EXPLORING THE EFFICACY OF DIGITAL TOOLS FOR THE DESIGN AND CONSTRUCTION OF HYBRID BUILDINGS

Kemi Adeyeye[1], Christine Pasquire, Dino Bouchlaghem and Jim Chandler

Department of Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU, UK

Hybrid buildings are defined as buildings that combine both new and old elements for reasons such as expansion, rehabilitation, redevelopment and regeneration. The advantage to maintaining building value and facilities management are also discussed. The research project described seeks to explore digital tools such as photogrammetry as a means of acquiring existing building information in hybrid building design projects.The project is based on the premise that 'as built' information acquired using digital tools can be combined in a mixed-reality modelling environment for interpretation, analysis and use as part of a digital architecture process, thereby providing an homologous and flexible data source at minimal expense in time and cost. Discussed are the methodologies proposed for this research.

Keywords: digital architecture, digital photogrammetry, hybrid buildings, mixed reality modelling.

INTRODUCTION

On average, the volume of building stock in the United Kingdom grew by 12.5% in the last five years and latest statistics (DTI 2006) show a 14.3% increase in building refurbishment projects (repair and maintenance) compared to new work which grew by only 10.9% between 2000 and 2005. To meet the demands of building users, at least 1.5% of the building stock is demolished and replaced with new stock while a further 2.5% is subject to major refurbishment and renovation each year (Lee *et al.* 2005)

Refurbishment and regeneration schemes are on the increase in most urban areas to balance the economies of scale and ensure the demand and supply needed to sustain the economy. Using the motor industry as an example, Adam (1989) explains that used car business sustains new car business, arguing that obsolescence in architecture will contravene user wishes. In addition, it may consequently lead to buildings e.g. housing, no longer being affordable for the average citizen. He suggests that the solution perhaps is in adaptable lifetime buildings capable of refurbishment to suit multiple needs over time. This suggests that the conversion of existing structures for more timely uses; housing, corporate, academic or industrial, will continue to increase and design professionals will continually be required to either replace or balance past footprints with modern, forward- looking buildings.

[1] o.adeyeye@lboro.ac.uk

Adeyeye, K, Pasquire, C, Bouchlaghem, D and Chandler, J (2006) Exploring the efficacy of digital tools for the design and construction of hybrid buildings. *In:* Boyd, D (Ed) *Procs 22nd Annual ARCOM Conference,* 4-6 September 2006, Birmingham, UK, Association of Researchers in Construction Management, 663-673.

Hybrid buildings are buildings where new elements are added to existing building environments for the purpose of modifying or enhancing building use and performance. These refurbishment-type projects constitute largely to work carried out by the construction industry in the UK as in most progressive countries. This is because this practise extends the service life of buildings and reduces the annual replacement rate of a building stock below what would otherwise be required to sustain a set quantity and quality of buildings. Thereby decreasing national costs required to sustain buildings, consequently increasing consumer surplus. It also leads to reduction in waste products from demolition, reduces pollution from manufacturing and construction processes, and ultimately decreases the throughput of resources (Johnstone 2001)

Although building refurbishment and recycling enhances the value of building assets and makes economic sense, in practise it implies additional design complexity and construction complications, high risks, and increases pressure for timely and efficient project delivery with minimal cost. Safety and security in this construction environment are paramount issues especially for users; living or working in the building site, and for construction staff. Additional measures are needed to meet the legal requirement of ensuring a safe and secure building before, during and after refurbishment is carried out.

The difficulty experienced by design and construction professionals in refurbishment projects are further enhanced by lack of ‘as built’ information that often characterises such projects. Information (drawings etc) provided at initial stages are often inadequate or incorrect. The heterogeneous and multi-format nature of presenting data creates further difficulty in correlating and consolidating information on existing buildings. The probability for design error at a very early stage is increased as a result of these issues.

