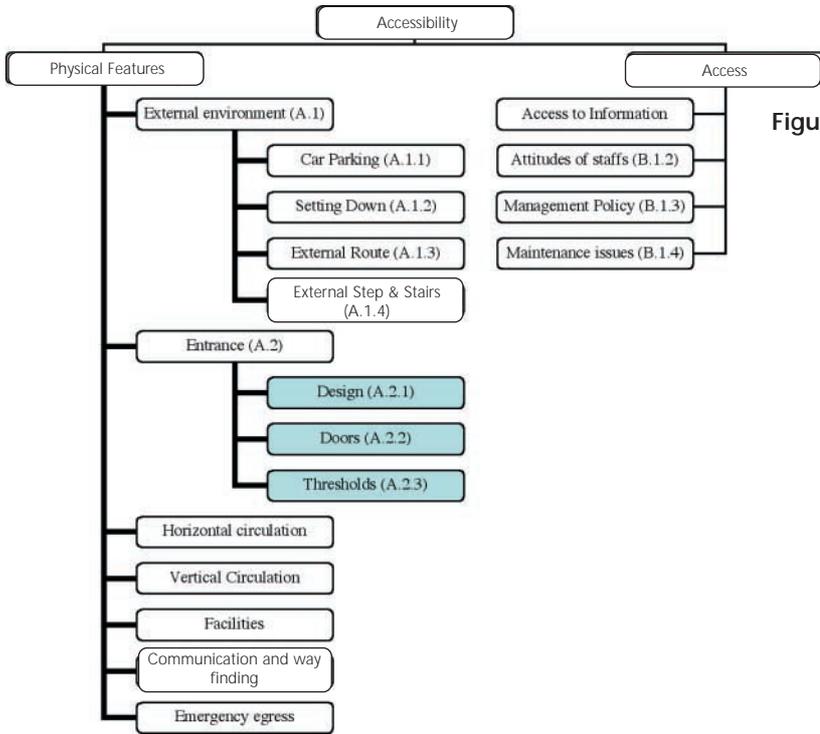


Figure 4: Accessibility Assessment Model

Figure 5: The Lowry extension

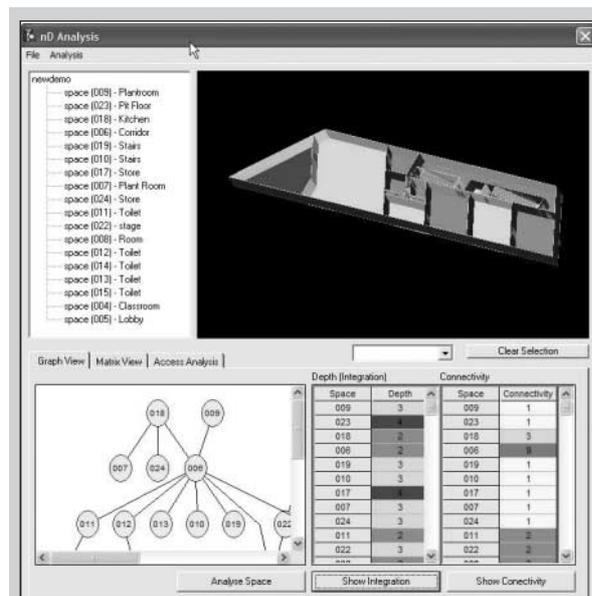
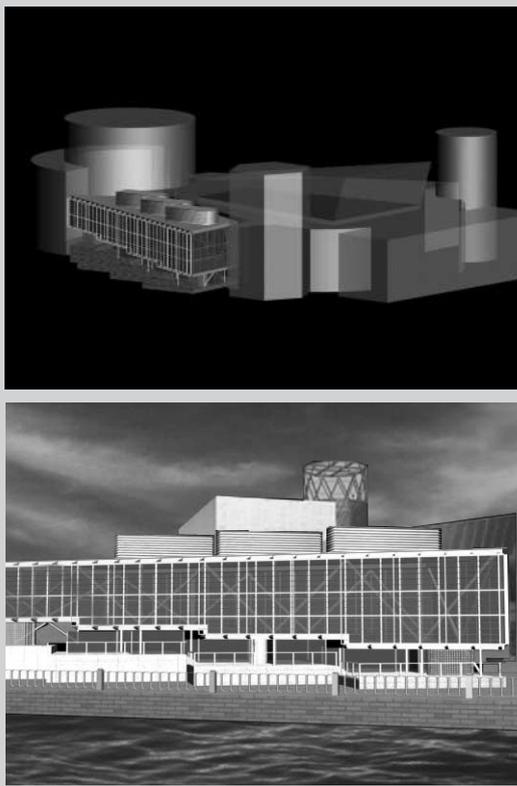


Figure 6: Screenshot of nD prototype tool, displaying accessibility analysis

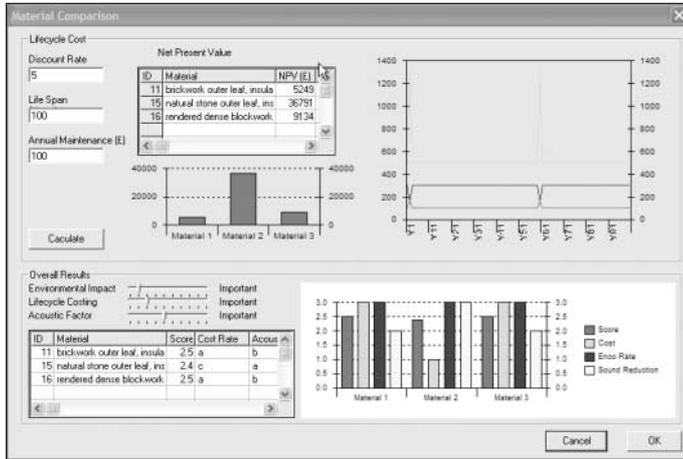


Figure 7: Screenshot of nD prototype tool, displaying the AHP technique for determining suitable building material in accordance to lifecycle costing, acoustics and environmental impact factors

3.0 2nd International nD modelling workshop aims & objectives

Since the 1st international workshop, the concept of nD modelling has been gaining worldwide momentum in both research and application. Increased interest in the level of research can be gauged by the growing number of conferences and research papers/ projects on the subject: the 10th ISPE International Conference on Concurrent Engineering, July 2003, Portugal; and The International Conference on Construction Information Technology (INCITE), February 2004, Malaysia, to name but a few. In addition, a growing number of organisations have also started to apply product modelling techniques on their construction projects.

In order to enable widespread nD-enabled construction, there still exist a number of implementation barriers. Therefore, the aim of the 2nd international workshop was to tackle the strategic and operational issues confronting nD modelling, and to define the future research agenda to fill these gaps. The two-day workshop was structured to address the differing challenges exposed by the ARC industry and specific construction projects respectively. Table 1 illustrates the research structure followed in the workshop and the expected deliverables.

	nD-enabled construction industry	nD-enabled construction projects
Aim	How to create the general conditions to support nD modelling	How to bring together various elements/ stakeholders on specific projects
Type of Analysis	Broad, holistic, conceptual model, highlighting what elements are important	Good practice case studies illustrating how elements can work synergistically
Focus of Analysis	Generic industry level highlighting any differences by country	Project specific, highlighting interaction of companies in industry context
Output	Advice on how to create the conditions to maximise the potential for appropriate nD-enabled construction	Advice and illustrations on how to realise users requirements through nD-enabled construction
Stakeholder Addressed	Government/ industry bodies	Clients and construction companies

Table 1: Workshop structure (adapted from the work of Professor Peter Barrett)

The first day concentrated on reviewing the progress of development and implementation of nD modelling in each country, thus establishing synergies and gaps between each region. The second day investigated in detail the barriers and solutions posed at the

project level, and again the barriers and enablers were identified with possible policy improvement actions. The last session of the second day started to define the future research agenda: workshop participants were asked to envisage the future of nD modelling on a 4 year and 8 year timescale.

3.1 Data analysis method

All the workshops were tape recorded and subsequently transcribed. The approach underpinning the analysis of the transcription is that of qualitative data analysis. Qualitative analysis provides insights into theoretical and applied studies of knowledge, perception and cognition (Denicolo & Pope, 2001). As there were between 3 – 6 researchers collaborating on this work, they provided a degree of triangulation by carrying out the analysis of the data independently and in parallel.

An iterative process of content analysis and interpretation was adopted. Firstly, a text-mining software tool, TextAnalyst, was used to analyse the content and interpret the data (see Figures 8 and 9). Based on the natural language processing technology, the tool was useful in coding, structuring and sorting the data; it provided quantifiable information such as weightings of the relationship between the key topics, which are extremely time consuming to produce manually. Figure 8 shows the key topics TextAnalyst has identified based on the transcripts. Figure 9 shows the relationship matrix between the topics and the colour in the matrix represents the weighting of the relationship; the darker the colour is, the stronger the relationships are. The longer the bar is, in any given column or row, the greater the weighting of the topic due to the greater number of relationships with other topics. For example, Figure 7 shows that 'information' (topic number 4) not only has more relationships with other topics than 'technology' (topic 6), but that but that its relationships are more significant due to the heavier weightings with 2 of the 9 topics. In addition, opposites (or bipolar) themes were also assigned. For example, some participants viewed the use of 3D CAD as a tool to improve communication with construction professionals, whereas others saw it as a medium to assist communication with clients.

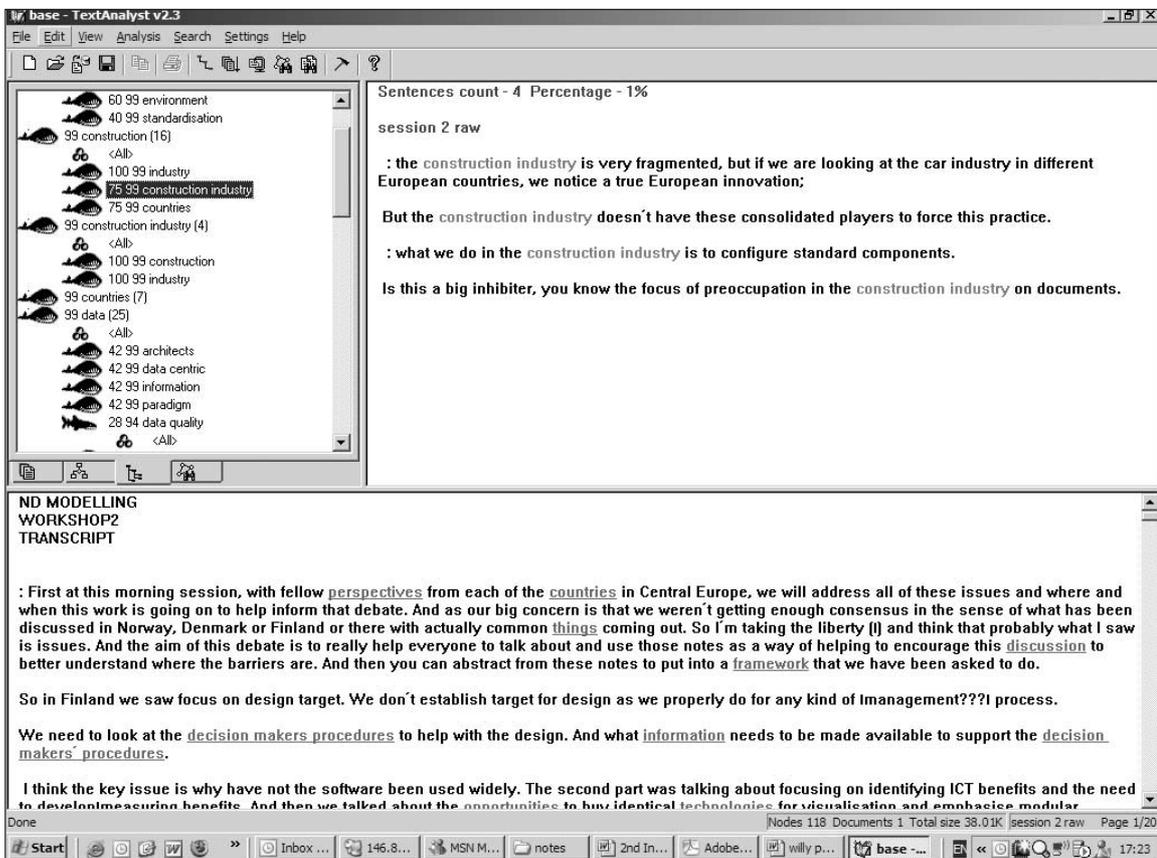


Figure 8: Text Analysed in TextAnalyst

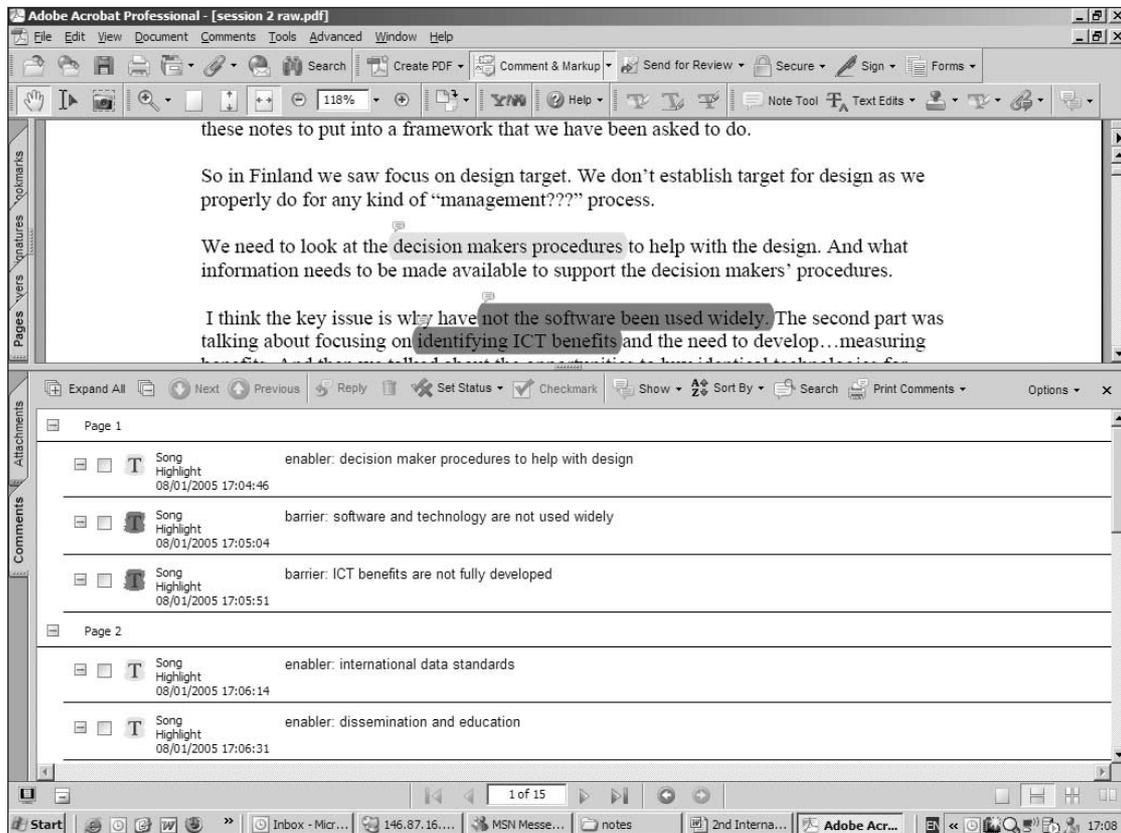


Figure 10: Analysing the transcription using Adobe Acrobat Professional

Finally, in order to triangulate the manual and automatically generated content analysis of the workshop transcripts, the key themes identified were then compared. This added rigour to the search for segments and assisted in identifying unique aspects of the data. A way of visually summarising a consensus of the major themes emerging from the workshops was found to be via cognitive mapping using 'Decision Explorer,' which facilitated the summarising and presentation of qualitative data.

Not only does this report present a summary of the 2nd international workshop, it also combines the findings from all 5 workshops to produce an nD road map of the future.

4.0 nD-Enabled Construction Industry: Current research & development activities

During day 1 of the 2nd international workshop, the participants were firstly asked to divide themselves into 3 equal groups: Far East and Australasia, Central Europe, and Canada and the Americas (note: for an equal balance, there were some anomalies to the groupings of countries) to discuss current research and development activities related to nD modelling in their own respective country. Presentations from each country's representative were made, a brief summary is outlined below; full presentations can be viewed by visiting <http://ndmodelling.scpm.salford.ac.uk>

Group 1 – Far East & Australasia

- Australia: research was being deployed using IFCs to develop a system that will be able to undertake core checking of building standards, utilise visualisation techniques and look at on-line scheduling
- China: whilst there aren't many research products for nD modelling, there is a demand, from the larger contractors & clients in particular, for better knowledge of the products possible
- Qatar: the SIM-CON project was presented, which simulates real-time construction activities in an object-orientated virtual environment, for example the noise and cranes
- Singapore: various e-submission and e-plan checking tools are being developed to enable authorities to measure benefits to individuals & industry

Group 2 – Central Europe

- Denmark: work is focussing on how IFCs can benefit the community, a requirements model is currently being developed
- Finland: work being undertaken in decision-making tools
- Norway: majority of industry is document focussed, work is being undertaken in decision-making tools
- Netherlands: evidence presence in changes in building codes and regulations
- UK: evidence was presented of both industry and university drives for nD, but these were pockets of best practice and occurred mostly in large scale projects

Group 3 – Canada & the Americas

- Canada: in industry there is little nD modelling development but there is the widespread adoption of process modelling & management techniques. There is limited government support for research but high level of university activity; research is currently concentrated on product models with sustainability, e-management, mobile technology, ontologies, simulation, product models and visualisation
- Malta: research concentrates on accessibility and associated legal requirements. It is being driven by legislation
- Chile: are not developing new technologies but are concentrating on maximising the benefits of existing technologies e.g. Microsoft excel, 2D modelling, 3D modelling. Major gap between large organisations and SMEs
- USA: some industry partners are trailblazing with nD (e.g. Gehry, Disney), but not mainstream. Some government projects have insisted on the use of 3D modelling

4.1 Discussion issues: barriers & drivers for development, the relationships between them, and implementation of nD modelling

In the same regional groups, participants were asked to consider the barriers and drivers for development and implementation of nD modelling. The discussions were recorded, transcribed, and analysed using both TextAnalyst and Adobe Professional to produce the cognitive map shown in Figure 14.

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In general, the groups all agreed that there were no specifically regional or national barriers related directly to the uptake of nD modelling per region/ country; the challenge of nD modelling is global and the barriers and enablers quite generic. The ease and speed of implementation, however, would depend on differences in government, politics and culture. Thus, a greater need for collaboration is paramount. Figures 11, 12 and 13 summarise the barriers and enablers identified by each regional group.

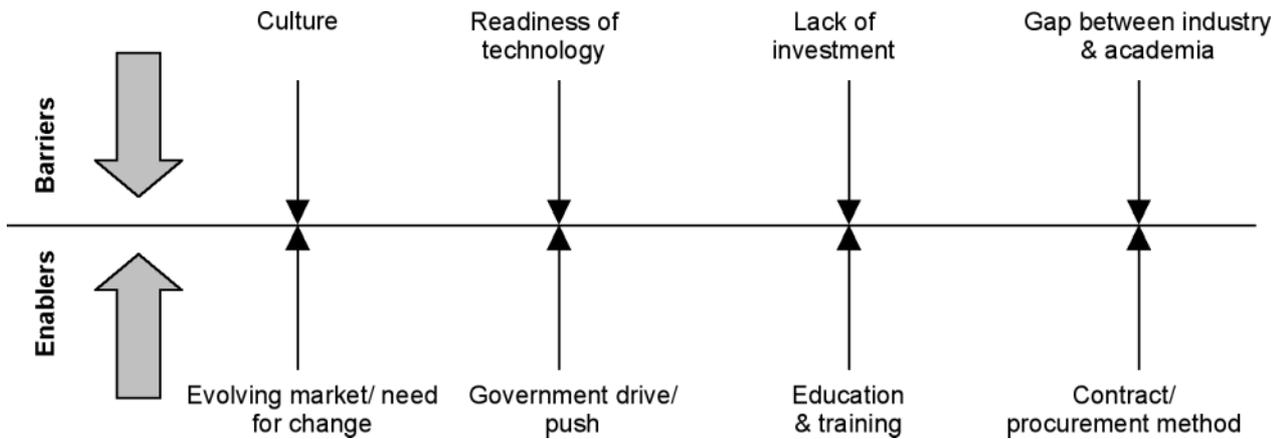


Figure 11: Barriers and enablers towards nD-enabled construction: the Far East and Australasia response

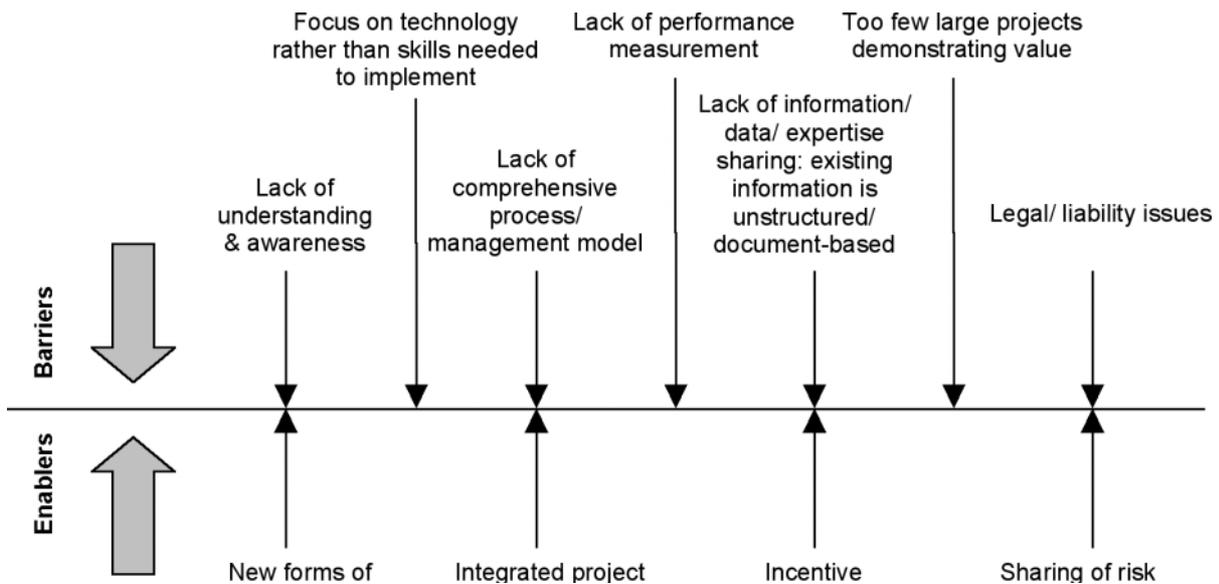


Figure 12: Barriers and enablers towards nD-enabled construction: the Central European response

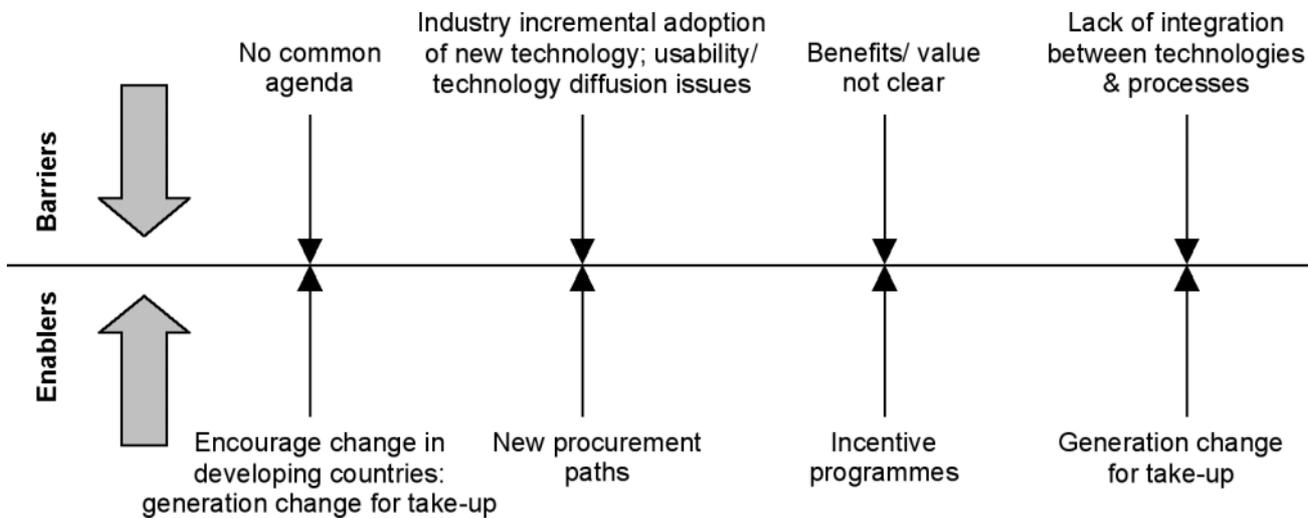


Figure 13: Barriers and enablers towards nD-enabled construction: Canada and the Americas response

4.1.1 Barriers

It was noted that there were various overlaps in the research and development being undertaken across the world. However, despite this, when the issues under general discussion were classified according to the regional groups, there were no overlapping issues common to each of the three regional groupings. The Far East group stated that within their individual countries, the problems were almost national, which implied a need for country-specific solutions, for example government policy. The only issue common to all regions was agreement that collaboration, more specifically the lack of collaboration, was acting as a barrier to the development and implementation of nD modelling. The need for more collaboration was seen as such a burning issue in the Far East-Australasia group in terms of priority that resolving this was crucial. The other two groups provided greater depth of explanation of what was needed to resolve this issue. It was stated that for true benefits to be realised, everybody concerned needs to get involved. However, it was thought that this would bring additional problems as this inclusive approach would mean incremental adoption of the relevant technologies which would create a ‘chicken and egg’ situation: there would need to be a critical mass of existing users of technology to encourage others and reap the full benefits of nD modelling. The situation was likened to the adoption of the telephone: what impetus would there have been for the first adopters of telephone technology when there was no-one else to call? The European group emphasised different aspects of collaboration and argued that there was a ‘need for working differently through programs for information sharing-not just the data but the intellectual expertise that creates the data.’ They argued that the modelling based approach that the nD project advocates encourages collaboration through the sharing of information and re-use of data and that this also helps facilitate a move away from the prevalent document based approach.

The Far East group questioned the readiness of the technology based on its current usage rates and the amount of development that was needed to make it ready for widespread use. Through their group discussions, they argued that although there is investment to overcome this barrier the software is not readily prevalent in the market currently. Part of the reason for this is the need for the concept of nD to be transformed into an actual product. An additional means for overcoming this barrier would be financial initiatives and the development of industry-university relationships was cited as a key requirement. The way that academia currently thinks about industry is providing an additional cultural barrier for this relationship. But it was not thought that these relationship barriers are insurmountable: the belief was expressed that industry is ready to change, and that improved education programs would provide the mechanism for this. However, this would require the involvement of the education providers and,

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perhaps more fundamentally, the industry managers who would have a role preparing the workforce in terms of exposure to the new ways of working and thinking that nD and object modelling requires. However, even with the best of intentions changes to education and training and the effects of these might take time to run their natural course based on circumstances we don't have as much control over as we might like. The Americas group argued that it might take a generation to see things truly change; in their group they had discussed how increasing familiarity with technology and the spatial concepts needed to work in 3D & 4D environments is not an easy problem to solve. They provided the example of 11-13 year olds in schools in the UK using very simple CAD like software in materials resistance classes and this was cited as an example of the start of the building of the pre-requisite frameworks in their minds about how to deal with 3D information. The usability of the software on the market will also affect the uptake of nD and the Americas group cited the ease of use of object CAD as opposed to 3D CAD as one example and argued that the lack of consistency of 2D means that its current availability and use is not as much of a benefit as it should be.