Successful design interventions are gauged against traditional design parameters; scale, form, style, identity, cost, adaptability, usability etc. These factors are difficult to measure via condition surveys alone. Other pervasive surveying techniques for acquiring quantitative building information are delimited to one and two-dimensional information of objects in space. This is useful to some extent for positional/spatial information but inadequate for descriptive/contextual information. Auxiliary qualitative information of buildings and environments are needed to complement initial survey results, fill in information gaps and give an overall picture of the existing situation.

Digital surveying tools such as photogrammetry or laser scanning offer potentialsfor generating accurate dimensions. From these processes, a three dimensional model of an existing object can be derived, using photos or scanned output. Hence the opportunity to create three-dimensional digital representations of an object which can then be integrated with a proposed design in a mixed (real + virtual) reality environment. The implications are that designs can then be analysed for context, spatial and structural compatibility with minimal surveying and modelling costs.

This also allows for various design options and spatial interpolations to be investigated together with the client and other interest groups with no additional time spent on rebuilding physical models each time an alteration is made. Also, by exploring different design and construction scenarios accurately and to scale in a mixed reality environment, proper planning can be devised to facilitate time saving, highly productive and cost-effective construction.

The innovative combination of digital information acquisition, processing and fabrication tools such as photogrammetry, mixed reality modelling and digital fabrication technology may further blur the ever diminishing boundaries of architecture, manufacture engineering, computing, multimedia and robotic technology while actualising a more interactive and hands-on approach to design. The outcome of this research will be particularly useful in exploring modern tools for digital architecture and fabrication which can be used to record, (re)design, preserve, restore, fabricate new and existing buildings.

BACKGROUND: IMPORTANCE OF INFORMATION IN HYBRID PROJECTS

The increase in refurbishment work in the UK adds gravity to the need for a system of obtaining accurate digital information for remedial or interrogation, for repair, maintenance, renewal or integration of a new element to an existing building. Especially as these instances entail working with little or no building records, within spatial constraints, stretched resources and very little margin for error. Yet it is found that rarely, if at all, would a project be delayed (Fig 1) while a search is undertaken for additional, but unknown information (Leslie & McKay 1995) despite mistakes especially due to insufficient or inaccurate 'as built' information could prove to be expensive.

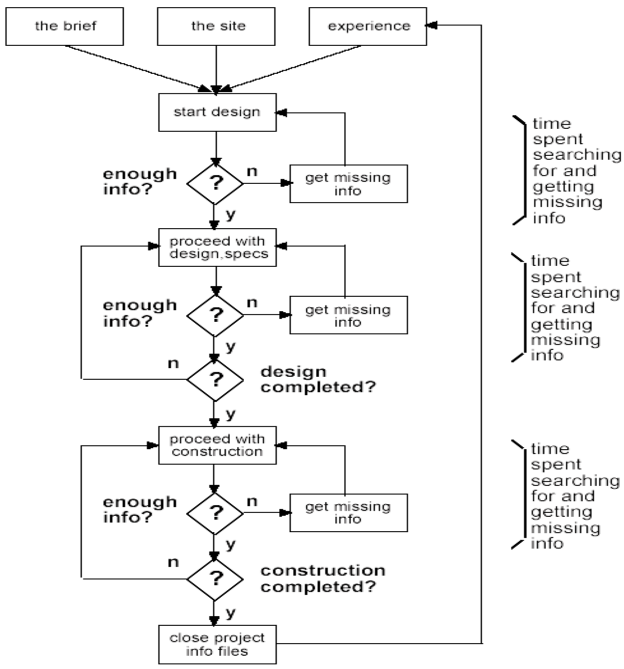

Figure 1: Getting missing information can take time (Davidson 2004)

The possibility of rework due to design error in hybrid buildings is enhanced by the availability or non-availability of detailed and relevant information; acquired, interpreted and communicated by the design team to construction professionals.