Whilst lack of education itself is currently a barrier, it was argued as important to make explicit exactly what the knowledge is that needs to be passed on. The European group argued that there is a lack of more general understanding of how things work in the present, never mind how they should work in an idealised future. More specifically, there is a lack of understanding of the practicalities of working in multi-disciplinary groups and the kinds of processes that will be both necessary to facilitate this and become a resultant outcome of such working. In a similar vein, there was a cited lack of understanding of nD process and the management of the data that would be required through the model's lifecycle and even a lack of understanding of the data required at each stage of the process for the necessary decision-making processes to occur. The reason for this was given as being due to the heavy document focus of the industry at this time. All of these barriers emphasise the importance of understanding nD and its implications for construction as a new set of processes first and foremost and before these new processes are mediated and supported by technology.

There were also contradictions between the groups regarding the barriers that they cited: whilst the Far East group thought the lack of investment in technology was problematic, the Europe group thought that there was too great a focus on technology in simulation terms. Instead, like the importance ascribed above to understanding the processes, data needs and management issues before the automation of the processes in a what-if model, they argued that the emphasis should be upon understanding the skills needed to assimilate nD into current working practices without the technology push. It was thought that there is too great a focus upon central databases and this is in contrast to the amount of development that is taking place on data and data standards such as STEP and IFCs which are being adopted. A further contradiction regarding technology emerged over the acceptance of the need for change: the Far East group argued that there was a belief by industry in the need for change, but the Europe group refuted this and argued that in their experience there was a lack of awareness of the need for change. In the case of the latter, this was tied in very closely with technology investment and with the group uncertain of the need for this investment when it was believed that we [the industry] already do things well. They did concede that this lack of awareness for the need for change was related to the lack of performance data that currently exist to demonstrate value – or lack of this – and this itself is a consequence of the lack of nD process. The lack of large, integrating projects demonstrating the potential opportunities was also cited as a barrier as was the lack of incentive program more generally. The Americas group called for a greater demonstration, and in the public domain, of the economic benefits that nD processes and technologies could enable. The Americas group pointed out that there might be a communication problem and this might be adding to the confusion over the need for change based on the way it is framing the problem: nD and more specifically nD technologies have been framed as a solution to a specific industry recognised problem, not as one of numerous solutions for its more generic problems. This situation is probably exacerbated by the cited lack of a dominant client, as compared to the aircraft industry. The use of the term '4D modelling' was also deemed to be too academic and that comprehension would be aided by talking about scheduling instead.

Despite the far-reaching consequences for all involved, the legal implications of the incorrect use of data in the public domain were only discussed within one group. It would be expected that this issue would be of major concern because not only can it have effects on an individual basis – problems of protection of professional boundaries – but worries about such problems then impact upon the organisation more generally and can detrimentally affect culture change, cooperation, effectiveness of team-working and so on.

4.1.2 Enablers & Drivers

In terms of the enablers for development and implementation of nD modelling, there was agreement upon the importance of new forms of contract with all three discussion groups citing this as a driver. The move from traditional to new contract forms – such as PFIs and PPPs – puts the contractor more in the role of a service provider, and this is differentiated from the role of the constructor. These new forms of contract were cited as providing drivers to exploit the available technology and other vehicles for integrated teams. This need is becoming ever more necessary as changing procurement processes are forcing people used to working in sequential ways to collaborate with one another. The new contract forms prevalent within the UK include PPPs, PFIs, LIFT (which is service, procurement and contractual arrangements for healthcare) and LEP (Local Education Partnership).

The only other issue that there was any agreement on, in so far that more than one group discussed them, was the need for a change in approach. The Europe group argued that a goal-based approach is needed which understands individuals' information requirements for performing their roles. This itself is dependent upon being able to understand the roles that people play in their (integrated) teams. But it was argued that a team-based approach should go further than fostering and encouraging collaboration and examining roles, and enable the individual to perform a role in any part of the lifecycle of the construction process. For this to be achieved, the correlations and relationships between roles and processes need to be understood. In contrast, the Americas group argued that the change in approach should move beyond enabling the provision of a product – in this case, the building – to the provision of a service and the corresponding change in mindset, for example the design and creation of space for an activity.

In terms of new approaches, a move towards enterprise agendas was also suggested and supported by industry champions whose role it would be to convince individuals of the importance of future visions and pathways for the industry of the future. This viewpoint was supported by the Americas group who argued that it is essential to establish the route that needs to be followed in order to reach our vision of the construction industry of the future, and that this needs to be the emphasis over the current approach of just selling the endpoint. The examples of the mitigators being used at VTT (Finland) and CSIRO (Australia) were given by the Far East and their role working at the interface between the clients or users and the applications that are required. As well as drivers from within the industry, the government was also cited as an institution that could and should influence change from outside the industry by setting standards and developing enabling infrastructures. In terms of other external organisations and institutions that could influence change, the Americas group were undecided whether there should be a reliance upon global players to act as the catalyst for change, in part because they were not sure if the conditions are right yet for change. This opinion, of the Americas group, contradicts the opinion of the Far East group that there is in fact a force for change.

The only remaining drivers for change, those that do not fit into the loose categories above, include the belief that there are actually better products on the market in terms of the available technology and the opportunities offered by educating the workforce.

4.1.3 Relationships between the Barriers, Enablers & Drivers

In order to establish further the relationships between these enablers and barriers, all transcribed texts were entered into text mining software, TextAnalyst, to help identify the key topics and relationships between them. As the groups were restricted to the identification of around 4 enablers and 4 barriers, there were various overlaps or linkages to the issues identified. On grouping the

issues, it became apparent that they centred on the infamous people, process and technology categories of modern innovation. With help of the text analyst, we are able to relate these key topics with early identified enablers and barriers and develop the following cognitive map (see Figure 14). The arrows in the diagram show the existence of a relationship between the topics connected and the greater the number of linkages from a given topic, the more important that topic was deemed to be. With this in mind, 'lack of process/ management model' is a more significant barrier as it is connected to 4 further topics than 'lack of performance measurement' which is connected to 2 further topics. Additional gravitas to a topic is provided by the existence of double headed arrows which show that the dependency of the relationship is two-way, for example whilst the sharing of risk mechanisms was seen to have a causal effect upon enabling new forms of procurement, the relationship was not bi-directional and so it was not believed (or at least not stated) that new forms of procurement could encourage the sharing of risk mechanisms.

Whilst care must be taken with the conclusions that are drawn from qualitative data categorised and analysed in a quantitative way, general trends based on the numbers of linkages and significance of the topic linkages can be established. 65% of the barrier topics had at least one bi-directional linkage to another topic, whilst only 36% of the enabler topics had at least one bi-directional link. The barrier topics also tended to have a greater number of bi-directional links which superficially at least, shows a tendency to recognise the connections between problems rather than the positive inter-relatedness between drivers for change. This finding is probably more to do with years of experience dealing with the various barriers and difficulties inherent in the industry and the uncertainty of the practical realities of the industry of the future, than being due to a cohort of individuals prone to negativity about their powers to implement change!

The barrier topics with the most connections were lack of understanding and awareness (5 links), incremental industry adoption of new technology (usability/technical issues, 4), unclear benefits/added value (4), too few projects demonstrating value, lack of comprehensive process/management model, gap between industry and academia, and lack of integration of technology and technical processes (all 3 links). The most significant enabler topics were people and culture, and process, two of the generic themes with 5 connections apiece, followed by government drive/push. Whilst ascribing weightings to these topics does not allow us to understand the issues discussed in any depth, it does determine consensus on the issues that need prioritising due to the impacts and relationships they have with other issues. For this reason, such a cognitive map can help us to determine the main concerns that a road map for future research should embrace.

4.1.4 Actions and Policy Actions for Change

During workshop discussions a number of actions emerged, some of which are related to policy. The mind map in Figure 15 shows the actions for change and some of the related sub-issues. It also shows some of the more general discussion issues that are more relevant to providing the context for policy and change. The main policy actions identified included:

- Promote nD modelling and prepare the workforce through education and training programmes
- Promote nD modelling through champions, thus to increase awareness of and drive the nD agenda forward and to increase collaboration amongst developers
- Develop and apply new forms of procurement that foster nD
- Develop technology transfer agencies to act as incubators for 'spinning out' prototypes
- Awareness
- Pan-European projects/ vehicles

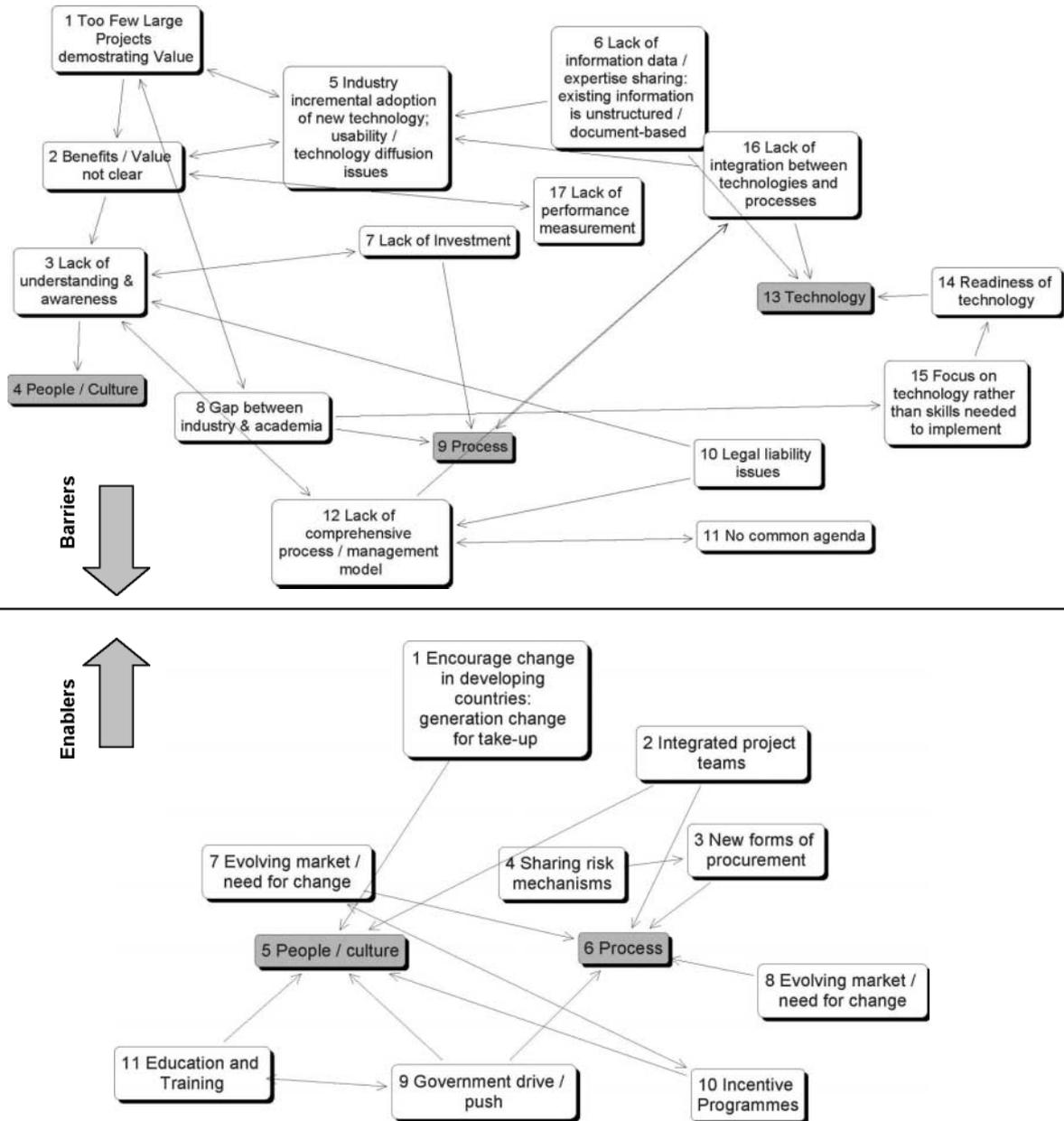


Figure 14: Cognitive map illustrating the barriers and enablers towards nD-enabled construction

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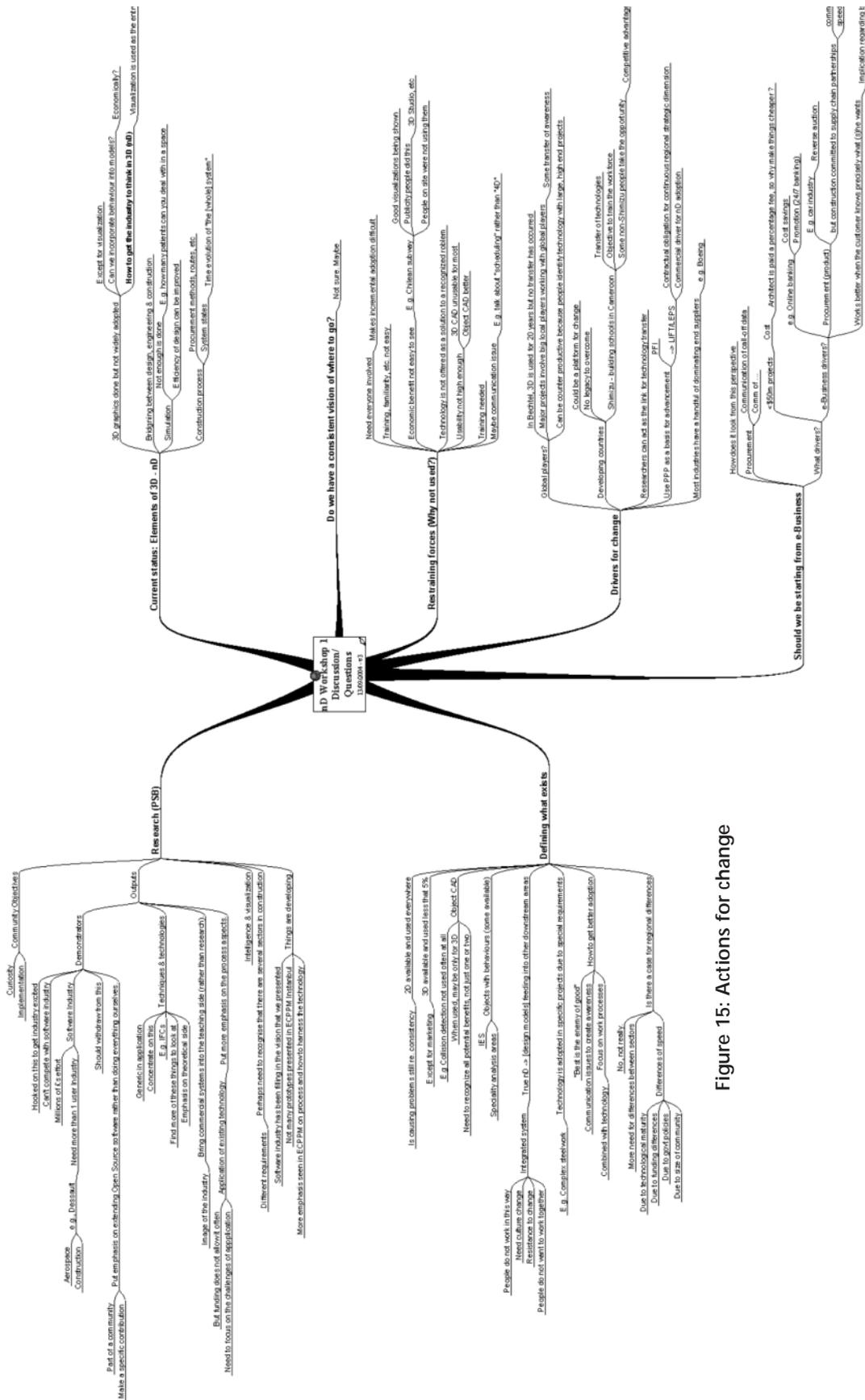


Figure 15: Actions for change

5.0 nD-Enabled Construction Projects

During day 2 of the 2nd international nD modelling workshop, participants were divided into 3 groups to discuss the barriers, enablers and potential solutions to a number of key issues pertinent to the uptake of nD modelling at the project level. The issues identified at the 1st international workshop fell into three categories and so for continuity purposes, these categories were retained:

- Process and data
- Education and training
- Interoperability

The results are summarised in the following section.

5.1 Process and data

The principal topic of discussion for the process and data group concentrated on the lack of a project business model within an organisation (see Figure 16). It was identified that large organisations, around the world, were in general, aware of the need, and are in fact moving towards a single building product model. Yet project business models to support its adoption were not in place. This is somewhat paradoxical since the value of nD modelling for the organisation can be questioned without the presence of such a model. Thus, it became apparent that there was tension and imbalance between industry and organisation levels of nD modelling.

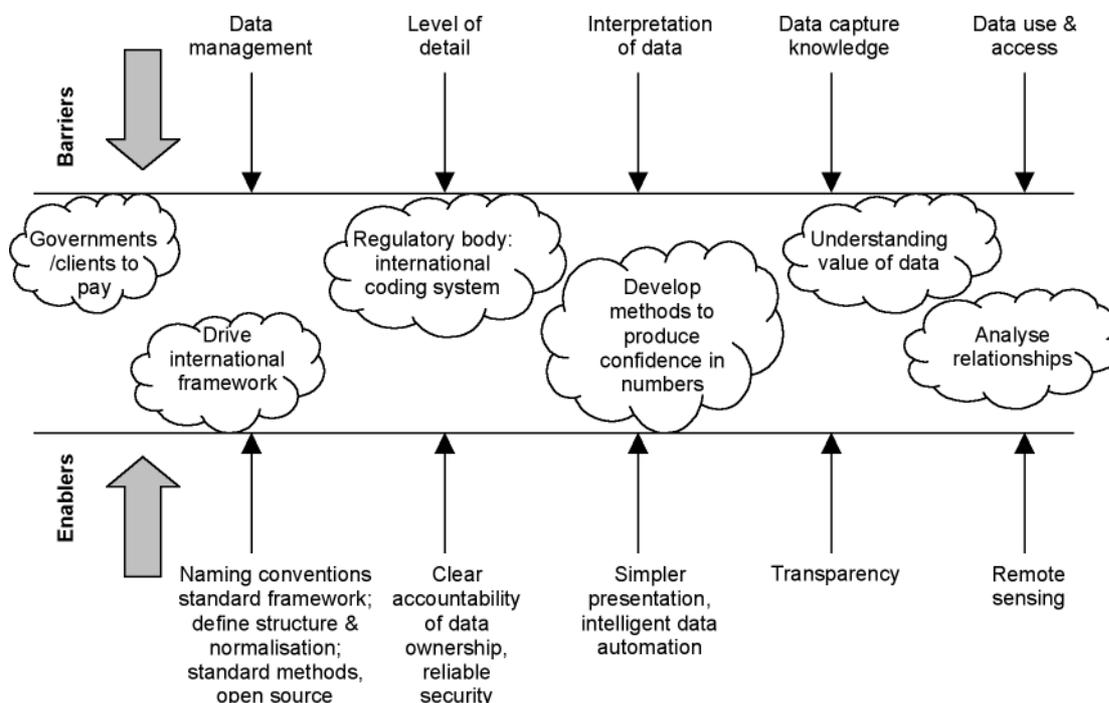


Figure 16: Process & data - barriers, policy actions and enablers towards nD-enabled construction

Process inconsistency was also noted as an inherent barrier. What was foreseen to be required is a set of comprehensive data standards/ regulations that would be transparent. Moreover, it would take the form of a sophisticated data management system that enables the sharing of risk and ownership for the entire project team – thus, the legislative structure of construction will have to

change. Data accountability would have to be inherently built into such a system, possibly embedded within the process. Therefore, it would be clear where the data was produced, who had contributed to it, and so forth – it would be an evolutionary accountability system. The data would be intelligent; it would automate itself into specific data sets. In order to achieve this, the data must be normalised and organised in such a way that the relationships between the different sets would be clear. Due to the complexity of the proposed data structure, it is perceived that an international regulatory body is required to drive this framework forward.

5.2 Education & training

The education and training group identified a list of barriers and enablers related to nD implementation at the project level (see Table 2).

Barriers	Enablers
Rapid changes in technology: e-learning platforms age quickly	Modular approach to material preparation
Understanding needs of industry, not desire of the industry	Close liaison with industry – course advisory committees, visiting professors, networks, etc
Pressures (external) on universities to commit to education & training	e-learning may reduce demands on physical resources
Changes in society, lifelong learning, mature age students, etc	Flexibility in delivery – anywhere, any time, mobility
Wider participation in education training	Ability to model users & their skills and needs; multi-lingual text for same visual material; different material for different needs based on the student ability; provide alternative materials for different learning styles and content
Provide flexible & independent learning; experience gap between industry & academia	e-learning will provide opportunities for work/ study flexibility and improve quality
Re-inventing the wheel; lack of 'indexing/ retrieval' of standards	Shared modular 'learning objects'; definition of key words/ metadata
e-learning costly to develop	Standardisation of e-learning
How to disseminate nD education material in different styles	Build repository of learning objects
Poor quality of teaching materials	Shared learning objects
How should education change to gain maximum advantage from new learning technologies	Maintain links with educational researchers & industry
Recognition & reward of effort in preparation of materials; recognition of 'online' courses; willingness to share	Change of culture

Table 2: Education & training - barriers, policy actions and enablers towards nD-enabled construction

The most pertinent issue for the education and training group was understanding the needs, and not the desires, of the industry. The solution posed was to establish strong links with industry to review the content of the nD modelling research agenda – having members of industry on course advisory committees, as visiting professors, involved with networks etc. Moreover, there must be succinct mechanisms in place so that the new tools and techniques can be fed forward into organisations easily – the teaching material must reflect the technology diffusion issues.

The infamous question of bridging the experience gap between industry and academe also emerged. Professional development schemes – which would be free to SMEs – were noted as a possible solution to continually retrain the workforce as and when new tools and techniques emerged. This, it was perceived, would help to break cultural resistance, the biggest barrier to change. Problem based case

study learning should be used as the medium for learning; ideally with architectural and engineering students collaborating on the same problem (interdisciplinary learning) – thus encouraging stakeholder involvement, team play and demonstrating the integral need of nD modelling. Shared modular learning objects were proposed as a solution, which will also combat the ‘re-inventing the wheel’ issue. It was perceived by the workshop participants that the modules have fine local granularity. Thus, the course should be broken up into script components that can be mis-matched between a number of courses. This would also inevitably reduce the cost of developing e-learning tools. Further, these tools would be language independent, and be of several learning mediums, e.g. visual and text.

5.3 Interoperability issues

Interoperability was recognised as a pertinent barrier to the implementation of nD modelling. However, the work undertaken by the IAI in IFC development was noted, but more research was required in the areas of standards formation. Other integral technologies were also discussed; XML was favoured by the workshop participants as an overarching structure, but they were uncertain that it was able to cope with the large datasets necessary for model building (see Figure 17). A combination of a single model server and semantic web was posed as a possible solution that would be service orientated. Moreover, the technology must be linked to the process – a research area which has scarcely been tackled by the research community to date. Most importantly, the tools developed for nD-enabled construction must be simple, reliable, and easy to use. The workshop participants all agreed that they were working on these issues, but were uncertain about the scalability of their models. This, again, is an area which needs to be investigated.

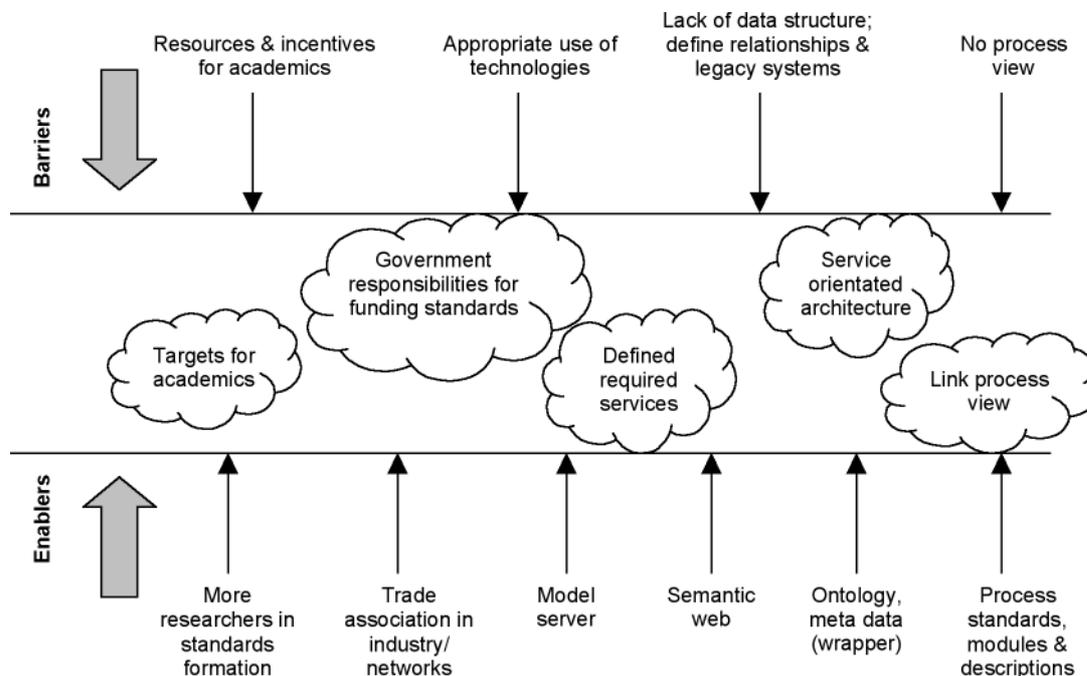


Figure 17: Interoperability - barriers, policy actions and enablers towards nD-enabled construction

6.0 Skills and Competencies for the Future

The final session of the 2nd international workshop concentrated on the future of nD modelling. The workshop participants were asked to paint a scenario of where they realistically saw nD modelling in 4 years and 8 years time. Moreover, what specific skills and competencies would be required to achieve these goals? This, thus, contributes to the future research agenda. Initially this was done in three separate groups. The groups' future scenarios are summarised below, the results are used to bring together a combined international research agenda:

Scenario 1:

With these skills...	... and these actions...	... in 4 years we will...	... and in 8 years we will...
More and better computer modellers	Continuous development of process and data standards	Sophisticated object model	Mature new devices
ICT and industry liaison skills	Create multi-tiered layers of information for building and urban data	Some level of integration	New design paradigm
Joint industry/ academic workers	Expand and co-ordinate nD network	New devices	New processes
	Partner with ICT industry	Initial industry uses	Intelligent nD-modelling
	Educate but also understand industry	Usable project server	
	Be positive		

Scenario 2:

With these skills...	... and these actions...	... in 4 years we will...	... and in 8 years we will...
Researchers capable of developing conceptual framework and industry deployment	Full requirements definition leading to a conceptual framework	Robust, tested, unified nD framework	Benefits clear to all clients and government
Industry people interested in deployment	Develop future processes for new ways of industry working	Early commercial implementation	
Synthesis of design and build	Develop and follow road map	Serious demonstrations of business case	
Skills to develop new processes	Inform the business case	Broad deployment amongst industry leaders	
	Development of pay as you go software		

Scenario 3:

With these skills...	... and these actions...	... in 4 years we will...	... and in 8 years we will...
Business skill	Need a driving force – look to key clients especially government	Wider use by 'outsiders' in determining 'value' on projects	Part of an 'enterprise' server
Training for using nD management	Market nD as a means of demonstrating value	97% 2D => 30% 3D	nD use is mainstream
Technology => pressure on employers	Link nD to business/financial users	Use in all government major projects (school to healthcare)	nD integrates other technologies. Eg. E-business with fluent user interfaces
HR, new roles => new skills required		nD part of 'model' server	

All three groups' discussions were also entered into the text-mining tool for further analysis to identify the key themes discussed in the workshop. The software established the following key themes and relationships between the themes. The number in the bracket following the key theme represents its relative importance weighting as generated by the text mining tool – the higher the rating, the more important the issue:

- Skill and Competences (99)
- Industry Deployment (99)
- Conceptual Framework (99)
- Technology (78)
- ICT Industry (78)
- Implementation (70)

These issues are represented in the following diagram (see Figure 18) based on the relationships indicated from the software. Although it is very high level, it is quite consistent with the summary from each group. This helps us identify the key theme across all three groups based on the detailed discussion.