Design and building activity has evolved tremendously over the past two decades mainly as a result of the successful adoption and innovative use of digital technologies in the field of architecture and building engineering. Digital architecture, the prevalent use of computer based technologies now enhance graphical abilities through digital interfaces that allow for more careful and thoroughly acquisitive understanding of our world than ever before (Labadie 2001) especially to acquire, process, translate and combine information for effective representation and production of architecture (Fischer & Kunz 2004)

The main advantage is that digital tools make the process of design and construction easier compared to other traditional means. Architects can now easily produce three-dimensional design models to support two-dimensional drawings. Virtual reality applications also means it is possible to analyse spatial relationships, simulate building functions and analyse performance before it is actually built. Previous research (Gaiani 1999; Milgram & Kishino 1994) identifies that the difficulty is beyond the visualisation and communication of design concepts, because translating the real into the virtual for design and back again for construction is not merely a question of measurements and their transposition. Therefore, the exploration into digital tools such as photogrammetry (deriving three-dimensional models from photographs) or even laser scanning technology (using lasers to acquire three-dimensional information of an object's surface) will seek to enhance the recreation of qualitative, non-geometric information to compliment current methods created by Vitruvius centuries ago (Gaiani 1999).

Initial review suggests that exploring a simplified method for information acquisition, analysis, resolution, communication and use is a timely exercise, especially the transposition, customisation and contextualisation of data capture and mixed reality modelling techniques currently employed in the automotive, aerospace, conservation and gaming industries for design prior to construction. Thereby, maximising technologies that 'already exist… to proffer a solution for information deficiency problems in construction. However, it will take a creative vision to see how these disparate tools and devices can integrate within the ideal design setting' (Anders & Jabi 2003).

The proposed research is adventurous in that it seeks a simple solution to a systemic need for acquiring and processing real 'as is' building information; A quick, cheap, easily operable and safe method. It will mainly explore novel, comprehensive yet flexible digital techniques and tools. Technological solutions to provide and transpose real and virtual data for the effective and accurate design of hybrid refurbishment work. This explorations will be beneficial for acquiring and processing information usable for designing, evaluating, improving or repairing building infrastructure (O'Connor & Tucker 1986; Cory 2001).

INFORMATION NEEDS SPECIFIC TO HYBRID PROJECTS

In every hybrid project, 'real world' information is required on various levels to differing degrees of accuracy and representation and at different stages of the design and construction procurement process. According to O'Connor & Tucker (1986), one of the primary causes of rework in construction is the documentation on which the construction activity is based. (Fig 2).

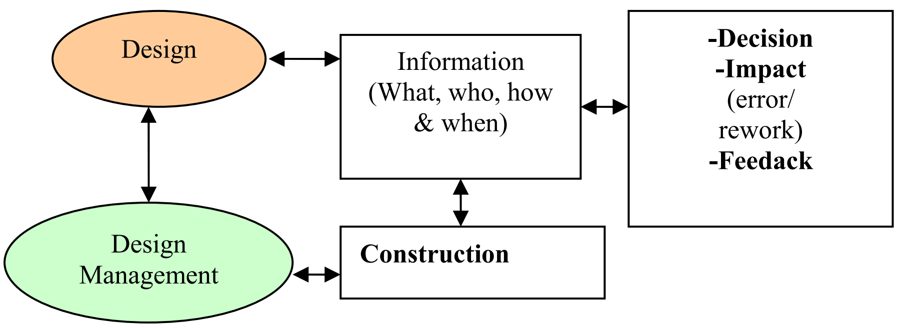

Figure 2: Information feed for design and construction processes (Simplified)

Building on an existing site implies that there will be environmental, spatial, structural, service, planning and organisational limitations pertaining to the five key building considerations; site, building fabric, structure, services and components. These limitations consequently determine the location and positioning of the new building with respect to the existing one. This makes it especially important that architects make design decisions based on cogent and precise data.