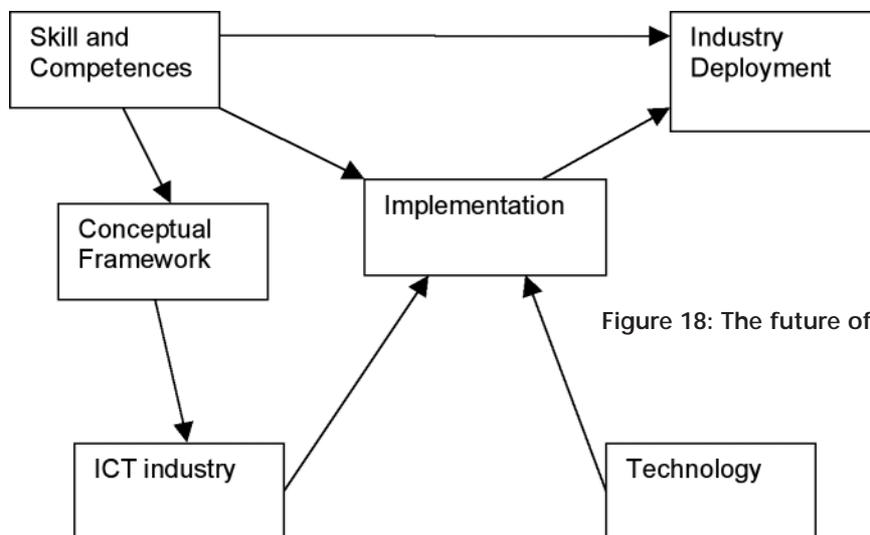


Figure 18: The future of nD modelling

The groups' future scenarios were then discussed and debated by the workshop delegates as a whole to see if a collective way forward could be developed. To be able to answer the rhetorical question of where nD development should be, the differences between the level of adoption, inter-operability of technology, level of technical maturity and migration path had to be recognised (similar to a capability-maturity model). Thus, if we know where we want to be, we can identify the mechanisms to get there, and from this we can synchronise technology and processes in a way to achieve the aims.

The workshop participants firstly agreed that nD technology is ready (see Figure 19), therefore, why wait 4 years for full adoption? It was understood that the majority of construction organisations across the world (primarily SMEs) were still working with 2D CAD, and although there is ample evidence of 3D CAD, many organisations were not using it succinctly but merely as a marketing aid. Therefore, it was suggested that maybe effort should be targeted towards getting all organisations to fully use 3D CAD, and not push nD until we achieve this milestone. It was agreed that the future of companies lay at the company level. At the moment

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nD has been a 'push' technology – developed by a small group of champions and pushed out for wider industry uptake. For companies to widely embrace nD, it needs to be of the interest to company decision makers. These are the people who make the decisions and can create the 'pull' needed for the technology to be fully adopted. Pull can also be created by funding and client bodies wanting to use the technology. It was identified that a possible target should be to have nD-modelling adopted for ALL major, governmental programs in 4 years. Initially it would be immature functionality wise, but once adopted, it would become the driver for the 8 year period to achieve e.g. better education, healthcare and prison facilities. The key here would be to use nD-modelling techniques as a way of obtaining and demonstrating 'value for money' that is so often cited as essential in government programmes. Notably, this approach is NOT incremental and is foreseen to be necessary for global adoption.

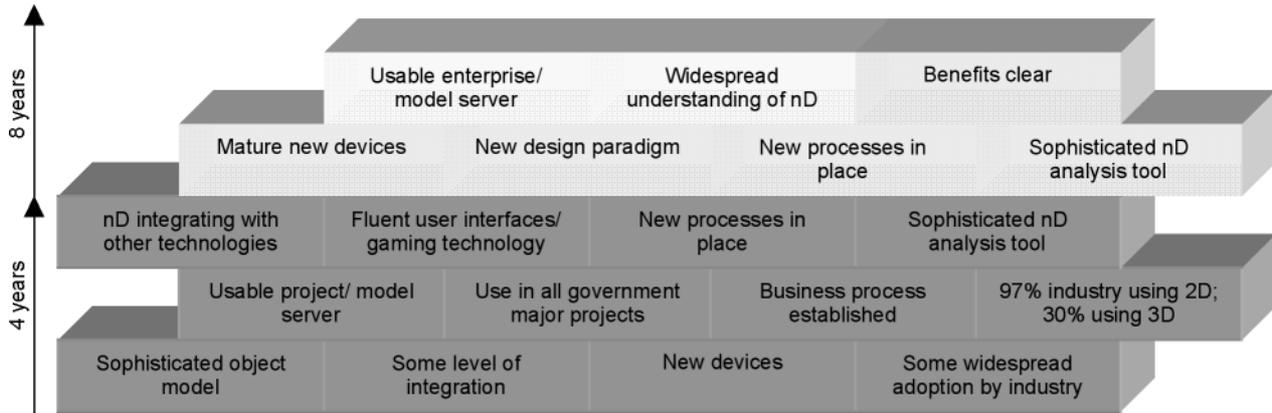


Figure 19: nD modelling – where in 4 and 8 years?

It was considered of crucial importance that nD must be integrated within the business model: without any value equations highlighting the business benefit nD will never be adopted. It was predicted that there will be major developments in e-commerce, and that this would prove to be a major driver for nD. The Internet is changing the way in which construction organisations operate (as evidenced through document management systems) and this would prove to be the impetus for greater co-ordination and communication of construction information. Over the next 4-8 year period it was predicted by the workshop participants that document management systems will migrate into data model management systems (model servers). These model servers will be apparent within the 4 year time period, but in the 8 year frame, these will become 'enterprise servers'. These enterprise servers will not only be organisation-wide but be moving towards integration across the whole supply chain. This target must be recognised now as a goal and must be reflected in today's technological developments.

Other issues identified that could push the uptake of nD include lifecycle issues, such as climate changes and energy use of buildings could be a major driver for the uptake of nD modelling. In addition, gaming algorithms to allow interfaces to be easier and more fluent to use can also be a development that can push forward the use of nD modelling. Thus, visionary project managers and software engineers with business skills are required. nD is also placing a huge demand on the way in which existing professionals are currently doing their job – process management, information management, boundaries are becoming blurred. Therefore, there will be changes with new roles within companies. The skills have to move up the value chain – away from the drudgery of drawing to adding additional value (not a re-educating exercise, but re-skilling exercise). Multi-skilling will also be necessary to make this work; if you cannot appreciate values of other's roles, you cannot offer data in the right format for it to be useful.

7.0 Workshop summary and roadmap for nD modelling

The results of this workshop and the preceding events are combined to produce a roadmap of the future. The wide range of participants from over 15 different countries has enabled the roadmap to be of a global outlook.

In providing a précis of the main discussion points over the series of national and international workshops, two main issues emerged: there is an imbalance between the supply and demand of nD modelling, with the former greater the latter, and there is little discussion about technology. With regards to the imbalance in supply and demand, there are a number of significant points, namely:

- Supply is over-developed
- Demand is under-developed
- Who needs nD modelling?
- Who benefits? Who loses?
- The research community are developing faster, smarter, cheaper, easier tools and more of them, but industry is not readily adopting
- The user communities are saying 'not yet', 'not now' or do they not understand the need?

Thus, the immediate question presented itself, namely 'if the industry is not crying out for nD modelling, then who are we changing construction practice for?' This stance was not foreseen as a negative demarcation as historically, innovative development – and thus, developments that will reap radical improvement/ performance gains – has not always been successfully predicted, for example, when facsimile machines were first launched the need was not apparent. It was not until they became widespread that their true benefits were realised and they are now essential in every modern office.

Although the majority of nD modelling uptake can be found in large construction organisations, in Australia there were several SMEs who had adopted the technology. This led to the discussion of why the uptake of nD technology is slow. Is it merely a change in mindset that is required or is the industry saying 'not yet, no now, maybe at some point in the future'? Innovation theory can be used to predict and explain this imbalance between supply and demand and it also provides an explanation of how the associated problems can be addressed. This was summarised in the technology development strategy diagram shown below in Figure 20.

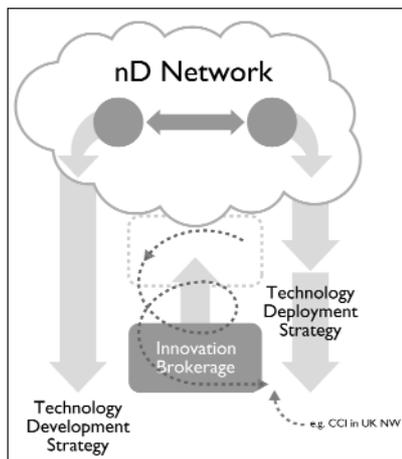


Figure 20: Technology development strategy

It is clear that, despite the great progress that has been made, for nD modelling to become standard practice there is still much to be done. There was widespread agreement that shaping the future requires much more than the refinement and development of existing technology. In part, the problem is typical of innovation theory. Future work must focus on technology deployment and innovation brokerage as well as technology development. Strategic issues need to be tackled as well as project focussed issues. Many of the desired landing places for the world of nD require a wholesale change in the way that the industry works and is organised. The means by which it would be possible to bridge the gaps between developing and developed countries, and newcomers to the industry (clients & service providers) compared to the established companies, and their respective usage and adoption of technology, was demonstrated by the concept of 'technology leap-frogging.' This is illustrated in Figure 21.

The second major issue that emerged from the workshop was that there was actually little discussion about technology in itself. This was at first surprising finding given the heavy presence of technical developers in the workshop groups. What emerged was that work was needed in the areas of psychology, organisation, social issues and culture – issues centred more around deployment and migration as opposed to technology gaps. Therefore, it was agreed that for widespread nD modelling to occur, these issues must be immediately addressed. From a technical stance, concentration should be placed on technology deployment and the migration path. It was envisaged that it would be preferable to:

- move to a role-based rather than discipline-based approach
- understand process at an atomic level
- all work in the same large organisation

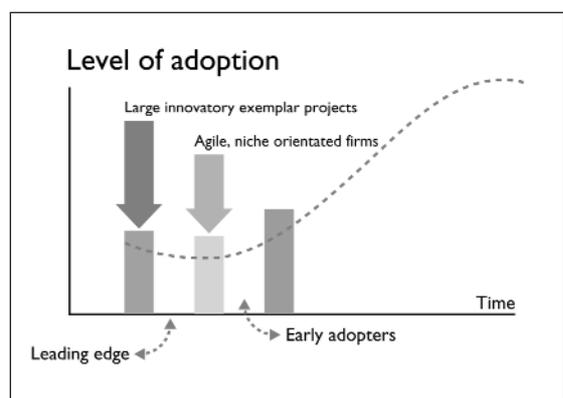


Figure 21: Technology leap-frogging

It was agreed that in order to achieve this, champions were required to educate the industry on the benefits of nD modelling. It was noted primarily that the structure of the industry was a prohibitor of the uptake of nD; other industries have integrated supply teams who were involved in driving change. In addition, innovation also occurs at bad times; a recession may be a major driving force for uptake. However, education also drives change – e.g. PPP and other government initiatives – so perhaps such a drastic driver is not needed. Other industries have been working in this nD way for quite some time and the example of new kitchens was

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given: a plan can be created instantly, and can be costed automatically and then bought. But for the construction industry and its many stakeholders, who will pay for the information that it put into the model? And how will liability issues be solved?

The following section presents the nD modelling road map for the future which divides itself into a:

- nD modelling framework
- and a nD modelling technology framework

7.1 nD modelling road map

The following road map is proposed (see Figure 22). It highlights areas of research over the coming years. The diagram helps illustrate and summarise the futures that were suggested during the workshops. The findings of the workshops were clustered into themes and are presented as repertory grids in the final road map. Whilst this report highlights the barriers and opportunities of implementing nD modelling in the construction industry, the road map presents a research agenda for global nD uptake.

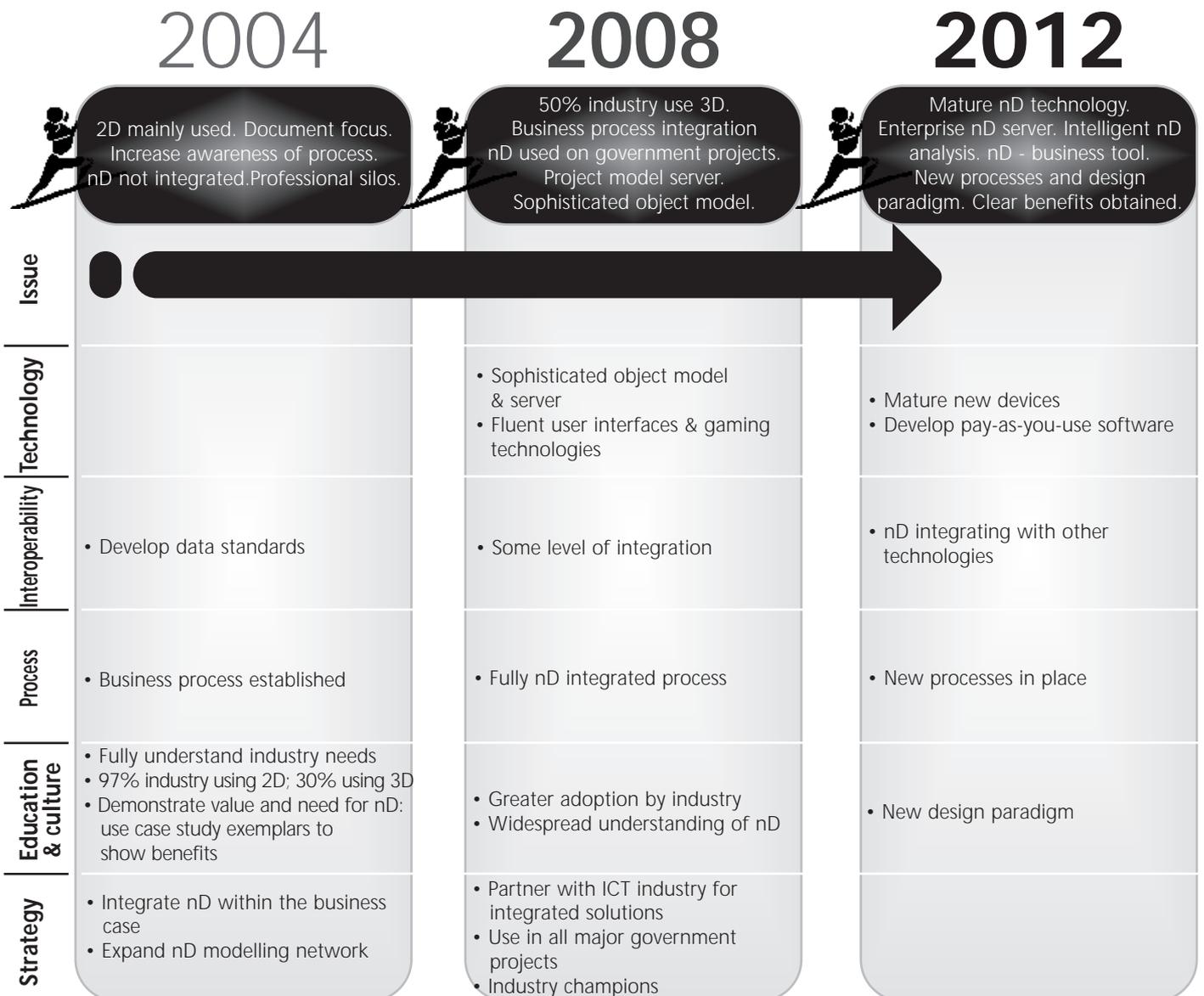


Figure 22: nD modelling road map

The diagram above mirrors the overall discussions generally in showing that, in order to reach the final nD destination landing place, the road map has to overcome more obstacles that are human and organisational in nature. Barriers of this kind have been cited in all the workshops as most problematic in nature due to the unpredictability of the behaviour of groups and individuals, and the multiple effects that that behaviour can have. Whilst the development and uptake of technology is also unpredictable, the specific issues do not persist in the same way as for the social aspects. More specifically, whilst we now have increasingly more sophisticated ways of remaining in touch as technical barriers continue to be broken down – telephones, fax machines, mobile phones, video-conferencing, wireless laptops, Blackberry multimedia tools – the social problems of their usage in the workplace for collaboration and decision-making remain. This general pattern was found in the nature of the drivers and barriers for nD implementation that were identified in each country: in Australasia 1 in 4 identified barriers were technical, in Central Europe it was 1 in 7 and in North America it was 2 in 4. Analysing the barrier topics by providing them with weightings based on the number of linkages showed that the most significant topics were social in nature, more specifically ‘lack of understanding and awareness’, ‘incremental industry adoption of new technology’, and ‘unclear benefits/added value’. The inter-connectedness of these barriers with others also means that, not only should they be prioritised, but that resolving these issues will have many knock-on effects to help resolve other barriers. Similarly, all of the identified enablers were social or cultural in nature which emphasises their importance as a mechanism for bringing about technical as well as cultural change. However, unlike the barriers, there were few relationships between the enablers identified which indicates that the enablers may be more independent of one another and that, therefore, there are likely to be few beneficial knock-on effects associated with facilitating the development of any one driver. The persistence of issues of this type being cited as a barriers and enablers is problematic as there seems to be no improved understanding as to how they can be resolved. Education/ culture and performance measurement, and business case and process were established at the 1st International nD workshop in early 2003 as being the biggest challenges and 1st priorities respectively (see Lee et al, 2003 for more details) and no examples were given, 18 months later, as to how these previously identified problems were starting to be tackled. As an interesting comparison point, more emphasis was given in the first international workshop in overcoming technical issues such as implementation/integration and data issues.

Despite this though, there are a number of contradictions and these are likely to result in slightly different pathways to, hopefully, the same goal. These contradictions had a more technical bias: whilst one region argued the lack of investment in technology is a problem, another region thought there was too much focus upon technology. Likewise, one group argued for the strong belief in the need for change, another stating that there was a lack of awareness of the importance of this. Whilst it was accepted that the barriers and enablers of nD are global and not regional, there are still important differences in the impacts that regional culture, politics and government can have. In focussing in the 2nd International workshop upon the implementation problems and practical actions for change, it is hoped that the message of the requirement to understand and change the social and cultural underpinnings before technical implementation is driven home and a significant part of this involves making explicit what it is we need to know, for example establishing good practice exemplars. As the ideas and work related to nD Modelling are developed in different contexts and on different scales, e.g. the nD Modelling components in the INTELCTES pan-European integrated project, it might be that the practical benefits and added value of the concept becomes clear.

7.1.1 nD modelling research framework

In order to action the nD road map, the nD modelling research framework illustrates key focus areas. The nD modelling prototype so far (see section 2.0) stands as a what-if analysis tool that enables the impact of various design perspectives to be highlighted. However, the road map and the development of the nD prototype identified a number issues that need to be accommodated, such as scalability, different actors/ users etc, and it should truly mimic the design process. Architects unconsciously think about buildings

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in several ways while they are designing (adapted from Lawson, 2004):

- A collection of spaces which may be indoors, outdoors or hybrids such as courtyards and atria
- A collection of building elements such as walls, windows, doors and roofs
- A collection of systems such as circulation, structure, skin, service
- A collection of voids and solids, as from an architectural perspective
- A series of layers such as floor levels

When designing, they oscillate without noticing between these descriptions of the building, thus adopting parallel lines of thought. In a similar way, if we are to fully adopt the nD concept we must first understand the human processes of designing so that it can be mimicked in the technology that we develop. We must simultaneously look at (see Figure 23):

- **Embrained knowledge:** encompassing the viewpoints of different stakeholders/ users of nD such as the client, architect, access auditor etc in terms of both feedforward and feedback of design information. Thus, it is actor configurable
- **Process knowledge:** so that it can harness and be harnessed within various operating schematics such as the business process, operation process etc. Thus, process configurable
- **Encoded knowledge:** ensuring the design conforms to the respective design standards. Thus, it is code configurable
- **Embodied knowledge:** enabling the scalability of use, covering a single building to city and urban use. Thus, is scale configurable

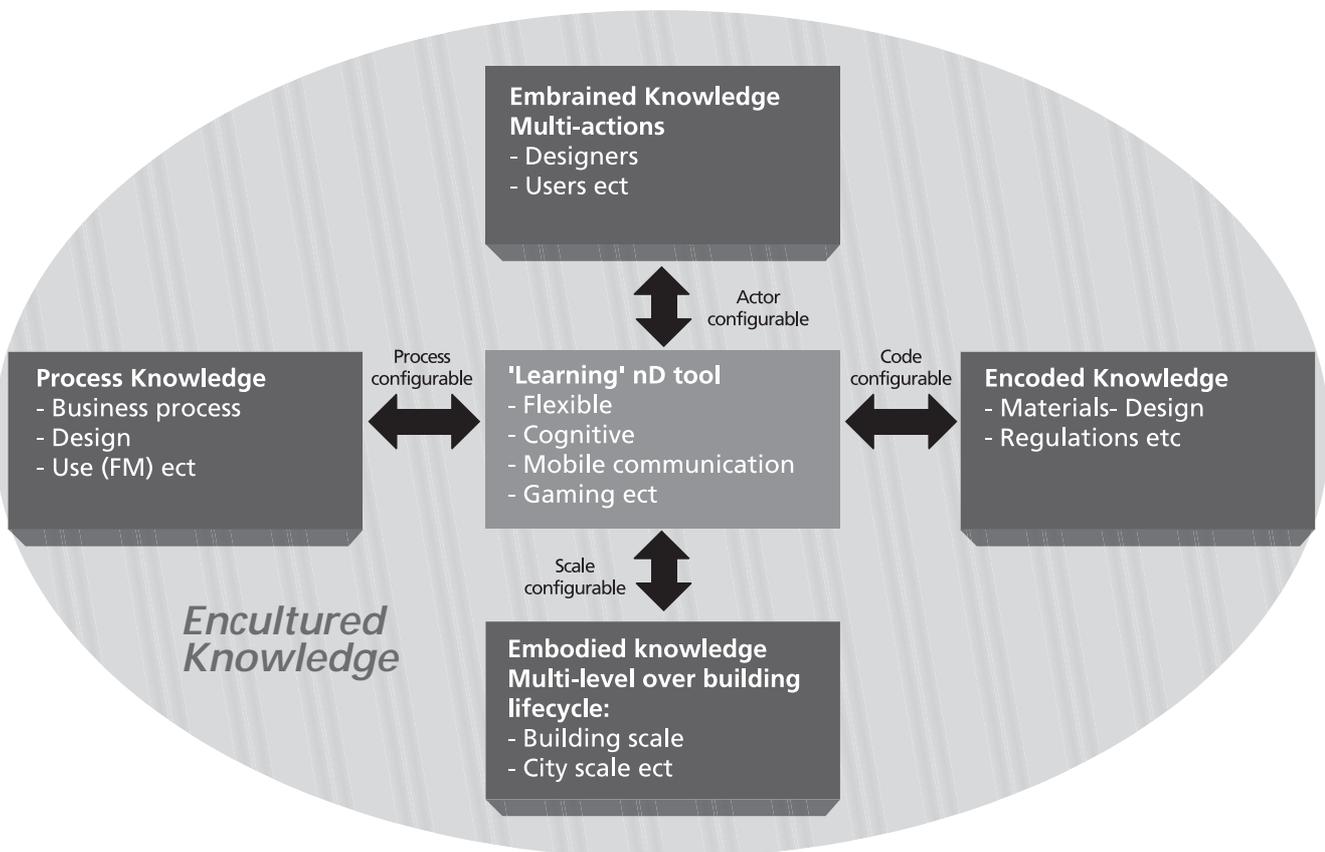


Figure 23: nD modelling research framework

Framed in these terms, this curious relation and messy mapping between problems and solutions in design is one of the reasons why architecture is not only challenging for the designer but also often so impenetrable for the client. Moreover, in doing so, the nD tool should be self-learning. The embrained, process, encoded and embodied knowledge can each in turn be self-improving, more intuitive and pro-active and thus, formulates encultured knowledge.

7.1.2 nD modelling technology framework

As a result of the 5 workshops, a new technology framework (see Figure 24 and 25) emerged to support the nD modelling road map (see Figure 22). The framework provides the architecture for different domain applications which are directed by business process and is based on a service oriented platform supported by various technologies such as visualisation, decision support and analysis:

- The technology framework is based on the service oriented architecture (SOA). The participants of the workshop recommended that a common framework and interface should be provided so that applications from different domains can work together. Furthermore, common technologies such as visualisation and decision support should be part of the platform. SOA is a technology which can be deployed to support this platform. According to the World Wide Web Consortium (W3C), SOA is 'A set of components which can be invoked, and whose interface descriptions can be published and discovered'. The nD modelling framework should provide the common technology components and data access as services for each domain application.
- It was also recommended that the framework needs to be driven by the business process. Different applications will be used at different stages of the process and the data requirements will be different. The process control mechanism has to be in place to ensure the right data can be served to the right application.
- The services include technology service and data service. The technology service provides common technologies, such as visualisation of the building data, multi-aspects decision support, data analysis for thermal, structure etc and process control mechanisms. The data service provides the data access to two types of data sources, building data and domain data. Building data can be described as data definition and representation of the building model and it has to be supported by interoperable data standards such as IFCs. Domain data is specific data related to each domain such as regulations for building accessibility, weather data for energy simulation, etc. Currently, these two data sources are often not linked. It is suggested that research has to be done to integrate the two data sources through developing common concepts (ontology/ classification/ dictionary).