Based on literature review, case studies and interviews, it was identified that at project inception, the design coordinator and/or construction manager should answer the following pertinent questions;

1. What information is available: Existing information comprise initial design drawings, engineering drawings and specifications. This is useful for initial conceptualisation and planning but in most cases additional information is required.
2. What information is needed: Because buildings change in use and character, additional information is often needed to assess building use, changes made etc
3. Method for acquiring information: A methodology should be decided. Either by organising user groups and consultations, carrying out a condition survey etc
4. What is the significance of each information type: It is important to allocate relevance to each time of information; drawings or user feedback, and identify the impact each has on design quality and/or ease of construction.
5. What skill, techniques or tools are needed or available: It is also important to designate resources; human or equipment for information acquisition at the early stages of the project.
6. When is the information needed?: Identifying information need is important but in instances of phased design/construction as it sometimes happens in hybrid projects, it is useful for cost and planning benefits to know when the information is needed.
7. What is the consequence of the lack of preliminary information needed: This is key to alleviating errors and rework. An impact analysis at an early stage will aid planning alternative solutions for aspects of design and construction for which there is little or no information.

In most instances, ‘as built’ documentations provided to the design team e.g. drawings, site surveys are dated and no longer valid because the existing building has evolved since initial construction. Processing information - ‘real’ geometric and symbolic descriptions of space (Steed *et al.* 2004) within minimal timescale, cost and human resources for remedial, rehabilitation or interrogation of existing buildings for repair and maintenance purposes or to integrate a new element to an existing building is made complicated by various software tools available. This leads to many different and un-interoperable file formats used by different construction disciplines involved in a project. This makes communication among design and construction teams increasingly difficult (Fischer & Kunz 2004).

There is therefore a need for a system that is cheap, fast, efficient easily operable: using skill sets that are already being utilised by most design professionals. An information source that is composite and homologous, providing two and three-dimensional information as well and pictorial or textural details of existing buildings and environments in a single format from which visible, active and passive information such as form, geometry and material or user interaction and spatial relationships can be deduced.

This digitally comprehensive system must be parametric or scaleable with commensurate precision, easy to use and cost effective.

RESEARCH METHODOLOGY

The aim of this research project is to investigate and customise digital technologies and techniques for the purpose of acquiring, analysing and presenting ‘real’ building information to reduce time, cost and skill implications of lack of credible information in hybrid refurbishment projects. The specific objectives are to:

1. Review information needs in refurbishment projects.
2. Explore and compare digital technologies and graphic tools as efficient surveying techniques for acquiring existing building information.
3. Conduct case studies of existing hybrid buildings and compare information acquisition techniques during the design stage with proposed digital technologies
4. Test digital tools within context of an experimental and life project
5. Measure and document results from additional qualitative information derived.
6. Analyse the efficiency of 3-5, compared to traditional methods using factures such as ease of use, time, data transferability etc

The methods used in this research are quantitative and qualitative. These are defined and detailed below:

QUALITATIVE METHOD

Based on the premise that value and facilities management epitomises the mastering of the influence of time in buildings or the built environment and the ‘change’ that results from the effects of time, this research seeks to explore methods for capturing dynamic or longitudinal change in buildings; change as a result of age, time, value, development and use or required, level or dimension of change needed for a building to retain or gain value (or fulfil specific needs).

In order to measure change in buildings, individual variables should be measured at various times and on separate occasions. This is rarely the case in most buildings, mainly because it is an expensive and in some instances, unjustifiable exercise. This has led to the prevalent dependence on retrospective data or information (drawings, surveys etc) in the construction industry. The result is that most hybrid buildings are commissioned with little or no progressive information available. Information acquired from surveys; cross sectional information acquired from data obtained at just one point in time (Plewis 1985) consolidated with retrospective data is a common method the construction industry employs; despite the low accuracy levels and the high probability for error.

The qualitative aspect of the research will fulfil objectives 1-3 stated previously and will comprise theoretical and conceptual data collection and processing. Theoretical methods will include; extensive literature review and expert interviews. The conceptual aspect will establish micro and macro level factors upon which the commissioning of hybrid structures and design decision making are based. These factors such as spatial need, influence of time and value, structural limitations will be clustered and plotted to form a contextual or hierarchical model (Kreft & De Leeuw 1998). The information derived from data sets and subsets of the model will drive the second aspect of the research and upon which decisions will be made to determine the efficacy to the proposed tools and techniques.

QUANTITATIVE METHOD

The second part of the project is divided into three practical aspects; testing, creating and measuring. Testing the proposed digital tools against parameters identified in the qualitative research aspect is important because it ensures that the proposed tools are capable of meeting progressive information needs required in hybrid building settings. The creating aspect of the project explores the process of inculcating the tools from project inception to completion. Exploring individual case problems and solutions. The final and most important aspect of the research is the measurement; defining context and analysing positive and negative differentials of findings against the starting question, which is: Will the use of digital tools efficiently provide progressive building information for the design and construction of refurbished buildings?

Micro and macro factors identified in the contextual model, for example; time, cost, skill required, accuracy, level of information provided, usability of data will be tested and measured from experimental and real design exercises in addition to technological impact (time/cost/value) tests on 'live' case studies.

The research is still at the early stages and currently exploring image acquisition methods; photogrammetry and photographic modelling as ready techniques for acquiring building information and mixed reality modelling for real and virtual design production, representation and communication.

DIGITAL PHOTOGRAMMETRY/ PHOTOGRAPHIC MODELLING

Numerous methods are available to capture real images; single or monoscopic imaging, stereoscopic imaging, panoramic, real-time imaging (videos), exocentric or egocentric, direct or indirect using metric or digital sensors. Photogrammetry is the practice of obtaining information about physical objects through the process of recording, measuring and interpreting photographic images (Stanbridge 2005). Architectural photogrammetry is a technique used to acquire three-dimensional geometric data of buildings for CAD model from images (Wiedemann 1997). Simply, it translates 2 dimensional images into 3 dimensional representations of objects.

Photogrammetry is currently used to acquire geographical and topographical information and in remote sensing. It has advance applications in deriving maps from aerial photographs and has been used in recording internal and external elements in buildings for conservation purposes. Close range photogrammetry uses similar techniques, the difference is that images are obtained using sensors located on the ground as opposed to vertically from the air.

Photographic modelling is a simpler, less accurate method for generating image-based representations of real spaces. Texture maps are acquired from the photographs and rendered to CAD models of spatial forms. But drawings and photographs alone, even if technology can now endow some of them with virtual three-dimensional qualities lack the all-important spatial and textural attributes that only a life-size representation is capable of reproducing properly (Fry & Martin 2000). Both techniques are being explored for the acquisition of real building information which can be combined with new designs in a virtual modelling environment.

MIXED REALITY MODELLING

Representations of space have a substantial role and a specific influence in the production of space. Their intervention occurs by way of construction… by way of architecture, conceived of not as the building of a particular structure… but rather as a project embedded in *spatial context* … that will not vanish into the symbolic or imaginary realms (Lefebvre 1991).

The main challenge faced by designers in hybrid projects is the successful interpolation of real and intended spaces to maintain existing context and relationships yet fulfilling new requirements. Design visualisation is key to communication and shared perception of designs and is essential for meaningful design development and collaborations (Dunston *et al.* 2002)

Architectural critical theory and philosophy's averseness to an Euclidean or Cartesian presentation of space is resolved by *mimesis* (McQuillan 2004) - a protean term indicating relation between that which is (real objects) and that which resembles it (or represents it such as photos or virtual objects).