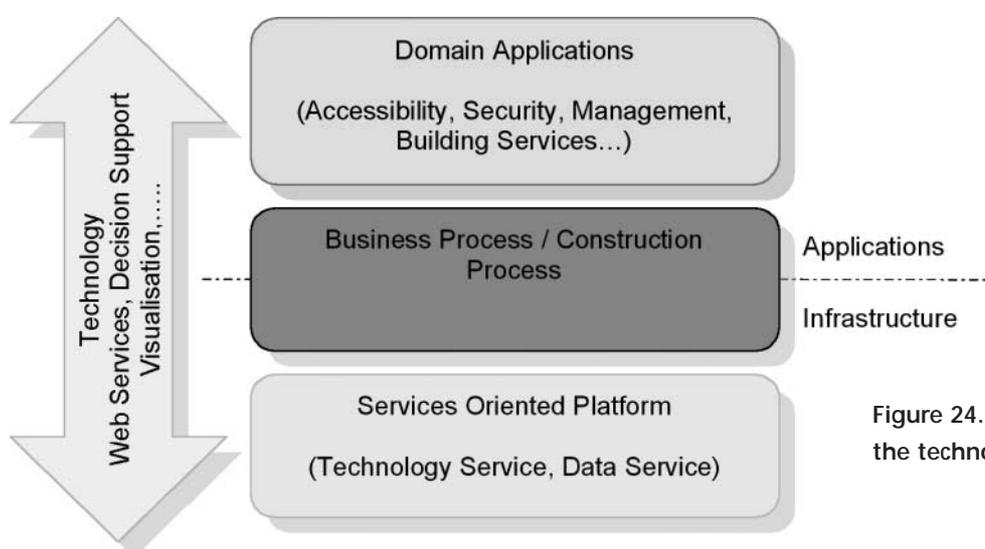


Figure 24. The overview of the technology framework

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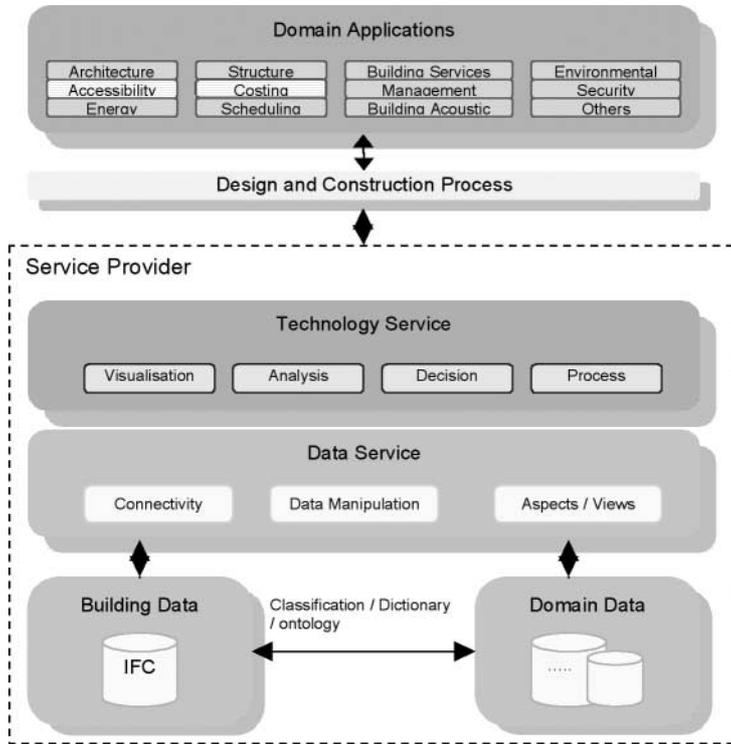


Figure 25: nD modelling technology framework

8.0 Summary

This report summarises the progress of the 3D to nD modelling project and the output of the 2nd international nD modelling workshop, before cultivating the findings of 5 workshops to form an nD road map of the future. This report has contributed to the ongoing debate on the value of nD modelling and as such, presents a research and a technology framework. The research team hope that the road map will be used to formulate agendas towards global nD-enabled construction. The research team are currently working to develop new research initiatives in this field and would welcome collaborative involvement.

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Appendices

Appendix A: nD related papers published thus far Refereed Journal Papers

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- Aouad, G., Lee, A. & Wu, S. (2004) nD Modeling in Construction: An Integrated Approach. Submitted to Architectural Engineering & Design Management
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Appendix B: nD related funding generated thus far

Assess the use of ICT in Urban Planning from DTI under the New Horizon Programme to (T Fernando)

2005 project funded by the National Science Foundation of the USA for collaboration between the Intelcities team and a group of academics lead by Albany University New York. (\$90,000)

2004-2007 Virtual Environmental Planning Systems, (project E109) 2004-8, Led by the UK Environment Agency, funded under Interreg IIIB (total project value 4.2 million Euro. Funding controlled by Andy Hamilton, as Salford lead: 517k Euro from EU INTERREG + £70k from the Office of the Deputy Prime Minister - ODPM).

2004 -2005 INTELCITIES. This 11.2 million Euro project of 75 partners including 19 major cities (Rome, Helsinki, Manchester, Marseilles, etc..) and 20 IT companies (IBM, Nokia, Cisco etc..) brings 794,534 Euros (£556,174) research funding to the university.

2002-2003 INTELCITY was a one-year RTD road map project funded by the EU DG Research Information Society Technologies (IST) Programme (350 Euros) exploring new opportunities for sustainable urban development (SUD) through intelligent use of Information and Communication Technologies (ICTs). (350,000 Euros)

2004-2005: 'Salford (UK) – China: towards global harmonisation of construction research.' Awarded £11,400 from the EPSRC for travel grant. (£11,400)

2005-2006: 'Designing fit-for-purpose schools: enabling student participation in the design process.' Awarded £69,816 from the EPSRC for 2 years. (£69,816)

2002-2007: 'VivaCity 2020' – in conjunction with UCL, London Institute, Sheffield Hallam University and Sheffield University. Awarded £2.75m from the EPSRC for 5 years. (£2.75m)

2004-2005 FM Database development for BNFL & Bucknall Austin (Industrial Contract, £30,000)

Appendix C: Research Papers

The ARK Smart Information System

M.C. Bacon

ARK e-management Ltd, UK

Abstract: This paper provides an introduction to the ARK Smart Information System (SIS). It describes the business context in which the technology was conceived, and how the system addresses those needs. It outlines the important technology principles, and the benefits of adopting such principles in a business environment. Finally it discusses the relevance of the technology to the thinking behind the 3D to nD project.

Keywords: Collaborative working, Information management, Interoperability, Open standards, Process management, XML

Background: The original idea for the ARK SIS arose in 1997 whilst the author was developing ideas to demonstrate how client organisations in the construction industry could exploit the potential of interoperable technologies in their businesses. At the time the author was chairman of the Client Business Process Group of the International Alliance for Interoperability (IAI), where he was also a director on the board of the UK Chapter.

The objective of the client group was to study the information issues relevant to the briefing of a new facility. The authors' proposition was that in order for such businesses to realise the value of interoperable technologies in their businesses, they needed to understand foremost what information it was that they needed as well as where that information existed. In the authors' view the briefing process for a new facility was ideally suited for exploring this issue, because the creation of a project brief involves substantial information collection and co-ordination activities. The author reasoned that interoperable technologies had the potential of being able to automate the extraction of important briefing information from the corporate databases and have the ability to assemble such information in a template for a project brief. Over a period of nearly two years the Client Business Process Group studied the business processes that interfaced with the project briefing process and in particular studied the information issues relevant to briefing.

In Copenhagen in 1998 the author proposed an innovative solution for the application of interoperable technology where a briefing template could query corporate databases and display the information in the project brief. He proposed that the manager of the project brief would then be able to use this information to document the business requirements. The presentation also explained that a major hurdle to the implementation of such a concept was that important information in project brief could not always be found on such databases, but was more often stored in documents. The investigations by the members of the Client Business Process Group showed that their businesses were heavily reliant on documents and importantly there was little control over the management of them. The author

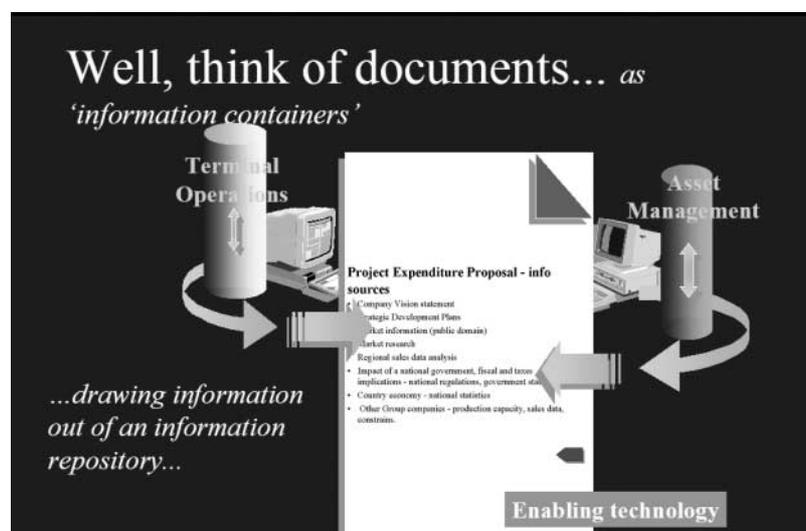


Figure 1 - Concept for an on-line project brief

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reasoned that until the businesses controlled these documents and indeed moved away from storing information in documents in preference to a database, then the opportunities for making the step changes in the briefing process through the exploitation of interoperable technologies were very limited.

The author reasoned that information for the brief had to be controlled by the briefing process. It was reasoned that without process control, important briefing information could be missed, or indeed too much detailed information at an early stage could obscure important requirements. Furthermore the originators of such information needed to be tracked through the briefing processes, so that an audit trail could be established, should requirements need to be changed. Briefing information also needed to be controlled in terms of the categorisation of the information. Individual requirements could impact on many parts of the brief and these relationships need to be understood in a well-managed brief. In conventional practice much of this information tends to be replicated, but as the original source of the information is changed it relies on the manual processing accuracy of the briefing manager to ensure that each part of the brief that uses this information is updated as well. The ARK approach is to reference only one source of the information and re-use it wherever it is required. This is what ARK refers to as the 'one instance of the truth'. As requirements change the source data is changed and every instance of it is automatically updated. This is analogous to the updating of CAD objects.

An early realisation of this concept was achieved during 1999 when the author worked with a small sub-group of the Client Business Process Group to investigate the opportunities offered by the XML standard promoted by WC3. In his capacity as Head of Process + Technology at BAA plc, this small group developed the BAA briefing template in XML and applied it to the BAA briefing process. The concept demonstrated how a briefing document moved through a managed process, and as users involved in the process contributed information so the document status reflected those information inputs whilst also providing version control and associated meta-information. The latter displayed the author of each part of the brief and the data and time when such changes were made and the approval status of each part of the brief at paragraph level. The approval status requirements reflected those that the author had developed for the BAA briefing process, and what would become know as the 'business rules' that controlled the operation of the technology.

The demonstration also showed how the whole process as well as the document could be both managed and viewed using a web browser. The group realised that the web browser could provide the interoperable interface to the briefing process and the information being managed by it. By using a web browser anyone (inside or outside) the business could potentially interact with the process and the information, in a collaborative authoring environment.

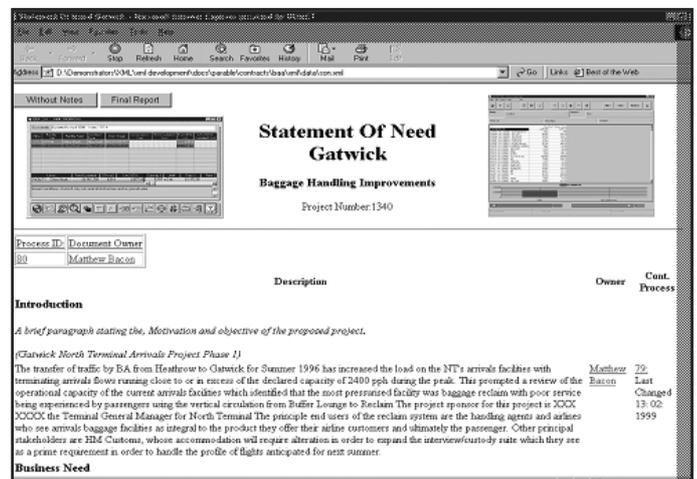


Figure 2 - Concept for an XML based on-line project brief

Development of the ARK Smart Information System

In February 2000 the author left BAA plc to establish ARK e-management Ltd with his business partner Lionel Prodders. The requirements for the system were developed over the next two years. Demonstration projects were carried out which proved the feasibility of the system. The key requirements were identified as:

Functionality

Technology

- Platform independence – constructed on open standards, specifically XML and Java.
- Designed for use over the Internet, using a web browser or any mobile device.
- Re-usable component based technology, where bespoke solutions can be developed built on a generic standard.
- Automated transformation of data into any file format appropriate to the process.
- Modular tools developed for specific functions in a process, configured for specific user needs.
- Able to interface with any type of corporate database.

Process

- A process engine that connects performers in the process through dynamic information exchange.
- Process engine able to be configured to meet specific business rules
- Role based so that users are able to interact differently with the system based on specific roles in a specific process.
- Automated task generation based on standardised workflows.
- Event notification enabling processes to be triggered by events.
- Phase control gateways, either automated (based on business rules) or manual control.

Data

- Application independent.
- Conforms to open standards.
- Extensible schema.
- Database able to adapt to changing business needs.
- Capable of transformation into any file format.
- Information
- An information processing 'pipeline' able to automate the structuring and storage of information.
- Automated meta- information definition as well as supporting bespoke meta-information definitions by individual users.
- Real-time reporting capability.
- Content and document based as appropriate for the business need.
- Role and process based security.

These requirements came about through a detailed understanding of the problems faced by most businesses concerning the management of digital information. The key problems faced by many businesses and collaborating teams within those businesses is that there has to be a significant reliance on the manual processing of information. This is brought about by the substantial reliance on documents as a means of information storage. The Butler Group articulated the issue in these terms.

'It is claimed, in the latest Report from Butler Group, 'Content Management - Getting to Grips with the Information Explosion', unstructured content, such as e-mails, images and documents account for over 80 percent of data in a typical business. Without the ability to organise this content, the information contained within it is lost, and a valuable asset is wasted.'

The Construction Industry has been very slow to recognise the limitations of documents as a vehicle for the storage of information. With the majority of information being unstructured it becomes very expensive and time consuming to process it. Inevitably there are substantial inefficiencies that arise. For example report writing, briefing, specification management, are processes that involve substantial human effort, because conventional practice is to manually produce information in word-processed form, create multiple copies in a review and distribution process, and then to keep track on who has what version of the 'current' document.

Extranets and document management systems help to simplify the process, but do nothing to drive out the waste of time in searching for information content; searching for a version that contained specific information; and re-creating information. Neither do they offer the opportunity that structured information does, which is to be able to integrate the data with other systems – notably CAD systems.

Collaborative working - data sharing and integration

In a collaborative project environment the need to share and re-use information is substantial. The 3D to nD project promotes data re-use and the creation of an 'integrated data model'. Yet where 80% of the project information is unstructured the scope of the model will be severely limited.

The challenge for the 3D to nD collaborative environment is further complicated because teams members will be working on different platforms, with different technologies. Interoperable standards such as the IFC's go some way to addressing this challenge, but because they are largely focused on graphical information exchange the standard does not address the other major information exchanges, such as project briefs, specifications, schedules and so forth. It is for this reason that ARK has created a truly interoperable system for such information exchanges. Being platform independent, and data agnostic, users are able to create project information in a 'neutral' environment and 'transform' the data 'on the fly' into most common proprietary file formats. The implications of this approach are radical. It means that a user is able to assemble information from any data source within the ARK information processing pipeline, and having viewed that information in their web browser as rendered as html, they can then choose to transform it into rtf; xls, or pdf for example, and save the file to their local drive. In doing so the information is automatically version controlled and date stamped.

Collaborative working – information management

In the authors' opinion one of the significant opportunities of the ARK approach to management of information content is through the exchange of data with the physical (CAD) model. The opportunity to enable an object in the physical model to acquire data from the information model is an obvious application.

The ARK approach to flexible data models also offers much potential. Using an XML database ARK have created the means to create schema independent of the database. This means that data in the database is stored in 'loose structures' that we call 'collections'. Each data fragment within a 'collection' is referenced by its meta-information, such as:

- Business context
- Process context
- Author
- Role/ Discipline
- Data + time
- Version status

The business context data can be managed at further levels of definition, so that information fragments can be traced at a fine level of detail. Each information fragment can be traced through its own specific URL, by this means offers the potential to be referenced by a CAD object.

The implication of this approach is that requirements data could now be tagged to the physical object model, and read by the user as one of the 'views' into the data model. This functionality would be able to support a review process and provide the basis for requirements compliance control. However there are many aspects to a project brief and only certain requirements will be appropriate for certain views of the model. For example a user from one discipline may not wish to see information relative to other disciplines because it could obscure the view of the information that they require.

The ARK approach to this matter is to automatically tag the data at the point of creation, as well as enabling further meta-data to be 'tagged' at a later time by users with appropriate authority to do so. 'Tagging' is the method by which meta-data is attached to a data object. The automated process is achieved by the control of information by 'context' as described above. Using this concept, information in a project brief could be tagged by specific disciplines so that briefing information can be viewed in the context of specific disciplines. This is analogous to layer management in 2D CAD applications.

Collaborative working – information classification

The 3D to nD project offers the potential to assemble data for the whole life-cycle of a facility from the Requirements phase through to Disposal phase. Within each phase of the life-cycle the participants in the processes that interface with the data model will require different perspectives on the information. Indeed the way in which each of these users would wish to organise the information would be quite different. For example in the Requirements capture phase a new facility might be defined by its Functions, and or, Business operations. Occupancy zones might also be another method of grouping requirements. Information created in this phase would be defined in terms of these categories. However in the Design phase, whilst some of these categories would no doubt still be relevant, the design team would introduce other categories in terms of system definitions – 'envelope', 'floors', 'sub-structure' for example. The way in which they choose to organise their information will be a function of the design process. In the Construction Phase, the construction team will wish to organise the information appropriate to how they will construct the facility. The categories might now be related to Phasing and Sequencing, or by Work packages or Trades.

Traditional document management approaches are incapable of managing information in this manner. Information contained in a document will be relevant to one or more classification structures for each phase. Inevitably if such systems are to service more than one phase, substantial replication of information is required as documents are re-categorised for the different phases. Such replication places a substantial burden on the document control and inevitably leads to the need for much manual processing of the information, which is time consuming, inefficient and prone to error.

The ARK approach to this issue is to store information at an 'atomic level', where information fragments can be assembled and re-assembled to suit the different needs of each stage of the life-cycle of a project. For example, the requirement for an acoustic property, maybe categorised in the Requirements Phase relevant to a room function. In the Design Phase it maybe further defined in terms of a property of room finishes in a performance specification. In the Operation Phase it may be used in the specification for a sound reinforcement system. The information fragment or 'atomic particle' is re-used in the different contexts in which it is required by the technologies appropriate for use in that phase. The ARK SIS provides a complete audit trail of all the contexts within which that fragment of information was used. This is what we refer to as 'information traceability'. In the authors opinion it will be a highly desirable feature of the 3D to nD model, because it will enable the design team to share information without having to manually process it through the re-keying of it from one context to another, from one application to another.

The approach that ARK has adopted to achieve this capability is by defining information schema independent of the database structure, as described earlier. This approach enables ARK to provide complete flexibility for its customers. It means that the schema can be defined to represent different perspectives relevant to each process phase of the life-cycle.

Collaborative working – team management

The 3D to nD project offers the potential to assemble substantial amounts of data from different processes involved in the delivery of a new facility. Control of access to information is essential in ensuring that users are not overloaded with irrelevant information, or indeed having to spend time sifting through information. A minimum requirement would be that they should only need access to information relative to their specific needs.

The ARK approach to this issue is to assign each team member to one or more 'roles' in the context of the system. The reason for this is that for each role, a user has specific tasks to fulfil, and for those tasks they require specific information. It is through a 'role profile' that the ARK SIM makes the information available to the user that they require for the task being carried out.

The approach adopted by ARK recognises that each person in a team usually carries out at least one or more roles. ARK defines these as 'Primary' roles and 'Secondary' roles. These roles may or may not be related to job titles. An architect (job title) could have a primary role as Project Architect, and a secondary role as Chairperson of design team meetings. Each role or sub-role can (if required) relate specifically to a project or business process, a contract context or sub-context (see below). When a user logs into the ARK SIS they are able to do so by Role and or Process context and or Contract context or Sub-context.

The process perspective would enable the person logging into the system to choose which process they wished to work in. For example they may have a role of Project Architect in a Briefing process as well as a Design management process. Once in this process context they would have permissions to be able to read, write, delete, update, project information relating to that specific process and none other.

The contract perspective would enable the person logging into the system to choose which contract they wished to work on. If they have been allocated the role of Project Architect on more than one project they would be able to choose a specific contract to work on. Once in this process context they would have access to project information relating to that specific contract and none other. By configuring a role controlled by both process and contract a persons access rights can be controlled to whatever level of detail is appropriate.

The role based access approach is critical to allaying concerns over information security. Access to very specific information can be provided through one or more Secondary roles defined for them. A Secondary role is often related to the Primary role (but does not have to be). Examples would be a member of a review team, a chairperson for a meeting type, a quality inspector and so forth. As part of a review team for a project brief for example, the author of information would be able to share information with only those team members who were part of that review team. The team based approach means that the ARK process engine is able to automate much of the information management in the review process. It also demonstrates that it is possible to create teams within teams for the purpose of carrying out specific project functions.

The power of this approach to access control is that links to information can be automatically made available to specific members of a team without the need for manual administration – such as having to manage information by email for example. As soon as information is made available for review, the ARK process engine triggers the distribution and notification process. On some government contracts the management team have to provide an audit trail that verifies who had access to information, and when such access was given. Email clients do not provide appropriate control and verification. However the ARK SIS provides a complete audit trail in this regard.

Collaborative working – process control

The ARK process engine (ARK Process Manager™) controls the ARK SIS. This is a rules based engine that automates the process of information 'distribution', event notification and 'stage gate control'. It negates the need for team members to manually circulate information by email and ensures that information is not replicated (which is what happens in email exchange).

The process engine is programmed by the business rules that control how the process is to function. It provides a real-time interface to project participants, so that once one member of a team has executed a task the process engine activates to next task in the workflow. In doing so it places the next task into the team members task portal that is responsible for that task. That person can be automatically notified by email or SMS if required. Real-time reports inform managers of the process where the tasks in the process have advanced to.

As the work for each task is completed, the 'task performer' documents the work that they have carried out. A 'task owner' is then able to finally close the task once they are satisfied that the work has been properly carried out. Information at each stage of the process is assigned a status and 'traffic light' status symbols can be displayed to show the status of each fragment of information in the process. A 'green traffic light', means that it has been completed and is approved. An 'amber traffic light' means that the work is in progress. A 'red traffic light' means that it has not yet been started.

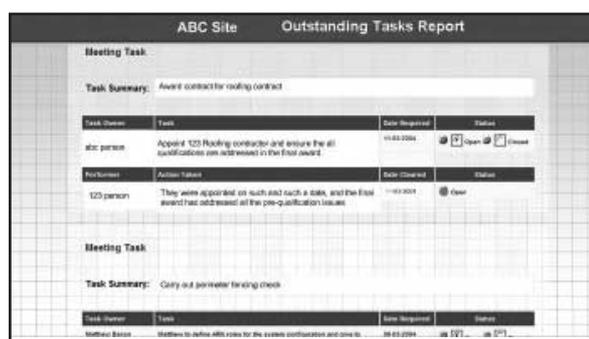


Figure 3 - A task status report

The status display can be used in a number of different ways in the system. In particular it is used for process control. A number of process systems (i.e. the Process Protocol) use the concept of stage gates to control the progression of the process from one phase to another. To achieve this in the ARK SIS the control is exercised with the information and an assessment of the risks associated with information status at the 'gateway'. ARK prefers to assign managers in the process as the 'gatekeeper'. The process defines what information is required in order to make an informed decision to move the process from one phase to

the next. An on-line report is made available to the 'gatekeeper' and this report dynamically assembles the information from the business systems operating in the process. It displays the information content and, where appropriate, the status for each category of information, using the traffic light paradigm. The manager (gatekeeper) can now review the information, contact the information owner (details of which are displayed in the report), and make an informed decision as to whether issues have been sufficiently addressed to enable the process to be advanced to the next stage.



Figure 4 - A process control object in an on-line report

This concept addresses the 'hard' and 'soft' gate principles expounded by the Process Protocol for example, but ensures maximum flexibility on behalf of the process owner to define what information should be categorised under each.

In technology terms ARK has designed a process control object that can be placed in any on-line form, template or meeting agenda for example. A 'approve' button activates the object. It is the activation of this button that moves the process from one stage to another. Only a person defined with the appropriate role in the ARK SIS has access to this control function, so ensuring compliance with the business requirements.

In terms of the 3D to nD project, process control will be required for all information being managed within each process phase. In design definition terms for example what status (sometimes called 'fixity') should design information be at to enable the process to be progressed from one phase to another? How do managers know, within a CAD model, how 'fixed' any part of the design is? How is information concerning design assumptions made available and which may affect design status? The challenge for the 3D to nD model is to be able to gain access to this meta-information and make decisions based on the findings. Without such information being available effective process control cannot be achieved.

Insight into the ARK Smart Information System

The ARK SIS comprises a suite of Internet based applications that are designed to work within a web browser. The application modules are designed around specific role based functions and business processes. This means that when a user logs into the system and selects a specific role, the system displays those application modules (tools) that the user requires in order to perform their role in a specific process. The application functions within each module can be 'switched on or off', depending on the users needs. This reverses conventional logic by making applications role based, rather than expecting the user to find the application function within a large application, which is the common approach of many software design houses. The author believes that this is a better user orientated approach and one that ARK's customers also like.

The application interface comprises interactive browser based forms and templates. Fields within the forms and templates enable the user to enter information into them. Once saved, the form processing technology writes the data to the XML database, and in doing so automates the process of information categorisation based on the agreed business rules with the customer. The process also creates the meta-data at the same time, so that each fragment of information is uniquely identifiable.

The ARK forms are able to replicate any interface, including word-processed type forms, and spreadsheet type forms. From the user perspective the user interface can be exactly the same as they are used to, thus avoid re-training in the use of the form.

The ARK templates are designed around a document paradigm, so that where a business uses standard document templates, (a project brief is a good example), the template is replicated in the browser. Both forms and templates are able to read from any database management system, so that it is possible to pre-populate sections of the template with corporate information. Information is entered into the template in exactly the same way as the word-processed template, but the storage of the information is radically different. In the ARK SIS all information is stored centrally, accessible by anyone with appropriate access rights. This provides the basis for being able to share the information with other business systems, and could provide the basis of being able to share the data with the 3D to nD model. It is this concept that the author first demonstrated in Copenhagen in 1999.

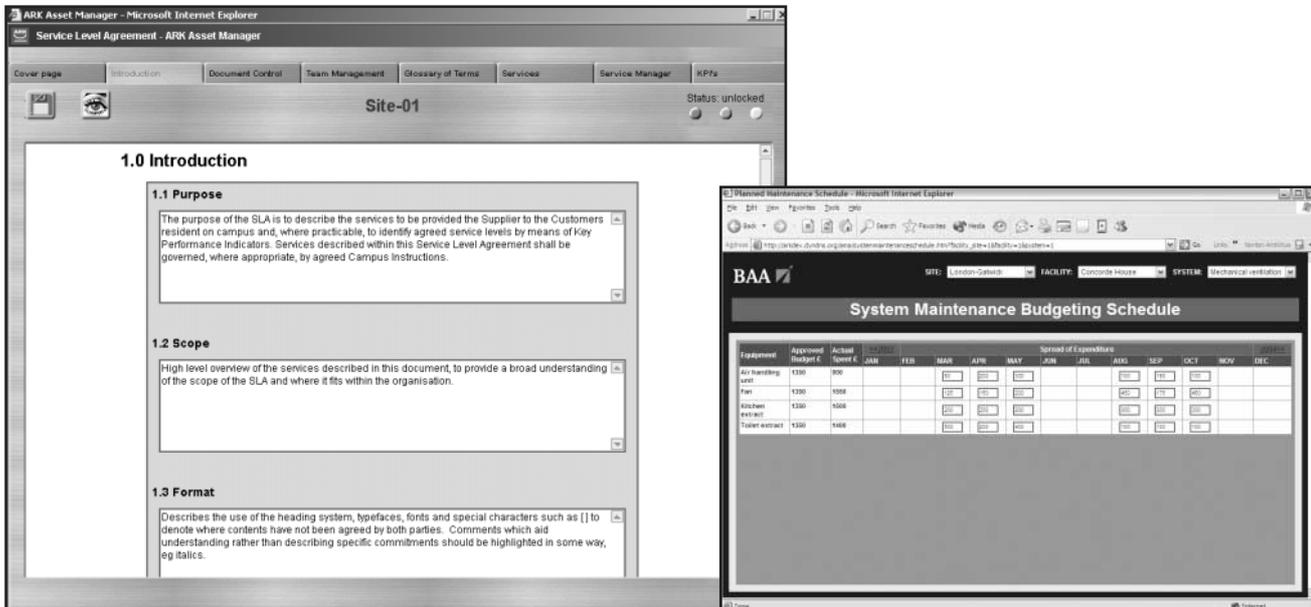


Figure 5 - Online templates. On the left a 'virtual document template' and on the right a 'virtual spreadsheet template'

Summary

This paper highlights just a few features that are particularly relevant to the 3D to nD project. The issues all relate to the management and control of data, and in particular the means by which textual information is created. For the potential of the 3D to nD project to be realised, the model must embrace information content management. It needs to address the need to move from a document centric approach to the management of textual information to a data centric approach. Until that happens, the scope of such a model will significantly be restricted.