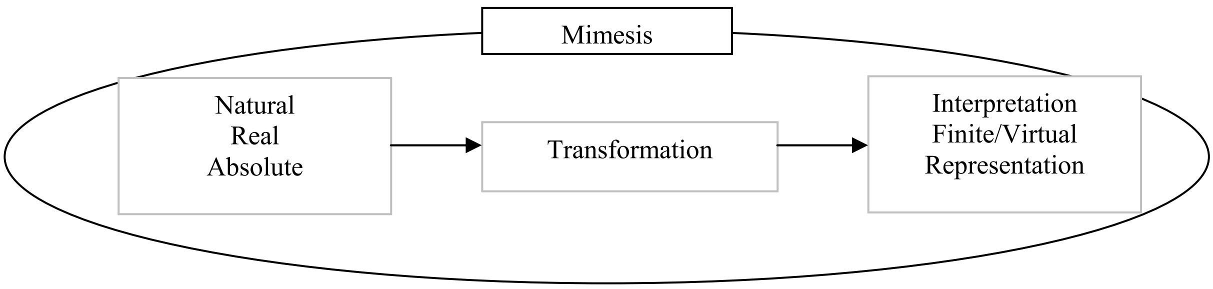

Figure 3: Geometry as Mimesis

Mixed reality produces *mimesis* (Fig 3) by merging real and virtual worlds using guiding principles such as 'principle of resemblance' and 'reproduction fidelity' for effective transformation (Milgram & Koshino 1994).

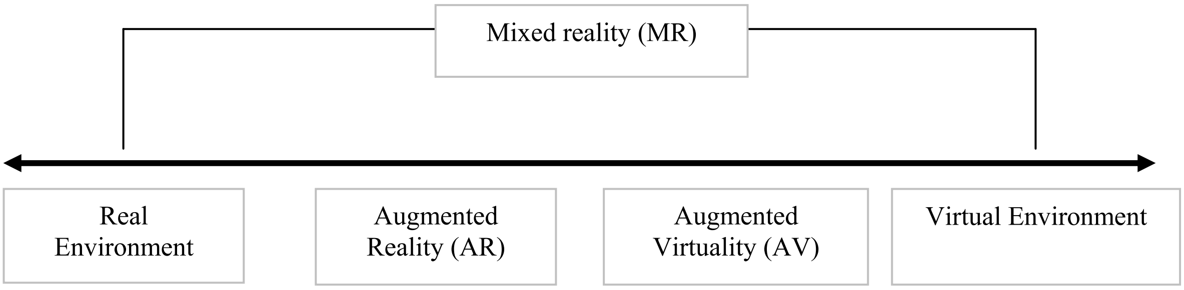

Figure 4: Simplified representation of a 'virtuality continuum (Milgram & Kishino 1994)

Mixed reality joins or overlays physical and virtual environments to varying degrees, using a number of different approaches, technologies and interaction paradigms (Milgram & Kishino 1994) e.g. photos, sound, drawings, haptic (touch) or video input.

For hybrid project applications, the approach employed is visual and image based. Three dimensional imagery representation and manipulation derived when a virtual object is integrated with an object from a real environment in a single display for single or multiple users. It is anticipated that this will enhance the perception of the designer on what exists compared with proposed creations.

FUTURE RESEARCH

Ongoing and future work will explore 'real' data capturing applications within specific design and construction contexts such as building service engineering, and the concurrent acquisition and use of information during the construction phases.

CONCLUSION

The proposed research into digital architecture and construction tools for hybrid refurbishment projects seeks to find a technological solution to providing cost effective methods of acquiring existing building information by exploring three issues; the possibility of carrying out composite three-dimensional surveys of buildings and built environments, integrating digital yet real life information with a proposed design in a mixed reality modelling environment thereby exploring compatibility between different design tools and lastly, enhancing design decision making based on an homogenous information source.

It is anticipated that findings will allow design teams to acquire needed information with less effort and cost for the design, renovation, refurbishment and maintenance of hybrid buildings. Information acquired may also be used collaboratively by other professionals to fine-tune fabrication, site safety, explore construction techniques, material behaviours and for effective maintenance of all aspects of buildings without the compromise of spatial optimisation, structural integrity and user needs.

REFERENCES

Adam, R. (1989) *Tin Gods. Technology and contemporary architecture*. Architectural Design Magazine, 9 October, VIII-XVI.