Engineering Assessment made Easy: The 'Energysave' Approach

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Abstract: Whilst naturally ventilated buildings are currently considered to be the ideal solution to low energy design there remain a large proportion of buildings for which air conditioning offers the only practical solution. This project is intended to provide a means to assess design options for such buildings at a very early stage in the design and in particular address the selection of the most appropriate system. The form of the interface is still developing and while it has been demonstrated to designers no third party tests have yet been carried out. This paper reports on a project that aims to show that a general description of the building can be used to generate sufficient data to drive a valid analysis using a detailed thermal model at the early sketch stage of the design process. It describes the philosophy, methodology and the interface developed to achieve this aim. The interface guides the user through the input process using a series of screens giving options for keywords used to describe the building; comprehensive default data built into the software are then attached to these keywords. The resulting data file is a building description that is the best possible interpretation of the design intent. This can then be used to assess options and guide towards a final design.

Keywords: Architecture, Engineering, Energy, Assessment, Sketch stage, Design process, Data transfer, XML

Introduction

At present, during the early design stage of a building, different options are assessed using simple tools (tables, graphs and software) that contain a large number of assumptions the very nature of which can bias choice or possibly lead to an inappropriate solution. It can be argued that the only way to provide a rational assessment of options is to use calculation methods that represent in detail the physical processes involved; this usually involves the use of dynamic thermal models. Many designers are of the opinion that, because not all details are known, then such tools are not suitable for application at early stages in the design. This view can be challenged because, even at the concept stage a great deal is known about the building, for example:

- Size;
- Number of floors;
- Occupancy;
- Preferred glazed areas;
- Insulation standards;
- Thermal mass;
- Required internal environmental conditions.

Notwithstanding this there is still resistance to the application of simulation, typical reasons given are:

- Too time consuming to input the necessary data;
- The program is not user friendly;
- Manual methods are quite adequate;
- Programs cannot be trusted;
- Do not understand how the program works.

Arups had already recognized the need to address these issues and encourage the use of simulation throughout the life cycle of the building and so, at their own expense, joined the International Energy Agency (IEA), Building and Community Systems, Annex 30 (Bringing Simulation to Application). Arup Research and Development was the official UK Participant.

The IEA project demonstrated the value of simulation throughout the design process, the value of good quality default data and the need for software validation. However despite identifying user friendliness as an important issue in increasing the uptake of simulation throughout the construction industry, it did not make a serious attempt to address that issue. The objective of EnergySave is to redress this.

State of the Art and Related Work

There have been a number of projects that aim to provide simple interfaces to assist the designer, for example:

- The 'NATVENT' project (Natural ventilation for Offices. BRECSU March 1999);
- The 'Office Design Tools' (Building Services Journal, December 1999);
- The 'Building Design Advisor (BDA)' (Papamichael, K. et al. Decision making through use of interoperable simulation software, Building Simulation '97. Fifth International IBIPSA Conference, Prague 1997).

The complex nature of ventilation, and the very uncertain nature of the boundary conditions (wind environment, pressure coefficients, for example) justify the simple nature of the analytical models used in the first two examples. The third is a way of using a detailed thermal model to analyse design options. The main difference between this work and the BDA lies in the interface. The BDA uses a graphical tool that requires each space to be specified in some detail. It is therefore close to a conventional analysis tool and as such is not suitable for studies at the sketch stage of the design. The method by which results are presented is however one example that will be examined during the project. Members of the EnergySave team have visited the Lawrence Berkley Laboratory in California and are therefore fully aware of the strengths and weaknesses of the BDA.

The intention of the EnergySave project is to make use of available software and skills. In particular, whilst a detailed thermal model is necessary for the implementation of the method there is no intention to develop that model. It is however important that the source code of that model is available to the team. The model selected is ENERGY2. This program has been developed in Arup Research and Development and has been exposed to the International Simulation Community by means of the IEA Annex 21 (a task shared project related to quality assurance and validation of thermal models).

In order to facilitate energy calculations it was necessary to develop generic system models. These are based upon those described in the CIBSE Energy Code 2, 'Energy demands for air conditioned buildings'. Arup Research and Development were involved in the drafting of this code and made significant inputs into the building description application of climatic data and testing of early versions. Although these models are very simple they capture the essential features of the systems. This means that the major inefficiencies are accounted for.

The Energysave Approach

The objective for the EnergySave interface is to capture the essential elements of a design in an unambiguous way to enable a valid energy analysis at the concept stage of a design. Of equal importance is that any data output should be in sufficient detail to enable the use of a detailed thermal model **1** for the prediction of energy consumption. This model would also be used at later stages in the design process so bringing a consistency to the analysis through out design. A second and equally important objective is to provide a mechanism to bring simulation to those who believe it to be too complex for their needs and far to difficult to use. This is done in several ways:

- The use of extensive, intelligent defaults to minimise the amount of data that are required;
- The use of a pictorial based input system to identify the main input parameters;
- The use of minimum data to describe building;
- A critical assessment of the most significant features that can affect the energy consumption of the building.

An example of the later is the way solar shading is described. In the case of passive buildings it is particularly important to ensure that the effect of any purpose built shade is accurately represented. In the case of air-conditioned buildings this is less necessary because energy consumption is far more closely related to systems and controls. EnergySave does not ignore external shade but on the other hand does not encourage users to be obsessed with complex representations. The form of the building is simplified, at present to a rectangle. While this is recognised to be a limitation it is also felt that the majority of buildings can be adequately represented. EnergySave is intended to apply to the norm. Section 4 (Overview of the interface) demonstrates the principles described above.

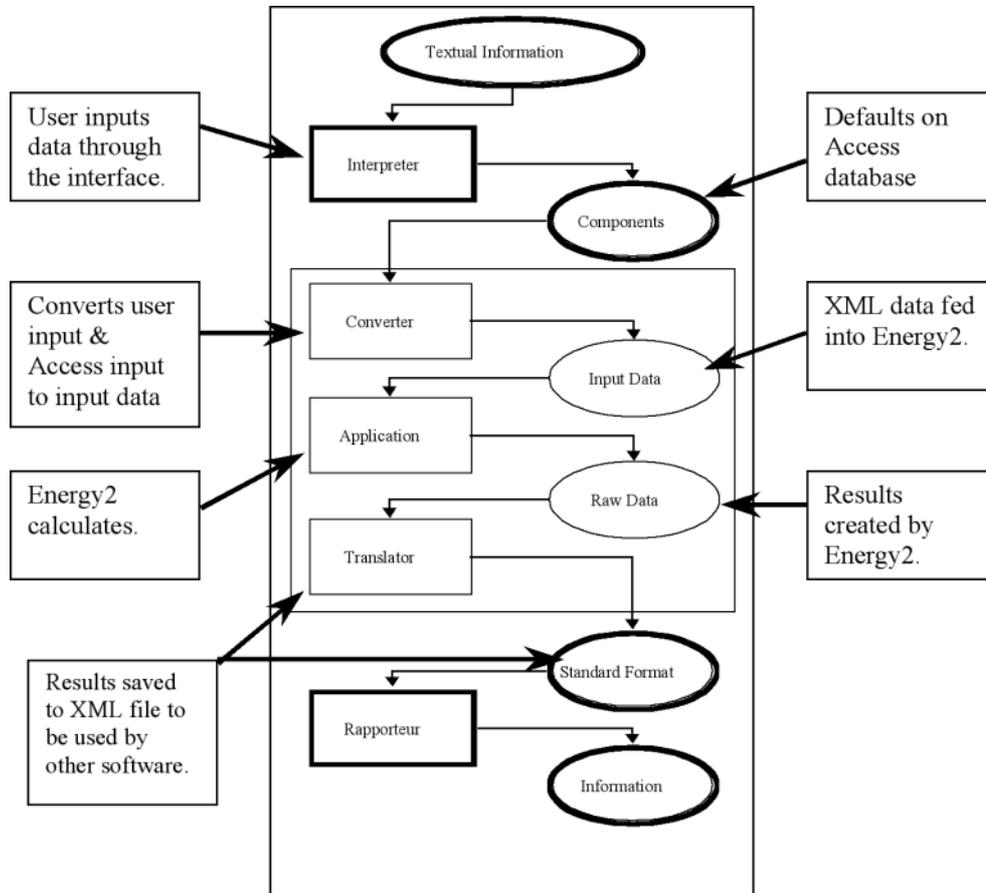
A second fundamental to the system is to use what is already available, thus the main database used is a commercial product chosen because the majority of PC users will have access to it. Intermediate data transfer uses an XML Schema taken from the public domain (Green Building Schema).

It is important to realise the EnergySave does not contain a calculation engine. It is intended that the XML file be described in sufficient detail to allow the use of third part 'engines'. This is direct contrast to the development of public domain engines in the USA.

***1** A detailed thermal model is usually a simulation program capable of calculating the performance of both building and HVAC systems at hourly intervals for the period of a year. In the UK context design programs based upon the CIBSE Admittance method are not considered to be detailed thermal models.*

Structure of the System

The following flow diagram shows the form of the system.



The interface between EnergySave and the application is the XML file. This Section briefly describes the system.

The Interpreter

The written descriptions are converted into components using rules developed from discussions with designers from the industrial partners who have also provided default data based upon previous projects. These are combined with user specific data into building and system components and written to a standardised data file. The data structure produced by this process is to be specified in sufficient detail to allow any developer to use their model in conjunction with this system. One function of the interpreter is convert simple descriptions into physical layers that are suitable for use in a detailed thermal model. Examples are:

- Opaque walls. Input U value and response time – output layers in the construction and the physical properties of those layers.
- Glazing. Input shading coefficient – output layers and basic properties such as transmission and absorption at normal incidence for each.
- The 'Interpreter' combines the default data taken from the database and combines that with the user input to write the XML file. It is important that a single XML file contains ALL options investigated. This can be done by specifying each as a new building on the same site (campus in the Green Building Schema).

The Converter

This is specific to the simulation model used it would be written by the application vendor to convert the data on the XML file to that required by the program.

The Application

In this case the Arup ENERGY2 program will be used. It could however be any appropriate model.

The Translator

This is specific to the program used in the analysis and is used to convert the predictions (raw data) into a standard format. This format is specified in detail to allow the system to be used by other software developers. The output from the ‘translator’ is to the XML file.

The Interface

This Section shows some of the essential elements of the interface and where appropriate how they can be used to set defaults. It is intentional that the screens – or forms – presented to the user do not have the appearance of a conventional Windows interface. It is inappropriate to display the complete interface, the sample ‘forms’ presented here are intended to highlight the main principles behind EnergySave.

Input data

This is an XML file containing:

- Location and climatic data information;
- A full geometrical description;
- Thickness and properties of the walls;
- Transmission, reflection and absorption characteristics of each element within a window.
- Shading details;
- The configuration of the HVAC plant.



Project Definition

In addition to capturing the standard inputs such as project description and user, the location and function of the building are defined. Location sets insulation standards via local building regulations and occupancy patterns and internal gains are set by the function. A default building is generated.

nD Modelling Road map: A Vision for nD-Enabled Construction

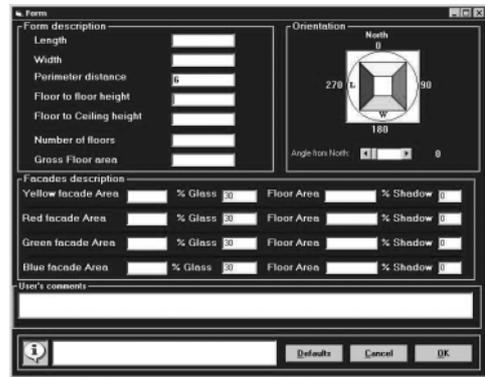


Location

The country map is displayed. Each region contains a link to a climatic data file. Software vendors can enter their particular file names on the database. Exposure is also identified. Because this can be done in several ways, an advanced option allows an alternative definition, terrain type. This is intended to provide data for software that requires some means to describe wind shading for infiltration and ventilation calculations.

Building's form

A simple model of a building is created, using zones based on the façades. The user inputs the length, width, floor-to-floor height, and the number of floors. Simple solar shading is also set here, another input (not included) allows for individual window shade to be entered.

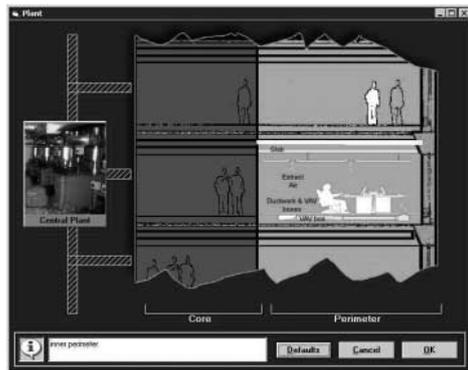
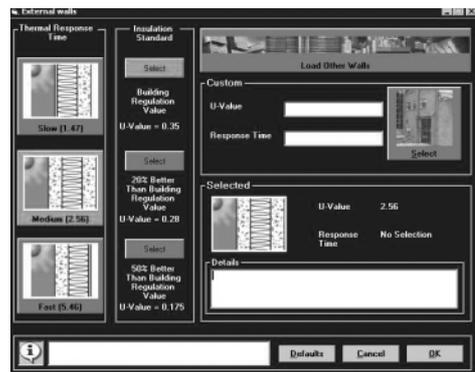


Internal Gains

Internal loads are defined by 'level', very high to very low. The defaults corresponding to these levels are displayed and it is possible for the user to make changes.

External Walls

Materials used in external walls can be selected. The variations are labelled by their U-Value and thermal response time (Admittance). The user can select the closest type of wall or alternatively create a custom wall using the advanced option



HVAC Systems

A side view cut out section of the building is split into the core, inner perimeter and outer perimeter. Each section can be 'filled' with heating and cooling systems. This is shown in the green section with the under-floor VAV system. As the user enters data, options are limited for other sections so that inappropriate combinations cannot be selected.

The Rapporteur

The nature of the output from an energy simulation requires specialist knowledge for a valid interpretation, in particular where comparisons are to be made. The rapporteur provides a facility to compare and interpret design options. It is hieratical in nature so the user is first offered overall energy (and CO₂ figures). It is then possible to delve deeper to looking order to develop an understanding of the performance indicated. Automatic comparison of options will be available. The rapporteur allows comparison of results for up to 4 options. The parameters covered are:

- Carbon dioxide production;
- Energy consumption in terms of electricity and gas;
- Energy consumption in terms of cost;
- A breakdown of the loads on the building (solar, infiltration etc.)
- An 'end use' breakdown – fans, boilers, chillers humidification etc.

The data are presented as both annual monthly totals.



Conclusion

The EnergySave project is intended to bring simulation to a wide range of building design professionals. To do this it has been necessary to make many simplifications to the description of a building and the associated HEVAC systems. These are based upon the relative importance of each element upon energy consumption. It is believed that the weightings used will result in meaningful predictions. EnergySave differs from other approaches to simplified energy analysis in that simplifications are made in the way data are described to the analytical engine and not in the engine.

Acknowledgement

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The Virtual Construction Site (VIRCON) Tools: An Industrial Evaluation

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Abstract: Implementation of the emerging information technologies in the construction industry has been relatively slow in comparing with other industries. Vast amounts of research and development conducted by academia have not been tested and/or implemented successfully in the real practices. Taken this issue into consideration, the VIRtual CONstruction site (VIRCON) research project, funded by the UK government, with the objective to develop a strategic decision support system for practical use to manage construction schedules, and in particular space planning. The successful development of the system was based upon the industrial requirements, real-life project data, and finally evaluated by the industrial collaborators. It is therefore the impetus of this paper to briefly introduce the VIRCON system and thoroughly report on the industrial user evaluation. The aims of the evaluation were to establish the usefulness and usability of the individual VIRCON tools, and to indicate the potential towards commercialisation and real implementation. Ten collaborators from the construction industry evaluated VIRCON through a real-life case study. The space planning approach and visualisation features developed in this project were found to be practical and communicative. Also, in order for IT system to operate in the industry (such as VIRCON tools) new ways of working in supply chain communications and management should be established. In particular, long term framework agreement, trust, engagements and standards.

Keywords: Visualisation, 4D modelling, Space planning, user evaluation.

Introduction

The VIRtual CONstruction site (VIRCON) project brings together academic and industrial collaborators in an attempt to push forward the state-of-the-art in construction project planning. The project was funded by the UK government, with the prime objective to develop a strategic decision support system for construction project and space planning within a desktop environment. VIRCON has been developed in response to the realisation that there is a looming skills gap in the construction industry amongst those with the expertise to plan major construction projects. In addition to this, there is a range of technical opportunities becoming available which may make it possible to bring computing to bear on what has until now been a task that is only tractable by experienced and expert personnel.

The VIRCON system allows planners to trade off the temporal sequencing of tasks with their spatial distribution, resulting in a more robust and rehearsed project schedule. Also, the VIRCON visualisation tools allow planners to better understand construction schedules through 4D (3D plus time) simulation and ability to visualise congestions and hot execution spaces on sites. During the past three years, the system has been successfully developed which was based upon industrial requirements, industrial real-life project data, and finally evaluated by the industrial collaborators. The prime objective of this paper is therefore to provide a background to the overall VIRCON system and to thoroughly report on the industrial user evaluation phase of the research project.

Construction Space Planning: VIRCON Processes and Tools

With increasing pressure for shorter delivery schedules, better utilisation of space resource on construction sites becomes more apparent. The Critical Path Method (CPM), a widely used scheduling technique in construction project management, however, has limitations to serve this need. Its fundamental was not designed to represent spatial and temporal aspects of the construction.

Moreover, its underlying complexity creates difficulty to evaluate and communicate the schedule. To overcome these limitations, the Critical Space Analysis (CSA) concept that emphasises on dynamic spatial configuration of task execution, as opposed to static site layout planning, has been developed [refer to Winch (2002) and North & Winch (2002)] and more information about this is given below. A group of tools that supports the implementation of the CSA concept have also been developed, based on the industrial requirements capture [refer to Kelsey et al. (2001)]. Fig. 1 presents an overview of the VIRCON tools and their associated processes. These tools are grouped into four categories based on their functionality and are described and discussed in this paper.

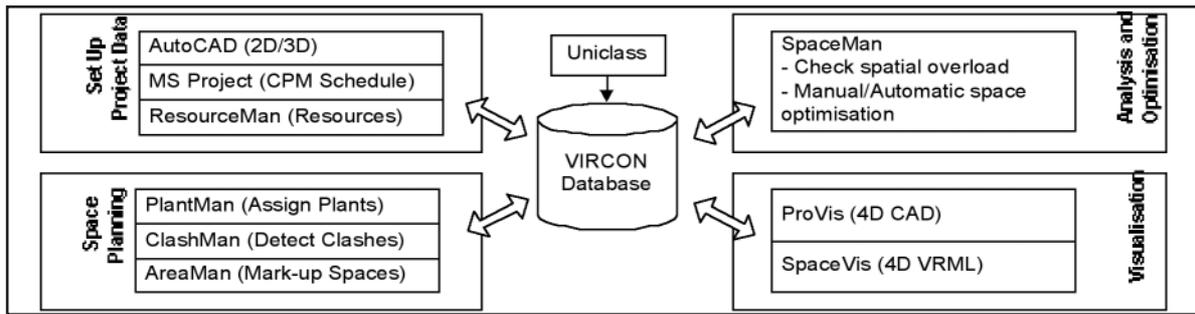


FIG. 1: Overview of the VIRCON tools

Set up project data

This process is about preparing the necessary data to run other processes and tools in the VIRCON system. Data on PBS is prepared in AutoCAD while WBS is prepared in MS Project. One of the first constraints that we encountered was the lack of standardization by CAD users such as architects and CAD technicians. Standardization is essential if integrated software tools such as the VIRCON system are to support and enhance the capabilities of construction planners to do their job. Set up phase involves four sub-processes including: a) prepare CAD data; b) set-up corporate resources database; c) VIRCON database; and d) populate VIRCON database. Each of these sub-processes is described below.

Prepare CAD and schedule Data

A pre-requisite work for generating visualization model for space analysis is the development of 3D CAD model. The level of details required for the model is very much depending on the nature of project. More complex projects that involve many disciplines (i.e., factory and hospital) would require more detailed and more accurate models to be developed. These detailed models can greatly help designers to ensure perfect interfacing between architectural components, building services, cladding and other building components. Furthermore, the models can be used as a communication tool that facilitates co-ordinations among various construction trades.

There are three types of 3D models that can be used to develop a reasonable planning and visualization system. The first type is called '2.5D model' which basically generated from simple extrusion of 2D CAD from a specified datum (McCarthy 1999). This type of model requires much less work in developing the original CAD model, and is appropriate where a 3D model is not justified for detailed analysis of product performance and clashes between products. The second type is called '3D wireframe or solid model'. This type of model requires true 3D modeling using polylines (wireframe) or solid CAD objects. The third type is referred to the 'IFC model' which is developed using a set of standard objects such as ifcColumn, ifcBeam, ifcWall, etc. This type of model can be interoperable among different compatible CAD packages. The VIRCON project did not adopt IFC CAD but was potentially compatible with the IFC approach. At present, IFCs are a technology that may or may not achieve diffusion in practice, and there are issues with the level of readiness and completeness of the IFCs. This was true at the start of our research when we had to make the decision, and it remains true today.

A principal objective of our research project as part of the EPSRC/IMI programme was to encourage industry to utilise the tools and this meant using the CAD information that the industry is producing today and rather than what it might produce in 10 years time if IFCs were adopted. The Teesside team has been involved in two major developments post VIRCON with the objective of producing 4D models for two commercial projects (White City project development with Balfour Beatty and Gas receiving facilities with F&G, project management arm of ATKINS). This would have been difficult if the system were designed to work on IFCs. The team has not yet come across designers, architectures or contractors who have been using IFCs in the UK, apart from on a few initiatives that have been funded by DTI. Our work is fully compatible with IFCs, and so its scientific impact should not be limited should the use of IFCs become diffused more widely. There are, therefore, no problems of lack of standardisation in this respect.

Once the 3D model is developed, each type of the product must be organized properly in separate layers. For instance, foundations should be in one layer which is separated from column and roof layers. In addition, BS1192-5 1998 was used as the standard for layering CAD drawings.

With respect to schedules and resource allocations, the processes comprise of five steps which are: (1) developing product-based work breakdown structure; (2) grouping CAD products; (3) linking product groups with activities; and (4) population of the VIRCON database. Product-based work breakdown structure is a medium that allows systematic and consistent integration of product and process data. In the case study that was used to for the evaluation process, it was found that the breakdown of activities in the original schedule didn't suit this requirement. Many products were not explicitly mentioned in activities. For instance, installation of extract fan, cable tray, and distribution panel are hidden in 1st, 2nd, and final fix M & E activities. This made it difficult to interpret the association between products and processes. To solve this problem, a product-based work breakdown structure was designed by considering the product layers in the 3D CAD model and activity list in the original schedule. The structure was broken down into four levels including: (1) Level 1 represented project title; (2) Level 2 represented summary tasks; (3) Level 3 represented products; and (4) Level 4 represented activities.

After all product groups are generated, the next step is to link these CAD groups with activities in MS Project. To enable this linking process, a new text field called 'Product Group' was created in MS Project. Considering the associated activity, the name of product group was then input into the Product Group field accordingly.

Set-up Corporate Resources Database

A stand-alone database management tool for legacy collection of resource data and space requirements was developed. The database holds information about plant and equipment that are available for the company to use and/or for the supply chain. Part of this information can come from manufacturers which include operation and space requirement data. Other information about efficiency and utilization can come from the company and its supply chain (Heesom and Mahdjoubi, 2001). ResourceMan is a relational database with a very user-friendly interface.

VIRCON Database

An integrated relational database that serves as a core infrastructure for the VIRCON system. The structure of the database was standardized in two ways. Firstly, we adapt the UK standard for the layering of CAD files, BS 1192-5. Secondly, we adapted the UNICLASS standard for construction project information using the principles of ISO Technical report 14177. The UNICLASS standard facilitates the integration of construction product and processes (Dawood et al. 2003). The initial product data input the VIRCON database comes from AutoCAD and process data comes from MS Project. AutoCAD data can be either 2D or 3D, and provide data on all components that makes up the facilities. All product information is populated to the database using a VB routine which has been developed in the course of this research dubbed DataExtractMan. Each table in the database represents a type of a product (i.e., foundation, first floor columns, etc) and all products coordinates and stored digitally in the database.

Populate VIRCON database: DataExtractMan – an AutoCAD macro that automatically interprets CAD layers (BS1192-5) and extracts 2D/3D product data into the VIRCON database. Using the layering standard, DataExtractMan creates a table in the VIRCON database for each layer in AutoCAD and reads all digital information in that layer and store them in the table, (Dawood et al. 2003). This is a fully automated routine and will save huge amount of time and efforts of the project manger providing that product information have been properly layered in CAD using BS1192-5.

It should be mentioned that not all project information is available at the pre-construction stage and sub-contractors might be reluctant to release information and commit them-selves and in particular their resources availability. Nevertheless project managers should be able to operate in this type of environment and VIRCON system was designed to be quick and intuitive and work with limited information. VIRCON database can also act as an IFC server and in this case the VIRCON tools can be used if and when IFC supported AutoCAD systems are increasingly used in practice, see Sriprasert 2004.

Space planning processes and tools

Once the project data has been set up, it can be read for the purpose of the execution space planning for the project, the main sub processes of space planning are as follows.

Assign Plant and Temporary Works to Weekly 2D Plan

This process is about incorporating spaces needed for plant and equipment that are deployed in a given week into a weekly 2D plan of the completed facilities. A software prototype dubbed PlantMan was developed to achieve this process. It reads VIRCON database to produce weekly 2D plans of the completed facilities and then incorporates space requirement for plant and equipment from ResourceMan. PlantMan incorporates ClashMan tool which checks clashes between the assigned plant and temporary installations using raw detection collision detection algorithm. This is particularly important function as one of the important planning issues is to avoid conflict between temporary facilities and plant. PlantMan is a stand-alone software and communicates with VIRCON and ResourceMan via ODBC and produces 2D weekly drawings of the finished facilities with marked-up spaces for plant and equipments (Heesom and Mahdjoubi, 2002). This is then stored as DXF files to be accessed by another tool for marking-up space availability dubbed AreaMan. This is discussed below.

Mark-up Available Spaces

Once 2D DXF files produced by PlantMan are ready, planners can access these weekly files to mark-up available spaces. Planners have to use their knowledge and experience to identify space availability in terms of location and size. A mark-up tool dubbed AreaMan was developed for this purpose. By simply clicking on the 2D plan, the actual space available in the week under consideration can be identified by the planner and their area can be calculated. This data are then read back to the VIRCON database. Project activities are allocated to the available spaces from AreaMan through a dialogue box written in MS project, [Refer to North and Winch (2002)]. All data in MS Project are then read back to the database. It should be mentioned that Space is treated in this project as a resource and space planning process is about identifying and allocating spaces to tasks and this was not automated as the industrial collaborators in this project preferred to see projects managers are 'engaged' in the process of space planning rather than leave the system to do it for them. It was thought that project managers will have more confidence in the planning process. The outputs of this process are WBS tasks which are allocated to available spaces. This is stored in the VIRCON database and ready to be accessed by analysis and optimization process. This is discussed below.

Analysis and optimisation tools Identify Critical Space and Time

Given the allocation of potential execution space requirements to activities, this process involves identification of spatial loading using the SpaceMan tool. An example of this critical space analysis is illustrated in Fig. 2. Since tasks have different start and end dates within the life span of the spaces, spatial overload occurs when the spatial requirements of all tasks allocated to an available space are summed (when executing concurrently), and found to match or exceed the size of that space.

Once the SpaceMan tool has completed its analysis task, it automatically populates the spatial loading of each zone and in each period in the VIRCON database.

Optimize Critical Space and Time

If a situation where the spatial requirement of tasks allocated to the available space currently selected exceed the available spaces (right light red in the space man interface) or/and currently selected task is on the critical path (left light red, see Fig 3) then SpaceMan allow users to optimize the schedule. In the case of manual optimization project managers can resolve conflicts by change the start of activities or/and changing tasks durations though altering resources. SpaceMan also allows the application of a simple 'brute force' algorithm to optimize the loading of tasks execution spaces. These algorithms try first to reduce space congestion though changing start dates of activities before trying more drastic solutions like changing tasks durations and resource allocation. A space congestion has been resolved for a particular period of time, SpaceMan updates VIRCON database with all space allocation data. After each optimization session, project mangers can visualise space congestion in 4D models of the project under consideration.

Fig. 2 illustrates the space planning and the CSA concept used in the VIRCON project. Using a new school project at Stockport, UK as a case study, plant and temporary objects were assigned and available spaces were marked. Since tasks have different start and end dates within the life span of the spaces, spatial overload occurs when the spatial requirements of all tasks allocated to an available space are summed (when executing concurrently), and found to match or exceed the size of that space. For example, space 1 in week 8 appears to be overloaded by concurrent execution of Task A and Task B.

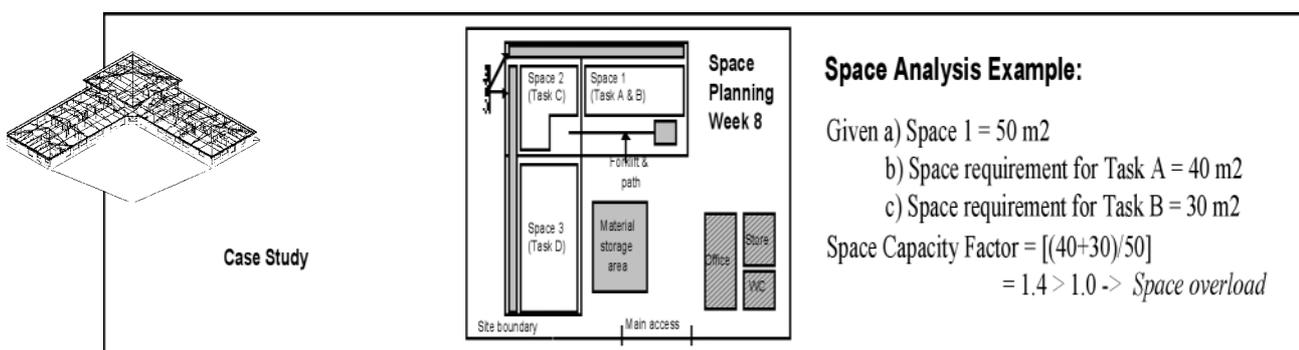


FIG. 2: Construction space planning and critical space analysis: VIRCON approach

nD Modelling Road map: A Vision for nD-Enabled Construction

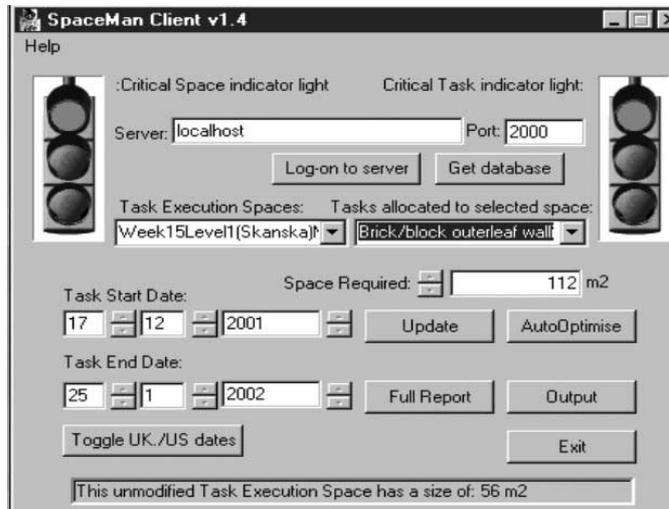


FIG. 3. SpaceMan Interface

Visualisation tools

Visual 4D planning and scheduling technique that combines 3D CAD models with construction activities (time) has proven benefits over the traditional tools in terms of better evaluation and communication of activity dependency as well as spatial and temporal aspects. Two 4D tools were developed in VIRCON project not only to visualise the construction products but also to visualise movement of plants/temporary objects and highlight spatial overload. These tools are:

1. ProVis – a 4D tool developed as a plug-in to AutoCAD 2000 and AutoDesk Architectural Desktop (ADT 3.3) for visualising traditional CAD or IFC 1.5.1 products. The tool also highlights locations of spatial overload as identified by SpaceMan. Refer to Dawood et al. (2002b). See Fig 4.
2. SpaceVis – a 4D tool for visualising construction products and movement of plants/temporary objects in VRML, VR web-enabled format. Refer to Heesom and Mahdjoubi (2001).

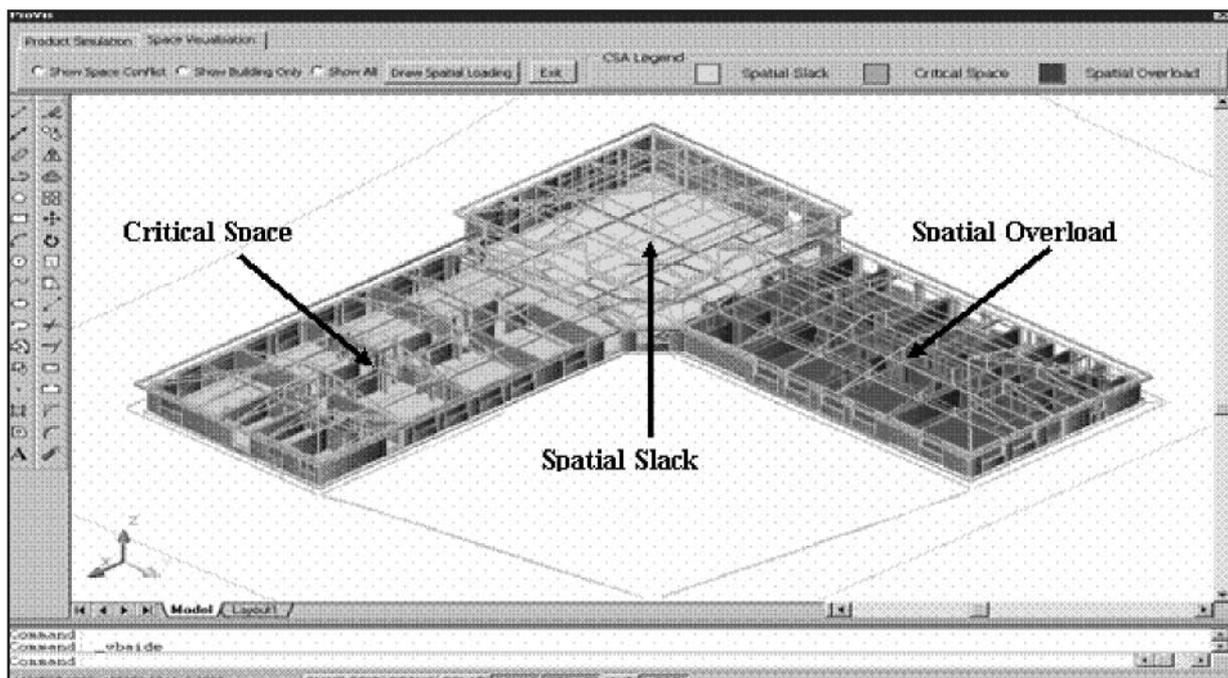


FIG 4. Visualisation of Stockport School case study using ProVis software.

USER EVALUATION

One of the main tasks of the VIRCON project is to conduct user evaluation using a historical case study supplied by one of the industrial collaborator. The aims of this evaluation are to establish the usefulness and usability of the VIRCON System, and to indicate where changes to the system might be needed. Previous literature by Borenstein (1988) and Bolois (1997) argued that one of the most important user assessment strategies is the field test, where evaluators assess developed software with actual case studies.

User evaluation design

Through pre-evaluation discussions with industrial collaborators, the user evaluation strategy was designed (i.e. the evaluators were identified, and the evaluation method and protocol chosen) to address the given aims.

Typical end users, such as civil engineering planners and project managers, of VIRCON were considered the most qualified to be expert evaluators. Such experts would be able to evaluate the system based upon their own experience of planning projects, and appreciation of how VIRCON may be implemented into their company. Ten experts (many of whom hold senior positions within their company) were chosen to evaluate the system. An overview of their background is shown in Table 1 below.

Project Planner	Skanska Construction	Leading Contractor; Current turnover is £1.3 billion with 17,000 employees worldwide.
2No Project Planners	Balfour Beatty	Leading Contractor; Current turnover is £1.44 billion with 25000 employees worldwide.
Professor of Construction Project Management	University	Academic with substantial experience in construction planning
3No. Project Planners	AMEC	Leading Contractor; Current turnover is US\$ 8 billion with 50,000 employees worldwide.
Project Manager	Ferguson McIlveen LLP	Leading Contractor; Current turnover is £8.77M with 190 employees worldwide.
Director of Production	MotEngil	Leading Contractor in EU.
Civil Engineer	VSS Civil Engineers	Consulting Engineers; Turnover £800K.

TABLE 1: Overview of Evaluators

The setting was to be five separate sessions where each evaluator could interact and use the system and to be supervised by the VIRCON development team. Each session followed the three-step procedure as noted below.

Evaluation Session - Three step procedure

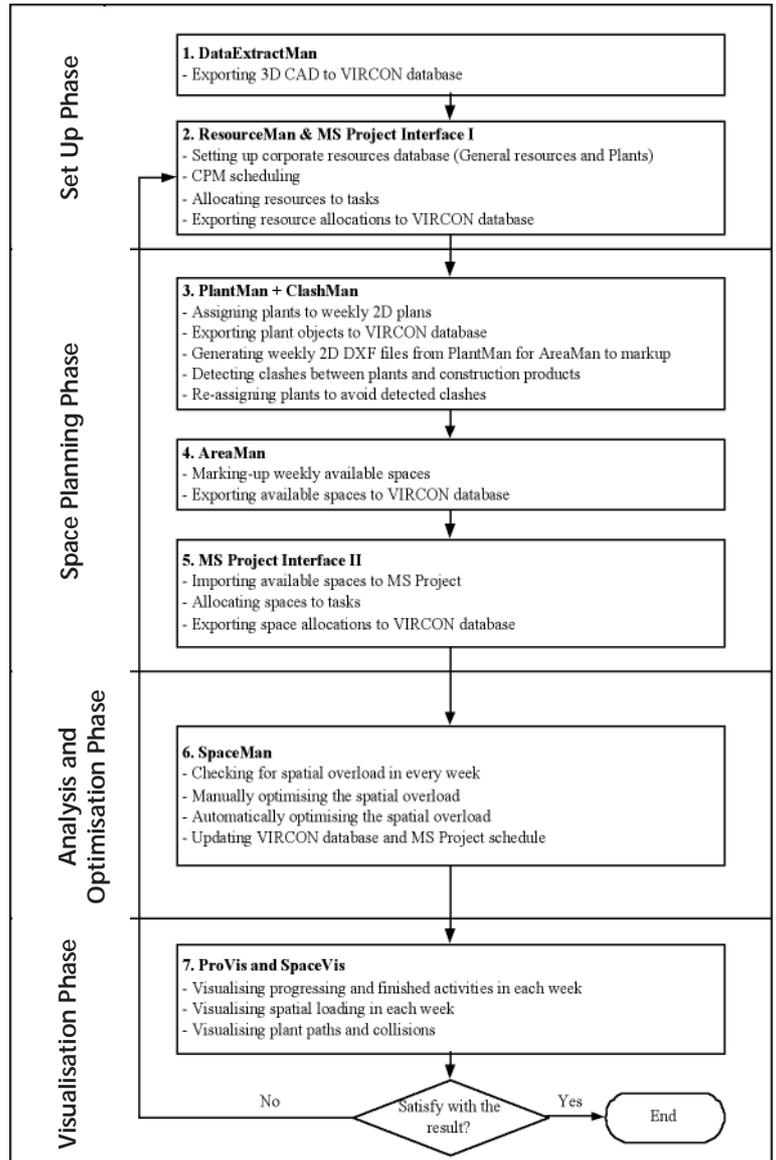
Step 1 – Introduction to VIRCON and the Case-Study

Each of the evaluator was given a brief tutorial on the use of the VIRCON system, and given an introduction of the real-life case study used in the evaluation (SKASKA Project).

Briefly, the case study comprised the £1.25M construction of a new school building, to replace Westmorland Primary School in Brinnington, Stockport, UK. The structure was constructed using the CLASP system (a rapid-build component-based method of construction for schools and other public buildings in the UK). The project also incorporated new environmental innovations such as recycled rubber floors, natural lighting, ventilation and heating recovery systems. The construction phase was seven months. The Contractor who carried out the works was Skanska Construction.

Step 2 - User Evaluation and Browse Session

In order to determine the usability of the system, detailed task instructions were prepared for the evaluator to work through, using the Stockport project as an example. The tasks were divided into four main phases, these being 1) set up phase, 2) space planning phase, 3) analysis and optimisation phase, and 4) visualisation phase. Table 2 below illustrates these phases within the VIRCON evaluation protocol.



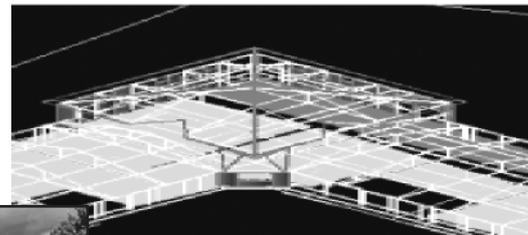
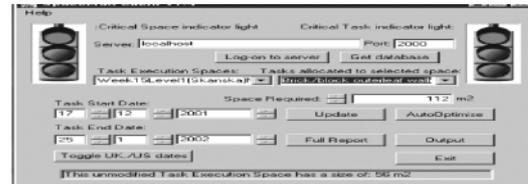


TABLE 2: VIRCON Evaluation Protocol (and typical VIRCON screenshots)

The evaluators, under supervision, followed the step-by-step instructions, but were given the freedom to change input values as desired, or explore the system to follow any points of interest. They were also encouraged to try to resolve any problems encountered without assistance. The tasks assumed a level of knowledge regarding the packages being used and industrial experience in the subject area. The questions on the usability of the system were interspersed between interactions with the system. The Evaluator gave answers in the form of 'Likert' scales - a value from 1 to 5 (easy to very complicated respectively), and was encouraged to propose specific recommendations on each tool.

Step 3 – Evaluation through questionnaire and Semi-structured Interview

Finally, the evaluator was asked to evaluate the overall usefulness, benefits and perceptions of future implementation and improvements on the VIRCON. The questions covered various aspects including potential benefits of using VIRCON as a strategic decision support planning system and communication tool, any cost implications and barriers for implementation into industry.

User Evaluation Results And Comments

The results from the user evaluation and browse session are shown in Table 3.

nD Modelling Road map: A Vision for nD-Enabled Construction

Item	Easy			Complicated	
	1	2	3	4	5
SETUP PHASE					
1.1 Appraisal of DataExtractMan					
Exporting 3D CAD to VIRCON Database	90%	0	10%	0	0
2.1 Appraisal of ResourceMan					
Setting up corporate resources database	50%	40%	10%	0	0
2.2 Appraisal of MS Project Interface I					
CPM scheduling	33%	45%	22%	0	0
Allocating resources to tasks	40%	50%	0	10	0
Exporting resource allocations to VIRCON database	70%	30%	0	0	0
SPACE PLANNING PHASE					
3.1 Appraisal of PlantMan					
Assigning plants to weekly 2D plans	29%	29%	13%	29%	0
Exporting plant objects to VIRCON database	56%	33%	11%	0	0
Generating weekly 2D DXF files	50%	50%	0	0	0
Re-assigning plants to avoid detected clashes	-	-	-	-	-
Detecting clashes between plants and construction products	38%	62%	0	0	0
4.1 Appraisal of AreaMan					
Marking-up weekly available spaces	60%	20%	20%	0	0
Exporting available spaces to VIRCON database	100%	0	0	0	0
5.1 Appraisal of MS Project Interface II (Allocation of spaces to tasks)					
Importing available spaces to MS Project	22%	56%	22%	0	0
Allocating spaces to tasks	22%	45%	22%	11%	0
Exporting space allocations to VIRCON database	44%	44%	11%	0	0
ANALYSIS AND OPTIMISATION PHASE					
6.1 Appraisal of SpaceMan					
Checking for spatial overload in every week	56%	33%	11%	0	0
Manually optimising the spatial overload	25%	25%	25%	12%	12%
Automatically optimising the spatial overload	44%	44%	11%	0	0
Updating VIRCON database and MS Project schedule	78%	22%	0	0	0
VISUALISATION PHASE					
7.1 Appraisal of ProVis					
Visualising progressing and finished activities in each week	56%	44%	0	0	0
Visualising spatial loading in each week	56%	44%	0	0	0
7.2 Appraisal of SpaceVis					
Visualising progressing	0	100%	0	0	0
Visualising plant paths and collisions in each week					
Total Percentage of all Tasks	52%	35%	9%	3%	1%

TABLE 3: Evaluation Results

Limitations and difficulties highlighted during the evaluation are outlined in Table 4 and Table 5 respectively. The comments given by the evaluators during the semi-structured interview are drawn upon in section 5.

VIRCON Tool	Limitations noted within VIRCON system *
Plantman	<ul style="list-style-type: none"> Plant could not be deleted once assigned. There is no error handling facilities. The generation of weekly 2D DXF files was considered slow by some evaluators.
ClashMan	<ul style="list-style-type: none"> The evaluator would have preferred to see the clashes (of products and plant) within the 3D model. The evaluator would have preferred to review the programme upon removal of collisions.
SpaceMan	<ul style="list-style-type: none"> One evaluator wanted to see the picture of spatial overload on the project plan simultaneously. Difficult to allocate space, as you cannot see allocated tasks, resources, spaces, etc. Could optimising options be chosen from a list rather than it be an automatic feature? An evaluator did not consider SpaceMan user friendly in that you had to change dates to one task without viewing its predecessors, successors and the affect on the project critical path and float. Need MS Project open to note manual possibilities.
AreaMan	<ul style="list-style-type: none"> One evaluator questioned why the program did not generate available spaces automatically.

(*Note – system limitations beyond the scope of the project have not been included within this list. Such limitations are highlighted later under Future Development)

TABLE 4: Limitations noted with the VIRCON system

VIRCON Tool	Difficulties Encountered
Plantman	<ul style="list-style-type: none"> Difficult to exit from assignment process. Entering incorrect level of floors made a mistake. One evaluator considered Plantman unreliable due to some bugs and no error handling.
ClashMan	<ul style="list-style-type: none"> On all occasions, no clashes were detected (due to bugs) so ClashMan tasks could not be undertaken.
Ms Project Interface	<ul style="list-style-type: none"> An evaluator was uncertain on what spaces had been previously allocated to tasks. Therefore, there was the need to return to AreaMan to review what information was input.
SpaceVis	<ul style="list-style-type: none"> On one occasion SpaceVis could not run the example due to bugs.

TABLE 5: Difficulties encountered with the VIRCON system

Outcome Of Evaluation

Analysis of the results

Analyses of the evaluation results show the concept to be relatively clear and the usability easy (85% within score 1 and 2 within the table). The reasons for 'harder' tasks were identified as being due to evaluators not being familiar with standard software being used (particularly AutoCAD and/or MS Project), their ability to manipulate the interface, i.e. familiarity with the icons/buttons, and confusion when there were 'bugs' noted (particularly within PlantMan). The evaluators generally considered that the tasks would be easier should they perform the tasks again.

Appraisal of VIRCON

Subject to a number of (achievable) enhancements, most of the evaluators considered VIRCON would be a useful strategic decision support planning system, and found the visualisation of the system helpful and informative. Specific areas in which the VIRCON system could add value to the construction planning process were as follows:

1. In the monitoring and optimising resource/plant levels.
2. In the identification and allocating of spaces.
3. As a communication and visualisation tool to describe the project to all parties involved in the project, and maintaining good relationship with the Client.
4. In increasing certainty to the schedule, and hence reduce project overrun.
5. In highlighting and reducing risk (i.e. recognises the constraints prior to construction).

Most of the evaluators found the manual optimising of the spatial overload, within SpaceMan, initially confusing. Limitations with SpaceMan were also identified which would need to be addressed to improve usability and usefulness. These were not being able to view Gantt chart and schedule information while carrying out manual optimisation, and the auto-optimisation possibly not providing the needed solution. Evaluators also questioned the realism of the manual optimising of the spatial overload. SpaceMan does not consider both horizontal and vertical types of movement and clashes. They advised that spatial overload depends on how good the data input is. VIRCON was expected to paint a blacker picture than real life, because in reality there is often more flexibility, where resources and plant tend to change daily.

Possible barriers to the construction industry adopting VIRCON were identified as follows:

1. Uniclass standard being adopted; and
2. It may be difficult to collect all the data required by VIRCON. At the initial stages of site instruction, for example, Contractors may not have, or wish to disclose all details of resources/plant etc. as this information may be used against him if he is late in completing the works. Contractors tend to keep their detailed schedules and not share it with other parties.

The evaluators advised that any possible savings in cost and time, made by VIRCON, would depend on the project type and situation. One evaluator advised that the detection of potential conflicts within the execution area could clearly introduce meaningful changes in the field operations and/or procedures. This will definitely save money and reduce/arrest overrun.

Despite the difficulties and limitations encountered by the evaluators, they generally gave favourable comments, showing a positive attitude towards the system. The evaluators could visualise how future extensions of the system would fit into their procedures, and the developers could identify how additions may be included in a final product. Overall, most of the evaluators would consider using the VIRCON system (again, subject to some achievable enhancements) within their company.

Appraisal of the evaluation procedure

The evaluation method adopted was considered suitable for this project. The detailed task instructions and questionnaire proved useful in structuring the subject's responses, and in prompting the evaluators to be as forthcoming as possible.

The mean time for an evaluator to complete the evaluation was 186 minutes (just over 3 hours). Some tasks took longer than others to complete simply because they called for more information to be input. The evaluator's attitude to the time taken to complete the evaluation was good. We understood this was due to their appreciation of the benefits of the system. The evaluators generally considered that the time to complete the tasks would be reduced should they perform the tasks again. As the system is further developed, more of the features are to be automated to further reduce the time taken on the system.

Looking Ahead

Further development of VIRCON tools

In addition to the improvements highlighted in the evaluation, the evaluator identified a number of areas for system development that are considered to be outside the framework of this current research project. The significant changes and additions to VIRCON were to:

1. allow interaction with Primavera (Planning Software);
2. include tasks that are not represented within the AutoCAD model. For example – cleaning and snagging items;
3. adjust the structure program menus/toolbars to be in the order that the tasks are carried out;
4. store the resource library alphabetically in ResourceMan;
5. allow visualisation of process clashes within the 3D AutoCAD model;
6. improve the accuracy of the drawing tools, zoom, etc. within AreaMan; and
7. incorporate safety issues in the space analysis.

Future evaluations

It is envisaged that further evaluation, utilising both historic and real-life cases will be undertaken once the VIRCON system has been implemented into a company's working procedures. Our Centre is currently in the early stages of optimising VIRCON for use with a major Contracting organization in the UK. At such a time, the learnability of the system may be assessed. This would be measured by the time and effort required to reach a specific level of user performance. In addition to supplying help manuals, it has been agreed that a level of training and support will be given. Further technical evaluations are also required to address the 'bugs' noted within VIRCON tools.

Conclusions

The objective of this paper is to introduce the VIRCON tools and processes and discuss the industrial evaluation of the tools.

It is concluded that this evaluation phase by industrial collaborators was successful in establishing the usefulness and usability of the system, and in prompting further changes to the VIRCON tools. Even though some limitations and difficulties were identified, the evaluators could visualise how the tools and future extensions of the system would fit into their procedures, and the developers could identify how additions may be included in a final product. The main reason for the success of the evaluation is that the industrial evaluator identified the potential benefit in adopting such a system. The usefulness of the research has been proven through a leading Contractor investing into further work for the VIRCON system to be introduced into their working procedures.

Acknowledgements

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Application of nD Modelling for Improving Construction Safety

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Abstract

During the past three decades, research efforts have been made to incorporate the use of three-dimensional computer modelling in design and construction. Most of these studies focused on construction scheduling (time) as being the fourth dimension integrated to three-dimensional models, systems or applications. In this regard and as a response to the nD Workshop hosted by Salford University, this paper reports an application of investigating construction safety in three-dimensional virtual environments (3D + Safety). Additionally, the paper presents a study conducted within the local construction industry in the State of Qatar, based on a series of Summer Research Grants.

Introduction

The conglomerate nature of the construction industry imposes difficulties on planners, designers, engineers, managers, and others who are trying to predict what kind of problems might appear during the construction phase. Research reveals that the actual construction phase is the most difficult and challenging phase to operate, control, refine, and manage within the construction industry [Barrie 1992]. During the past decade research in the area of computer aided modelling, simulation and visualization applied to design and construction was made to address different issues. Just to name few of these issues: design/CAD [Warwick 1991], construction planning and control [Kangari and Moore, 1991], construction site visualization [Cleveland, 1992], manipulator simulation [Alciatore and Traver, 1989], equipment operations and control [Opedenbosch, 1994].

Construction Safety

In general, large-scale accidents during construction are a nightmare that haunts the construction industry every day. Research on hundreds of accidents has produced four distinct accident-prone situations during construction [Kaminetzky, 1991]. First, when a temporary structure fails during construction. Second, when workers and materials or workers and equipment come into contact. Third, when workers follow unsafe practices or perform an operation with negligence. Finally, when an operation involves hazardous materials. This paper focuses on the second type as the case study presented later was directed.

Machine-Based Virtual Environment

The term Virtual Environment or VE is mainly describing a 3D computer generated immersive environment. Similarly, a VE for construction applications describes a semi or fully immersive environment, in which construction processes are visually animated and the user interacts with all visual objects within the environment. On these grounds, SIMCON is a three dimensional object-oriented virtual environment developed in 1997 at the University of Florida to visually simulate machine-based construction processes such as: material handling, earth removing and crane operations [Naji 1997]. The SIMCON environment was built using Sense8 WorldUp , a real time object oriented authoring tool enabling the distribution of fully immersive virtual environments. At run-time the SIMCON application is operated using the WorldUP stand-alone player engine. This OpenGL-based embedded engine handles the complex operations and math required to interact with objects, windows, view-ports, object behaviors and sounds through a high level scripting language syntactically equivalent to Visual Basic [WorldUP 1996]. The internal components of the player tool are as follows:

nD Modelling Road map: A Vision for nD-Enabled Construction

an object manager, an OpenGL graphics engine, a sensor manager and a run-time script handler. The object-manager controls all processes related to any visual object at the running mode as well as their associated properties. There are many ways to include different types of objects during the simulation. One way is by using the embedded OpenGL graphics engine and the associated CAD to create new objects, or from a data-base of many different CAD programs (DXF, 3DS, NFF...etc.) The OpenGL graphics engine controls the run-time viewing and rendering processes. The sensor manager manages all processes controlling different types of sensors such as: head mount displays (HMDs), three dimensional gloves...etc. as called by the application during the running mode. Finally, the script handler manages all embedded scripts within the compiled application and their relationships with respect to objects during the running mode [WorldUP 1996]. In the SIMCON application there are more than twenty seven different script modules written to control the simulation at run time (refer to the attached Appendix for Script code samples). Similarly, three compiled C routines and two DLL libraries were written to manage many complex GUI tasks in SIMCON. Figure 1 represents a general methodology of creating a compiled stand-alone application (virtual environment) using the WorldUP Design Environment.

*WorldUP is a registered trademark of Sense8-EAI Corporation.
Visual Basic is a registered trademark of Microsoft Corporation.*

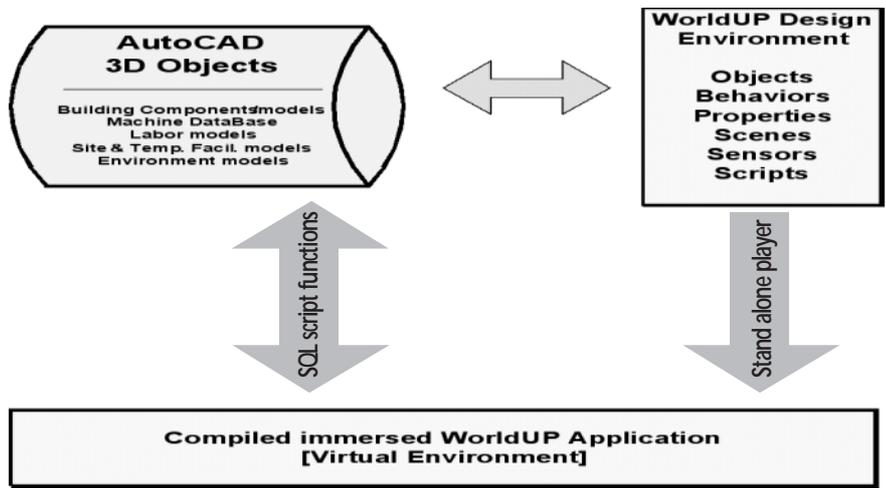


Figure 1: Virtual Environments Development based on WUP Design Environment

Object Oriented Process Modelling

The concept of object-oriented process modelling is the base on which the SIMCON application was developed. Earlier research during mid 1990s revealed positive results to model 3D building objects, machines and material in virtual environments [Opedenbosch and Baker, 1995]. In the SIMCON application there is a number of different object types which were pre-defined in order to simulate machine-based construction processes. However, the terrain object serves as the base for other objects such as: building component, machine, material or objects representing temporary site facilities [Naji 1996]. At run-time the user have the ability to choose either a flat or irregular terrain definitions stored as CAD files (Figure 2).

Similarly, machine objects such as: cranes, mobile cranes, excavators or trucks are all classified as machine objects with different properties and visual appearance. The structure of the mobile crane machine object and its hierarchy is presented in Figure 3. Although the SIMCON application was developed based on the idea of involving the user into the simulation process through a non-autonomous mode, there is an embedded scheduler. In SIMCON there are two modes to start a simulation: autonomous and non-autonomous. The autonomous mode is applicable to any material handling process in which the user chooses different spatial locations and a number of tasks to complete an operation. These pre-defined task behaviours such as: move, stop, load, unload etc. are visually represented during the simulation cycle by the chosen machine. These set of behaviours are controlled by the embedded Scheduler through a number of scripts and modules.

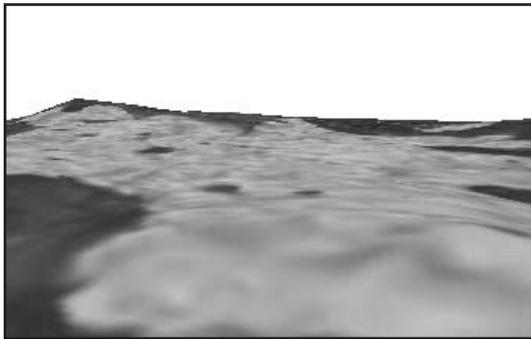


Figure 2: Sample NFF Irregular Terrain object

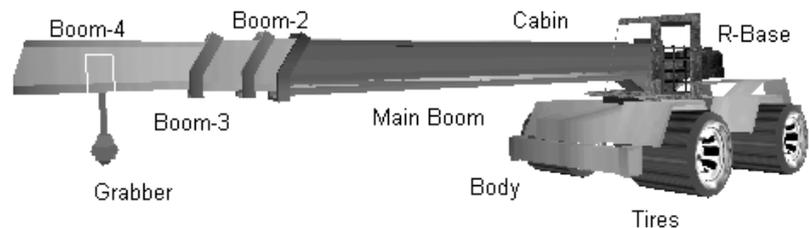
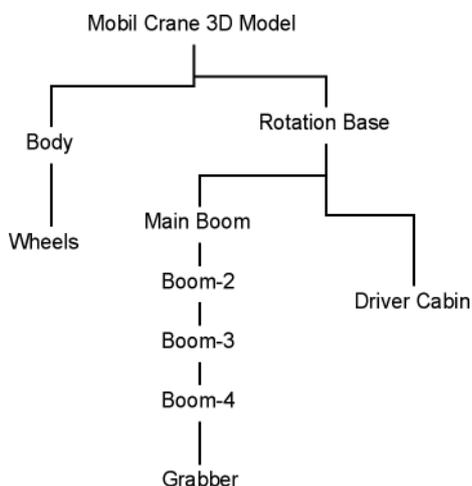


Figure 3a: Machine object in SIMCON

Figure 3b: Machine object structure

Another autonomous mode is triggered if the user wants to simulate labour movement between two different points in order to examine machine-labour collision within the available space [Naji 1996]. These particular two autonomous modes are extremely important to any project prior to the planning phase to overcome space limitations and to have an insight of actual construction site at early stages. The non autonomous mode in SIMCON is applicable to any other machine-based processes and the user has the ability to turn the simulation into a fully immersive 3D virtual environment at any time once the simulation cycle begins.

Object Oriented Building Assembly

One of the main elements in the SIMCON application is a set of modules and algorithms written as scripts which allow the user to include building definitions or structural components stored in a CAD file visually with the simulation. Different CAD formats such as: DXF, 3DS or NFF are mainly supported. Care was taken to have the SIMCON application extremely flexible in representing building components and objects. This is due to the fact that the simulation of machine-based construction processes mainly represents an interaction between a machine and building objects. In SIMCON the user has the ability to include CAD files representing building components or objects at any time during the simulation. Figure 4 presents a typical building object in SIMCON.

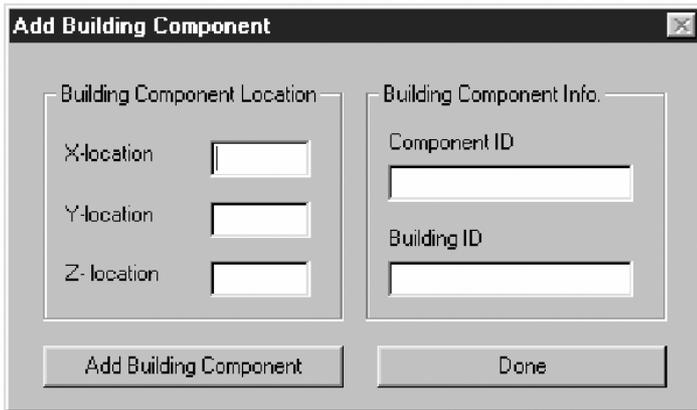
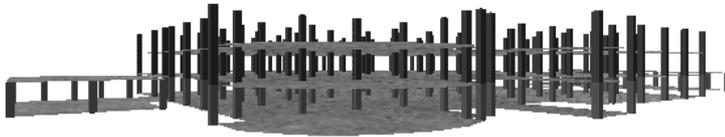


Figure 4: Building object structure/ BO Dialog box in SIMCON

Machine Objects

In the SIMCON application each machine object has the ability to move on either a flat or irregular terrain. That was done using a general terrain-following algorithm, and written as a number of scripts. Additionally, a general collision detection algorithm was written to perform collision detection checks during the simulation against other objects such as: other machines, building objects, objects representing temporary site facilities or workers. If the autonomous mode is triggered for simulating a material-handling process by any machine object, a General Problem Solving (GPS) algorithm is fired to visually simulate exact dynamic movement of the machine between the different stations (refer to Figure 5). Similarly, in SIMCON labour movement between two different spatial locations is simulated using the same algorithm [Newell and Simon, 1988]. This reactive algorithm consists of five different actions as follows:

- find target and move towards it.
- if obstacle exists on the path.
- move opposite from the target direction.
- rotate towards a free-obstacle orientation.
- move forward.
- find target and move towards it.

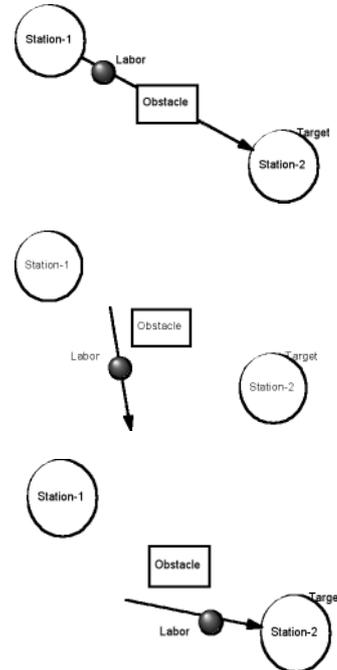


Figure 5: The GPS algorithm

Safety investigation Case Study

The case study addressed in this section is representing a mid size turn-key office building project in the city of Doha, capital of the State of Qatar. The total contract value is approx. \$2,500,000 (QR 9000,000) on a lump-sum basis. The project is located in Al-Gharrafa area with a total built up area of 8400 sq-m distributed on three identical floors. The main contractor of the project is a local Grade A contracting company with total annual projects of approx. QR 40,000,000 distributed on 12 projects. The total project duration as stated in the contract is 14 months. Due to space limitation safety of workers was a factor that should be investigated under different scenarios of machine-based operations. The study was initiated by the author based on QR 32,000 Summer Research Grant offered by the University of Qatar in 2002. It should be noted here that the case study presented in this section is one of six different case studies that were analyzed during the period 1998-2004. Three case studies were based on three summer research grants offered by the University of Qatar with a total value of ~\$ 30,000 (QR 98,000). Each case study involved the participation of a single research assistant mainly to facilitate technical support.

In this case study the SIMCON application was used to investigate different scenarios of machine-based operations within the available site space and its impact on workers safety during construction. Using the 2D plot drawings (AutoCAD file) a three dimensional model representing the skeleton building of the project was created. Four different entity layers were define in AutoCAD for the different structural components such as: foundations, beams, slabs, and columns. The exported AutoCAD (dxf) model was then loaded into the SIMCON application and automatically was referenced by the embedded WorldUP Player engine as a building object attached to a flat terrain in the scene graph. Other objects such as: machines, temporary site facilities, roads/vehicles, stored materials...etc. were loaded into the application through a number of dialog boxes interacting with the user. At this stage the scheduler module was launched through a number of scripts and interface dialogs within the application to define several autonomous machine-based operations such as material-handling (truck-based load/unload operations) based on the base-line scheduling information available. Additionally, annotation of labour-driven operations was visually simulated in the application. Based on the Qatar Building Regulations minimum clear distances between the building and the site perimeter, three different site layouts were to be analyzed. These scenarios represent the locations were machine-based operations should take place during the construction phase of the project. Figure 5a presents the SIMCON application at running mode. Figure 5b presents the accepted case study site layout.

Conclusions based on the case study analysis

The major advantage of this analysis that the project team was able to think, test, analyze and interpret data in a real-time visual format. The SIMCON application allowed us to test different scenarios of machine-based processes in a record time. As a result of this study a number of management planning decisions were made. First, as shown in Figure 5 the east side of the building should be allocated as a material storage area. Second, temporary site facilities should be installed at the south side of the building with one movable cabin located at the north side for the security team. Third, the two tower cranes should be located at the north-east and south-west sides of the building.

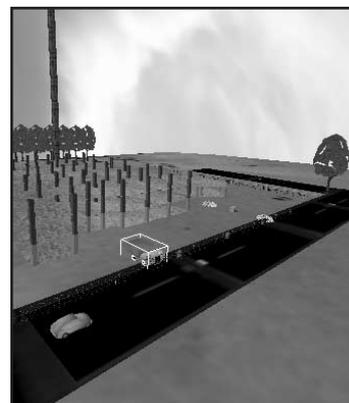


Figure 5a: SIMCON at Running-Mode

nD Modelling Road map: A Vision for nD-Enabled Construction

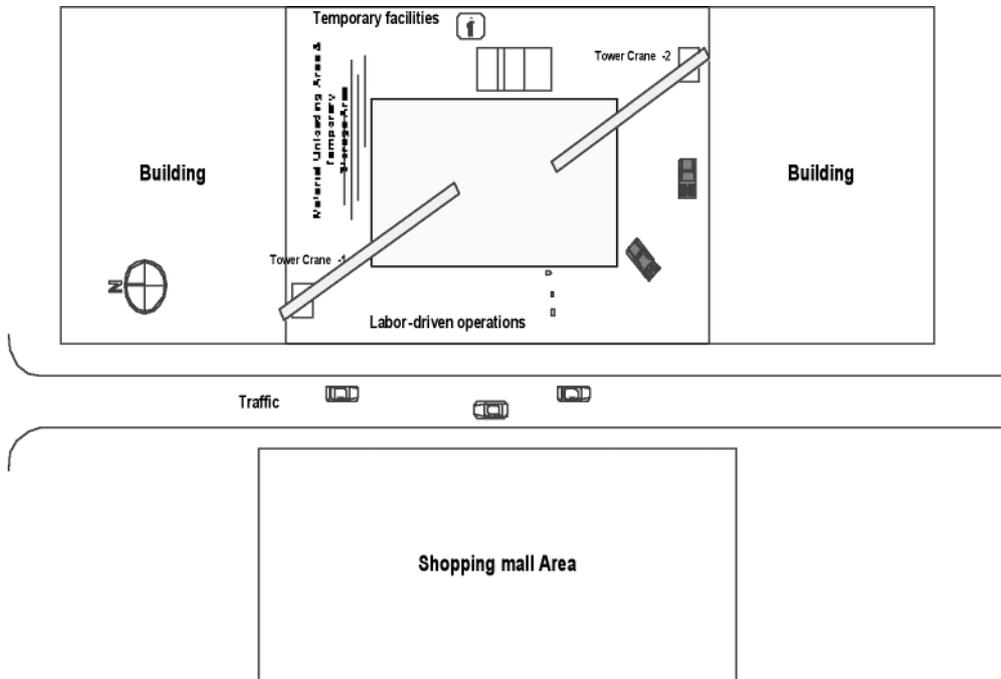


Figure 5b: Suggested case study's site layout

Current research and future directions

Based on the methodology presented in this study an on going research of applying virtual environments in decision support related to the conceptual design of residential housing projects (i.e. 3D + Decision Support in Design). Current effort includes updating the SIMCON application to accept large scale CAD definitions of complex housing projects, with more emphasis directed towards automated building regulations checks and decision support.

Acknowledgments

The author thanks the Office of Research at the University of Qatar for sponsoring this study through a total of approximately \$30,000 as three Summer Research Grants 2002-2004. The Author also thanks Prof. Ghassan Aouad, School of Construction and Property Management, University of Salford, for his invitation to the nD Workshop at Salford in September 2004.

Appendix

Sample Script Code for attaching HMD to User

'VISUAL Module, for adding HMD to user

Public visual as Boolean

Sub Main ()

visual=True

Dim s as script

Set s=GetScript('machine_viewScript')

Dim v as Viewpoint

Set v=GetViewpoint('machine_view')

v.AddTask s

End Sub

Sub right_move

Dim m as Excavator

Set m=GetExcavator('excavator-1')

Dim v as Viewpoint

Set v=GetViewpoint('viewpoint-1')

v.Rotate_y_axis,(5*PI/180)

m.Yaw 5

m.Heading=m.Heading+5

End Sub

Sample Script Code for GPS Step-1 (move towards target)

'This Task_Module is to let the Excavator equipment

'detects the location of the target object

'so it can adjust its orientation to it

Sub Task (t as Excavator)

Dim job as Script

Set job=GetScript('excv_going_to_targetscript')

Dim job2 as Script

Set job2=GetScript('excv_move_awayscript')

Dim tr as Tree

Set tr=GetTree('tree-1')

Dim bldng as Building

Set bldng=GetBuilding('building-1')

Dim m as Material

Set m=GetMaterial(t.goingto)

Dim t_o as Orientation

Dim tpos as Vect3d

Dim mo as Orientation

Dim mpos as Vect3d

t.GetTranslation tpos

m.GetTranslation mpos

Dim diff as Vect3d

Vect3dSubtract mpos,tpos,diff

DirToOrient diff,t_o

t_o.x=0

t_o.z=0

t.SetRotation t_o

t.Translate 0,0,10

If t.IntersectsMovable(tr) Then

MsgBox 'excavator is bumping into a tree,'

MsgBox 'trying to find it's new path...'

t.RemoveTask job

t.AddTask job2

Set t.Job=job2

End If

If t.IntersectsMovable(bldng) Then

MsgBox 'truck is bumping into a building,'

MsgBox 'trying to find it's new path...'

t.RemoveTask job

t.AddTask job2

Set t.Job=job2

End If

```

If t.IntersectsMovable(m) Then
    MsgBox 'excavator reached target...'
    t.RemoveTask job
End If
End Sub

Sample Script Code for GPS Step-3 (avoid obstacle)
'This Task_Module is to make the Excavator equipment
'move far enough from the obstacle

Public auto_flag as String
Public auto_machine as String
Public excv_target as String

Sub Task(t as Excavator)
    Set t=GetExcavator(auto_machine)
    Dim job as Script
    Set job=GetScript('excv_move_farscript')
    Dim job2 as Script
    Set job2=GetScript('excv_going_to_targetscript')
    t.Translate 0,0,300
    t.RemoveTask job
    t.AddTask job2
    Set t.Job=job2
End Sub
    
```

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Modelling and Visualisation of Information and Knowledge in the Construction Industry

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Abstract: The use of Information Technology offers the potential for revolutionary change in the effectiveness with which construction-related activities are executed and the value they add to construction industry stakeholders. Several attempts to take advantage of Information Technology in the construction industry are currently being carried out around the world, either at academic or practitioner levels. This paper introduces the concept of MODELLING AND VISUALIZATION OF INFORMATION AND KNOWLEDGE as a tentative point of departure aiming to bring near and act as a collaborative framework for different research efforts and organizations that currently deal separately with modelling and visualization issues in the construction industry, and contribute in this way to accelerate the transfer and adoption of research results to the construction industry practice.

Keywords: Modelling, Visualization, Information, Knowledge

Introduction

The design documents in their traditional form to a very great extent are a result of the traditional tools used for their preparation combined with the working process (Bertelsen, 1992). However, the format of the traditional design document (i.e. drawings) primarily aims at its efficient preparation by means of the traditional tools, but not necessarily at its practical use (Bertelsen, 1992). Dominant ideas associated to existing tools and work processes have been with us for centuries providing us a way of looking at construction projects. Whatever way one tries to look at how construction projects are executed today, is likely to be dominated by the ever present but undefined dominant ideas associated to traditional tools and work process that have accompanied us for centuries. Unless one can pick out the dominant ideas one is going to be dominated by them. If one can not pick out the dominant ideas then any alternatives one generates are likely to be imprisoned within that vague general idea (de Bono, 1970). In the construction industry, drawings are perhaps the main support for vague general ideas about different processes involved in the development of a construction project.

Drawings have become central tools during the design phase subsequently guiding the whole construction process, structural design is made based on them, and they end up as the main drawings in the final project document. But the fact that these drawings are so central in the process does not necessarily mean that – combined with a lot of text and the many details as later times have found necessary – they, in the best way, fulfill the design document's real purpose: The communication with the client, the users, the manufacturers, the suppliers, the contractors and the craftsmen (Bertelsen, 1992), who will use (decoding and translating) the Information and Knowledge (I&K) contained in the drawings to develop and communicate their own I&K. In this paper it is argued that Information Technology (IT) has the potential to impact how we think about and deal with I&K in the construction industry.

IT have transformed many aspects of our daily lives and revolutionized industries in both the manufacturing and service sectors. Within the construction industry, the changes have so far been less radical. Recent exponential growth in computer, network, and wireless capabilities, coupled with more powerful software applications, has made it possible to apply information technologies in all phases of the building/facility life cycle, creating the potential for streamlining historically fragmented operations (Gallaher et al,

2004). The capital facilities industry is changing with the introduction of IT tools that have the potential to revolutionize the industry and streamline historically fragmented operations. These tools include computer-aided drafting technologies, 3D, 4D and nD modelling technologies, and a host of Internet- and standards-based design and project-collaboration technologies (Gallaher et al, 2004).

In this paper we present briefly some world class research approaches, strategies, and organizations (see Appendix) that are trying to pick out the dominant ideas to dominate them and contribute to produce a very important change in the construction industry. These research efforts are mainly related to how I&K is represented (i.e. Modelling) and communicated (i.e. Visualization) in construction industry projects. It is argued in the paper that, to some extent, these research efforts are grappling with the same overall concept. In this sense, 'Modelling and Visualization of Information and Knowledge' is introduced in the paper as a concept that could help to integrate current research efforts in specific areas of IT in Construction around the world, and accelerate the transfer and adoption of research results to the construction industry.

Modelling and Visualization of Information and Knowledge

Currently, retrieving information and knowledge from project documentation is not a direct process, but demands for prone to error mental transformation and interpretation processes, and then for communication mechanisms among all those persons involved in the information and knowledge retrieving activities. Construction projects are commonly represented in design document's, being drawings (Plans, Cross Sections and Elevations) the main means to deal with the geometrical shapes that will become the physical components of the project during and after its construction stage. There is nothing vague about a geometrical shape. As a situation it is very definite and people know what they are looking at: Geometry. However, a construction project is not about geometry, but mainly about Information and Knowledge coming from different disciplines and different people making and keeping commitments.

Knowledge seen both as process and stock (Davenport and Prusak, 1998) is not neat or simple, it is intuitive and hard to capture in words or understand in logical terms. The simplest transformation to move knowledge from construction documents to people minds is done by the human eye and brain by visual observation. In fact, studies have shown that we receive approximately 80% of our external information in visual form (Intergraph, 1998). Knowledge derives from information as information derives from data. If information is to become knowledge, human must do virtually all the work and not computers. However, visualization of digital models can contribute to rapidly convert information into knowledge in people minds. The mere existing of knowledge is of little benefit, it becomes a valuable corporate asset only if it is accessible, and its value increases with the level of accessibility. Again, visualization of digital models represents a communication aspect that had not been previously available to construction project stakeholders in the way it is now.

Current research and development strategies, approaches and organizations like VDC (Virtual Design and Construction), nD Modelling (n-Dimensions), BIM (Building Information Model) and FIATECH (Fully Integrated and Automated TECHnology) (see Appendix) use digital models of construction industry projects based in three-dimensional objects linked to project information and data that can both be visualized (i.e though a computer screen). We argue that there is not only data and information contained in these models but also knowledge what is modeled and then visualized. In these models, knowledge can be considered to be 'extracted' from human minds and then represented (i.e. modeled) and visualized (i.e. communicated) to/by other people without necessarily needing an explanation from those who originally 'produced' the knowledge (i.e. 4D construction sequence visualization).

This approach to modelling and visualization of information and knowledge differs from existing 'knowledge technologies' like expert systems, case-based reasoning, and neural networks in the fact that knowledge is captured since very early stages of the project and is permanently refined in a dynamic process in which its accessibility, quality, availability, usability, usefulness, etc. vary according to the different project participants and stages.

Picking out the Dominant Ideas

VDC, nD Modelling, BIM and FIATECH are examples of established labels for world class research efforts tending to build around themselves meanings, contexts and lines of development that represent conscious efforts to pick out the dominant ideas in the construction industry projects processes development, focusing with unprecedented opportunity and precision mainly on answering to the questions: What will at the end need to be constructed? How much of this or that will be constructed? and When will it be constructed?, these research efforts act as active changing agents trying to push the construction industry to adopt new available technology under a proactive approach instead of waiting to be taken by the storm of new technology (Sawyer, 2004).

Though in understanding something names do not actually have to be used, most people find convenient to do so. Names are vital for communication and useful for understanding a situation (de Bono, 1970). Challenging a label, a word, or a name does not mean that one disagrees with its use or that one has any better alternative (de Bono, 1970). In this context, trying to see things as they actually are and not in terms of labels have led us to propose MODELLING AND VISUALIZATION OF INFORMATION AND KNOWLEDGE in the construction industry as a concept that must keep the meaning of current and future research efforts as intact as possible, and without challenging if current labels are right or wrong, could act as a theoretical bond to integrate research efforts around the world and accelerate the transfer and adoption of research results to the construction industry.

It is suggested that by modelling information and knowledge effectively outside the human mind, the risk of underestimation of the complexity of human thought and/or overestimation of the capabilities of computers shall become greatly reduced. It is also expected that this balance in the interaction between computers and human beings shall be achieved providing new visual ways to impact the judgment and behavior of professionals whose role will not be replaced, but enlarged by the support of Information Technology.

Conclusions

With a definite geometrical shape it is easy to think of alternative ways of dividing it up and alternative ways of putting the pieces together again. It is much more difficult to do this if there is only a vague awareness of the situation (de Bono, 1970). The construction process as undertaken today inevitably cause mistakes, and to a big extent current work processes have been designed to cohabit with these mistakes, or making corrections easier to manage, or to a very lesser extent try to predict and eradicate them definitively from our construction projects. This situation reflects that our way of dealing with Information and Knowledge during a construction project is closer to a vague awareness approach than to systematized ways of predicting the outcome of projects making them more reliable and improving their performance during their life cycle (Fisher and Kunz, 2004). Unless one can convert a vague awareness to a definite pattern it is extremely difficult to generate alternative patterns, alternative ways of looking at the situation (de Bono, 1970).

The Modelling and Visualization of Information and Knowledge concept is proposed as a way to help to generate, under current and future integrated and collaborative research approaches, alternative patterns needed by the construction industry to take the step of change to embrace alternative ways of looking at how we develop projects supported by current available and future Information Technology.

The Modelling and Visualization of Information and Knowledge concept introduced in this paper also could serve as a point of departure, that subsequently refined and discussed, could lead to better reflect the whole scene of change emerging in the construction industry which, as argued in this paper, could be dealing with the same overall concept.

Appendix

4D CAD (Stanford University)

<http://www.stanford.edu/group/4D/>

Extending the traditional planning tools, visual 4D models combine 3D CAD models with construction activities to display the progression of construction over time. Traditional construction planning tools, such as bar charts and network diagrams, do not represent and communicate the spatial and temporal, or four-dimensional, aspects of construction schedules effectively. As a consequence, they do not allow project managers to create schedule alternatives rapidly to find the best way to build a particular design.

nD Modelling (University of Salford)

<http://ndmodelling.scpm.salford.ac.uk/>

nD Modelling is a term coined at the University of Salford as part of their 3D to nD modelling project whose aim is to develop an integrated and co-ordinated programme of research that will assemble and combine the leading advances that have been made in discrete ICT (Information Communication Technologies) and process improvement areas to produce a coherent process-orientated and ICT-enabled integrated prototyping platform for the construction and engineering industries. This research aims to move 4D modelling into nD modelling environments incorporating process issues that support the 3D modelling of buildings in addition out 5 more dimensions which include: time, cost, sustainability, accessibility and maintenance which will allow to integrate out work in unified way. The tool aims to allowing construction professionals to perform true what-if analysis at a very early stage of a project, based on the manipulation and impact of changes to the aforementioned parameters, so that informed decisions can be made.

Virtual Design and Construction (VDC) (Stanford University)

<http://scpd.stanford.edu/scpd/courses/proed/vdcert/>

Virtual Design and Construction, is the use of multidisciplinary performance models of design-construction projects, that allows you to model the project design, construction, operation, and economic impact in order to support business objectives. VDC involves the development of competence to model, visualize, describe, make predictions about and evaluate the product, process and organization designs of projects. Stanford University currently offers a Virtual Design and Construction (VDC) program designed to teach Architecture-Engineering-Construction (ARC) and facility management (FM) professionals how to use and obtain business benefit from use of computer models of projects. The Stanford VDC program is currently based in the following kinds of tools: 3D CAD, project process planning and cost estimation, organization modelling and analysis and 4D (3D plus time) animation.

Building Information Modelling (2002) (Autodesk)

http://www3.autodesk.com/adsk/files/2255344_BIM_WP_Rev5.pdf

Building information modelling is an innovative new approach to building design, construction, and management introduced by Autodesk in 2002 that is changing the way industry professionals worldwide think about how technology can be applied to building design, construction and management. Building information modelling supports the continuous and immediate availability of project design scope, schedule, and cost information that is high quality, reliable, integrated, and fully coordinated. Though it is not itself a technology, it is supported to varying degrees by different technologies. Building information modelling is, essentially, the intersection of two critical ideas: keeping critical design information in digital form makes it easier to update and share and more valuable to the firms creating and using it; and creating real-time, consistent relationships between digital design data—with innovative parametric building modelling technology—can save significant amounts of time and money and increase project productivity and quality.

FIATECH (Fully Integrated and Automated TECHNOlogy)

<http://www.fiatech.org>

FIATECH is a non-profit consortium focused on fast-track development and deployment of technologies to substantially improve how capital projects and facilities are designed, engineered, built and maintained in the United States construction industry. FIATECH leads The Capital Projects Technology Road map project, a cooperative effort of associations, consortia, government agencies, and industry, working together to accelerate the deployment of emerging and new technologies that will revolutionize the capabilities of the industry. The vision of the Capital Projects Technology Road map project involves: current and emerging capabilities in 3-D design, analytical modelling and simulation, intelligent systems and distributed information management that offer the opportunity to create a truly integrated and automated project design environment. FIATECH also envision that the project site and build processes of the future will be re-engineered to make use of emerging information and automation technologies to minimize capital facility delivery costs (labor, material and equipment), facility deliver time, and life-cycle costs. Linked to the master facility model, construction project management systems will continuously monitor the job site for compliance with cost, schedule, material placement and quality, technical performance, and safety.

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Improving Application Resiliency in the Face of Imperfect Information

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Abstract: The nD Building Information Model aims to capture all information needed in the building lifecycle from design to asset management or facility management. Data model such as IFC is designed to capture all known or essential building information throughout its lifecycle. This enables applications to collaborate on a single building model enhancing it towards complete and integrated information unit. While it will be perfect to have the complete building information in one single model, the reality is that it is difficult to achieve perfect data due to various reasons. One major reason is that the design and the data population largely depend on human efforts. Human efforts combined with equally imperfect nD modelling tools create the situation of having "imperfect" data virtually on every data the applications would expect. This research paper focuses on the efforts done in novaCITYNETS to address this issue in conjunction with the development and application of IFC model developed by International Alliance for Interoperability. The result of the research is in the form of the product FORNAX.

Introduction: 3D and nD modelling

The world of computerized building modelling started with simple 2D drafting with the assistance of CAD. CAD software has undeniably contributed to the improvement of the design and drafting practices that are used in many countries today. However, since the CAD tool is more task oriented, its values in building modelling is limited to documentation on paper or equivalent electronic representation; but it proves to be unsuitable for added intelligence and additional information related to building modelling, and easy information retrieval for other purposes.

Today, a lot of attention is placed on building information models (BIM) that capture not only building geometry but also other important attributes such as schedule, quantity, etc. While CAD tools have improved capabilities to handle 3D drafting, BIM requires more than 3D, hence the term nD is used. Two important requirements to be met for successful nD modelling implementation are: (1) the need for universally accepted building model standard specifications and (2) change of practice from the current 2D world into nD world. There have been several attempts to define building model standard specifications, such as ISO, IFC and aecXML. Among these, IFC which is designed to have the ability to capture complete building information in the whole lifecycle of the building has gained wide acceptance among implementers. With its evolution in the last few years, IFC has become much more mature and is ready to take on challenges facing the ARC industry.

IFC Model

IFC specifies how 'things' that could occur in a constructed facility (including physical objects such as doors, walls, fans, etc. and abstract concepts such as space, organization, process etc.) should be represented electronically [1]. Each specification is called a 'class'. The word 'class' is used to describe a range of things which have common characteristics. For instance, every door has the characteristics of opening to allow entry to a space; every window has the characteristic of transparency so that it can be seen through. Door and window are names of classes.

IFC specifies each building object together with its characteristics. For example, IFC specifies a fan more than a simple collection of lines and geometric primitives of a fan. It "knows" that it is a fan and the characteristics that make it one. Figure 1 shows how a fan is described in IFC.

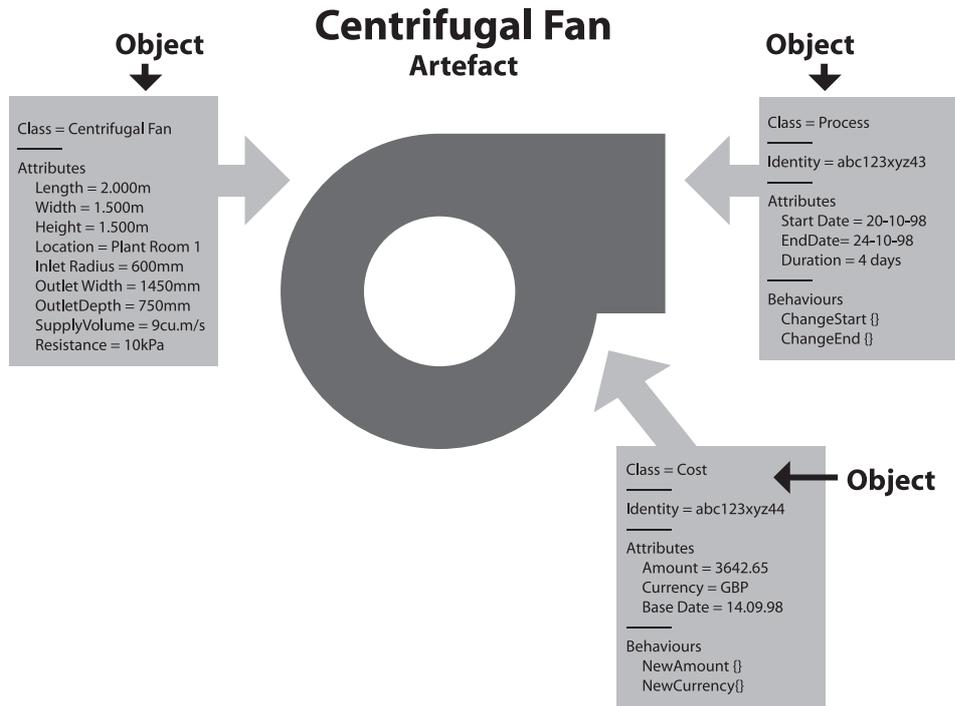


Figure 6 - Example of FAN in IFC model

In addition, IFC enables interoperability among ARC/FM software applications. Software developers can use IFC to create applications that use universal ARC/FM objects based on the IFC specification. A centrifugal fan object created in one application can be exchanged with and used in another IFC compliant application. This second application recognizes the centrifugal fan object, which reveals: "I am a fan and I know that I am a centrifugal fan. I also know how much air I must deliver against what resistance offered by the ducted system I am connected to, the radius of my inlet connection and the length and width of my outlet connection. Additionally, I know what my operation is, what my geometry is, and so forth."

The second application is able to understand these characteristics and add information to the object because it also uses the IFC specifications defined by the IA1. Applications supporting IFC will also allow members of a project team to share project data in an electronic format. This will ensure that the data is consistent and coordinated. Furthermore, this shared data can continue to evolve after design, through construction, and occupation of the building. This information generated by the project design team will be available to the building construction team and building facilities managers through their IFC compliant software

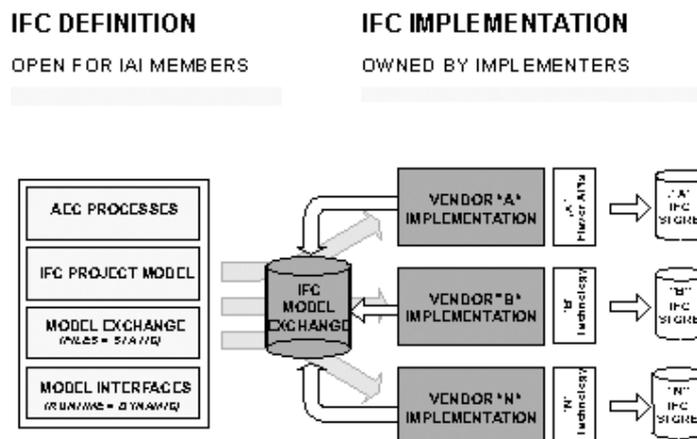


Figure 7 - IFC information sharing model

Imperfect Data

Presently major CAD vendors either have implemented IFC support or are in the process of implementing it. With the availability of CAD support for IFC data, we can expect many applications dealing with the whole building lifecycle to be ready to use the data.

One of the major challenges in dealing with data that is drafted by different people using different CAD tools is that there will be high probability of inconsistent data, referred here as the "imperfect" data. The imperfect data are caused mainly by:

- a. Different variations of building design. Building design involves human creativity and therefore there is almost limitless possibility of variations.
- b. Human errors/genuine mistakes.
- c. Use of CAD for drafting purpose only instead of using it as a proper building information model.
- d. Non-conformance to standards.
- e. Inability of CAD to export out the entire model into 100% correct IFC model.

In the face of imperfect data, applications that are built are doomed to fail due to over-dependence in the way a particular data has been presented. This way either the application will fail to function as expected when unhandled variations of data is encountered, or the application must build the capability of handling the variations within the software. This will cause a lot of inconsistency across different implementations and redundant efforts. Without consistency and simplicity of implementation, good building model like IFC and modelling tools that support it will find it hard to achieve successful acceptance.

Efforts to minimize imperfect data

There have been a number of efforts done to contain or minimize the impact of imperfect data. Below is the list of efforts currently being done.

Certifying CAD tools for desired output

Certification is one way to ensure that CAD tools produce data exactly as in the desired output. These efforts have been initiated by IAI international for IFC certification. To be able to cover specific domain of interests from the respective tools, IAI has to define the "view" in which the standards are agreed, defined and tested. To date, it has defined 2 views, i.e., (1) coordination view which covers essential requirements to enable basic building object interoperability of building information among different CAD vendors, and (2) code-checking view that contains additional requirements suitable for code-compliance checking.

The certification ensures minimum quality of data to be produced by different CAD vendors. The challenge remains in the area of how many views should be defined and fragmentation of compliance at different levels and different views from various tools that impair the ability to use the single model for whole applications within the lifecycle of a building. Certification also does not eliminate variations of output since they are still allowed under the IFC model to accommodate variations in CAD output and building object representations.

Use of additional tools to check data consistency

Tools such as Solibri model checker are popular in helping the building designer ensure that the design drafted is consistent. It is ideal to use these tools to check inconsistencies of building objects during the design stage. While the Solibri model checker is undeniably useful, it is limited in rules it can check. It will be difficult to expect such generic tool to anticipate and handle wide range of domain requirements of building model for other purposes.

Publishing standards or guidelines for end users

To further define conformance of the building model, modelling guidelines will be required and normally will be tailored for different countries to capture specific practices within them. With the guidelines or standards, there will be certain degree of improvement on the expected data. However, standards are only effective with certain enforcement, thus it will require additional tools to check the conformance. The difficulty in such implementation is that it requires heavy customization, separate from any other domain specific applications, or high dependency of human factors for conformance to the standards.

Another practical approach would be to conduct IFC tutorial. Lack of IFC knowledge among building designers and CAD users is a hindering block leading to improper structuring of building model. It also restricts the platform neutral data exchange – one of the promises of IFC. Spreading awareness about IFC and its model will help overcome some of these shortcomings.

FORNAX – an approach to code compliance checking

FORNAX is a platform designed to assist in rapidly developing the code checking applications. It uses IFC as the building information model and provides on top of it, a layer of wrapper objects encapsulating the complexity of code checking requirements and resilience towards imperfect data. These objects expose easy-to-use interfaces for code-checking application and let them focus on the domain problem they are designed to solve [2]. The position of FORNAX objects in the hierarchy is show in figure 2. The aims of the wrapper objects are:

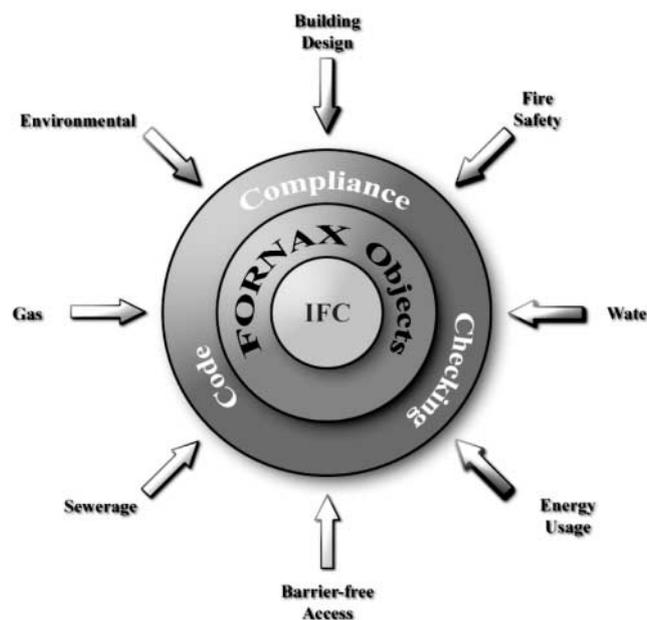


Figure 8 - FORNAX objects bridge the gap between IFC and the code-compliance requirements

nD Modelling Road map: A Vision for nD-Enabled Construction

1. Define and capture the higher-level semantics of building objects viewed not only from its physical elements in the construction but also from their usage point of view. For example 2 spaces for different usage such as a corridor and a kitchen have very different semantics in the usage of the space. They form distinct objects and may have completely different requirements. The higher-level semantics are not directly captured in the model as they are normally not part of construction.
2. Define and capture the higher-level semantics of abstract building objects like vertical shaft and apartment unit. These objects provide consistent interface to allow access to the information not only those found in IFC model but also those derived by the wrapper objects themselves.
3. Encapsulate complexity of handling the "imperfect" data. The objects will handle variations of the data for the applications using them. They have built-in intelligence to capture IFC objects and their "meanings" from sets of characteristics known to human observer. This resilience towards imperfect data will let the application focus on the domain problem being solved rather being overwhelmed by sheer limitless variations in data.

This combination of characteristics makes FORNAX a versatile platform to develop robust code compliance checking.

Advantages of using FORNAX objects

The advantages of using wrapper objects are that they deal with the complexity of handling data in its imperfections and free the applications to focus on the very specific domain problems they are designed to solve. This way consistency is greatly improved and the applications will be more resilient towards imperfect data. The wrapper objects do not remove complexity of handling imperfect data; rather they shift the complexity into themselves once. They will reduce redundancy in term of implementations and make it easier to implement applications using the nD model.

How resilience towards imperfect data is provided?

FORNAX objects minimize the dependency on explicit information needed from IFC model. Instead they derive as much information as they can from the geometry information available. This can be illustrated by few examples.

Spaces and their representations

Spaces are usually used to represent the bounded void. For code checking applications, it is important that these spaces fit the exact void. Failure to do so will lead to incorrect conclusions. For instance, a space is drawn too high overshooting the ceiling of a room as shown in figure 4. FORNAX objects work by resizing this space to its right size thus minimizing the dependency on the way space has been drawn in the model.

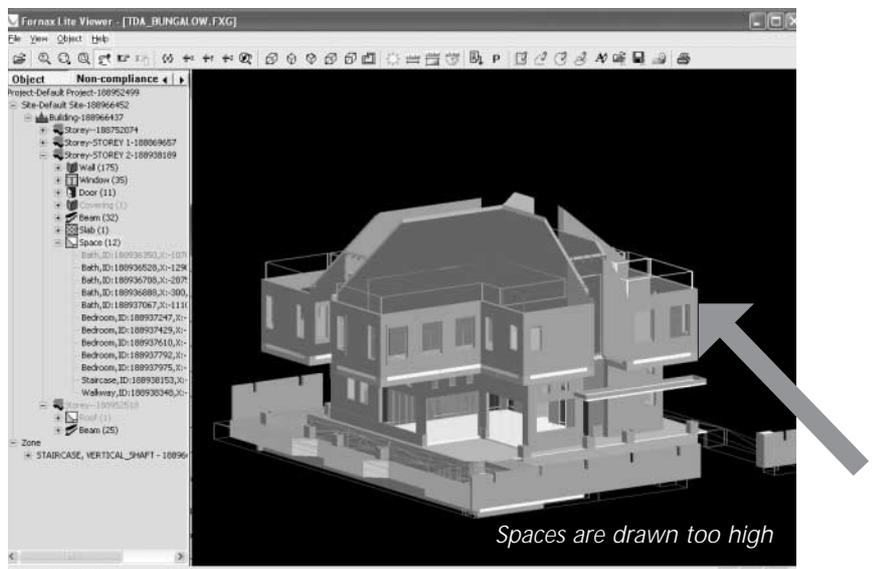


Figure 4: A model with spaces drawn beyond the ceiling

Minimum dependency on explicit input

FORNAX objects improve resilience by minimizing dependency on explicit input, wherever it is needed, from draftsman. Usually this is in the form of name declaration or property set. Since this information can be easily missed out, it will always render the applications incapable of identifying the objects using aforementioned input as their identification criteria.

An attempt has been made in FORNAX objects to circumvent this problem by using different techniques to derive as much information as possible. For example, instead of declaring a door as 'external' either in its name or through its property set, FORNAX objects take the approach of identifying the logical condition which marks this door external, which is its property of opening outside the building. With this, a concept of envelope is introduced to represent the external façade of the building. All doors lying on this envelope will be marked external. The concept of envelope has been extended to identify ventilation openings as well, which by definition also opens outside the building.

Intelligent name recognition

Use of dictionary, thesaurus and string pattern recognition with the defined level of match confidence can be used to tackle the typo problems. Therefore, the system will be able to determine "refrigeration room" as a "refrigeration room".

Intelligent identification of objects

The system will be able to identify objects intelligently. A toilet can be identified by the presence of washbasin or WC, a kitchen by the presence of stove.

Recovering from data inconsistency

Data inconsistency in the form of conflicting information is very likely. For example, a space is declared non-sprinkler protected but sprinklers are detected in it. In such cases, FORNAX objects will take the most reliable of the information. In this example, the presence of sprinkler is sufficient to declare this space as sprinkler protected.

Related approaches

The approach taken in FORNAX stands out different from any other method attempted today in terms of reliability and extensibility. In general, there are two approaches:

1. Closed system, having built-in rules in the system. They are based on proprietary system and are only capable of handling specific application. For example, BP-Expert was developed in Singapore for code-compliance checking. It falls short of the intended results due to its proprietary nature and inability to add new capabilities.
2. Mapping approach, where data from the existing systems using existing proprietary model is mapped to IFC. This allows existing applications to continue to perform without change. While it is practical, in particular if backward compatibility is required, this approach, however, soon finds its limit due to the incompatibility of the proprietary data model, and failure to handle complexity and imperfect data.

FORNAX objects in reality

FORNAX objects have been implemented in the product FORNAX developed by novaCITYNETS, Singapore. Current capabilities have been tested to reliably handle:

1. Code checking system, implemented for Singapore CORENET ePlanCheck system that handle building code compliance checking for Architectural and Building services requirements. The system is in the final stage of completion and ready for real deployment.
2. Energy simulation, implemented in the research project with National University of Singapore and Temasek Polytechnic Singapore combined with EnergyPlus simulation engine.

Future work

Work remains to be done in improving FORNAX objects' resilience against variants of imperfect data. All such tools will always fall short of meeting the limitless possibilities of variations and FORNAX objects are no exception. However, work is still underway to detect mistakes commonly made by draftsmen and this is on the on-encounter basis. However, there remain some situations, where inconsistencies are hard to detect. One such example is shown in figure 5, where a collection of beams is being used as the replacement of a slab.

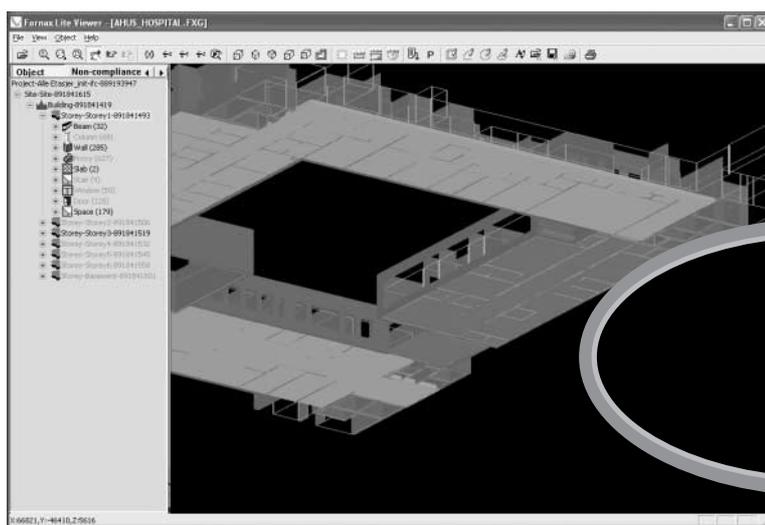


Figure 5: A model where beams, shown in circle, are being used instead of a slab.

Conclusion

Building information model is a powerful concept to centralize the building-related information from all phases of construction life cycle. However, imperfect data is a problem to reckon with if data accuracy is what is required by different stakeholders. Therefore, several steps are being taken to improve the data, which affect several key players involved in building construction life cycle. An attempt has been made to make code checking applications resilient to imperfect data in the product FORNAX and it is showing itself to be a powerful and versatile tool for developing automated code-compliance checking applications.

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Appendix D: 2nD international workshop sponsors



Centre for Construction Innovation (C.C.I)

by Steve Jessop, General Manager, Centre for Construction Innovation

The Centre for Construction Innovation (CCI) is pleased to support this progressive study into the exciting field of nD modelling. The Centre brings together a broad range of industry specialists and academics as multi-disciplinary participants in the fields of best practice, education and training, seminars, workshops and in-company support, facilitating change by learning, debate and experience.

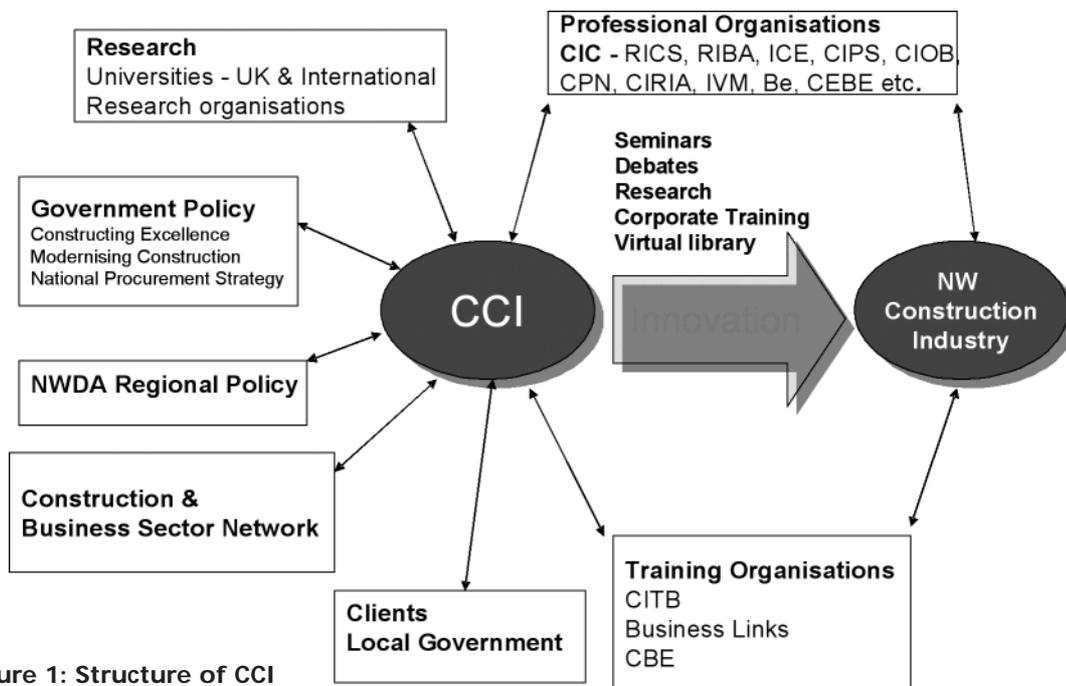


Figure 1: Structure of CCI

The Centre works both with supply side and demand side and supports industry directly where the need for change is recognised and we work with clients in driving through change (to improve health and safety, sustainability, to achieve wider community benefits, as well as more traditional targets of performance). The aim of CCI is to support and accelerate the transition of the construction industry in the region to a knowledge-based economy by stimulating regional creativity and innovation and improving access for the whole of the construction supply chain to modern practices, advanced construction research and development resources and ICT, Internet and digital media technologies.

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Regional business are encouraged to play a leading role in the development of a leading edge enterprise culture across the region with a particular emphasis on business networking, innovative uses of integrated teams, partnering, sustainability, health and safety, advanced e-commerce & visualisation technology. To achieve this aim, the centre brings together the academic expertise of the north-west Universities research base with the national policy of Constructing Excellence and the regional agenda of the North West Development Agency. In doing so the centre works collaboratively with appropriate national and regional networks and organisations such as Manchester City Council, Construction Best Practice Clubs, Business Links, CITB, CIC, CIRIA etc.

CCI have recently collaborated with Manchester Digital Development Agency to provide Visualisation Technology to the Greater Manchester business community. The MANCHESTER ALWAYS ON project is funded by the North West Development Agency and is part of the UK initiative to encourage broadband take-up. Broadband offers the business the opportunity to access 3D Visualisations via the Internet so improving competitive advantage. The purpose built Visualisation Centre situated within the CUBE building in Central Manchester also offers local business easy access to state of the art technology for business use.



CCI // 3d VISUALISATION



CCI 3D Visualisation offers a conduit facility for business to see, enjoy and utilise nD modelling research, outcomes and goals to further their business aspirations.



salford centre for research & innovation
in the built & human environment
an EPSRC funded centre

Salford Centre for Research and Innovation (SCRI)

The 3D to nD team works closely with the Salford Centre for Research and Innovation (SCRI) in the built and human environment. SCRI is funded by the Engineering and Physical Sciences Research Council (EPSRC), in recognition of the leading role the University has played in construction and built and human environment research excellence. It was established in January 2002, and it brings together a diverse group of leading international academics from the schools of Construction and Property Management, Information Systems Institute and Art and Design. SCRI is positioned within the only, and most highly rated double 5* Built and Human Environment (BuHu) research institute in Britain.

SCRI is collaborating closely with more than 60 national and international companies and institutions, representing all elements of the supply chain. The Centre develops industry relevant and appropriate research-based processes, management and operational frameworks, and Information Technology solutions in a holistic, multi-disciplinary, integrating and inclusive manner. A number of the research results from SCRI have informed the 3D to nD project in terms of lifecycle costing prototypes, integrated IT systems such as Gallicon and considerable input from the Process Protocol, Client Briefing and Requirements capture work. This strategic alliance with the 3d to nD team ensures the cross fertilisation of research ideas and outputs in a holistic manner.

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