Anders, P and Jabi, W. (2003) *Digital Design in Digital Technology and Architecture*, White Paper Submitted to the NAAB Validation Conference by the Association for Computer Aided Design in Architecture, 5-8.

Cory, C.A. (2001) Utilization of 2D, 3D, or 4D CAD in Construction Communication Documentation, *5th International Conference on Information Visualisation* (IV'01), 219-224.

Counsell, J., (2000) The management and visualisation of three-dimensional models using spatial database. International Journal of Computer Integrated Design and Construction, **2**(4), 225-235.

Davidson, C. (2004) A*genda 21: Information and documentation- A Research Agenda*. Universite de Montreal, Montreal, Canada: IF Research Group , October.

Department of Trade and Industry (2006) *Statistical Press Release, Construction Output: Fourth Quarter 2005*. http: www.dti.gov.uk/construction/stats/030306/tables.htm [3 March 2006]

Dunston, P.S., Wang, X., Billinghurst, M. and Hampson, B. (2002) Mixed reality benefits for design perception. ISARC 2002: *19th International Symposium on Automation and Robotics in Construction*, Sep. 23-25 2002, STONE, W (ed.) NIST Special Publication 989, Washington D.C. 191-196.

Fischer, M. And Kunz, J. (2004) *The Scope and Role of Information Technology in Construction,* CIFE Technical Report #156, Stanford University, February, 1-32.

Fry, M.F. (2000) Breaking the Mould: Digitised Images of Ancient Outdoor Stonecarvings in Ireland. *Irish Studies Review*, **8**(3), 293-302.

Gaiani, M. (1999) *Translating the Architecture of the Real Into the Virtual*. Officina Infografica, Facoltà di Architettura di Ferrara, Italia. http://www.medicif.org/Events/MEDICI_events/Milan_nov00/Proposals/canadagaiani.pdf

Johnstone, I.M. (2001) Periodic refurbishment and reductions in national costs to sustain dwelling services. Construction Management and Economics, **19**(1), 97-108.

Kamat, V.R. and El-Tawil, S. (2005) Rapid Post-Disaster Evaluation Of Building Damage Usingaugmented Situationalvisualization, *Proc. Construction Research Congress, American Society of Civil Engineers*, Reston, VA.

Kreft, I.G. and De Leeuw, J. (1998) *Introducing Multilevel Modelling*. London: Sage Publications.

Labadie, J.A. (2001) The Graphical Interface in the Digital Millennium: The Past is Present. *5th International Conference on Information Visualisation* (IV'01), p246.

Lee, C., Hayles, C. and Ebgu, C. (2005) The adoption of requirements management in the delivery of refurbishment projects In: Sidwell, A.C. (Ed.), *QUT Research Week*, 4-8 July 2005.

Lefebvre, H. (1991) *The production of space*. Nicholson-Smith, D. (Transl), Blackwell Publishing, p42.

Leslie, H., McKay, D. (1995) Managing information to support project-decision making in the building and construction industry. CSIRO Division of Building, Construction and Engineering. In: Davidson, C. (2004) *Agenda 21: Information and documentation- A Research Agenda*. Universite de Montreal, Montreal, Canada: IF Research Group , October.

Love, P. E.D., Mandal, P., Smith, J & Heng Li (2000) Modelling the dynamics of design error induced rework in construction, *Construction Managements and Economics*, **18**(5), 567-574.

McQuillan, J. (2004) Mimesis, the Eternal Theory of Art. Lecture Notes *AHRA International Conference*, University of Nottingham.

Milgram, P. and Kishino, F. (1994) A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems*, **77**, 1321-1329.

O'Connor, J.T. and Tucker R.L. (1986) Industrial project constructively improvement', in 'Modelling the Dymanics of Design Error Induced Rework in Construction'. In: E.D.P. Love, P. Mandal, and J. Smith, Modelling the Dynamics of Design Error Induced Rework in Construction, *Construction Management and Economics*, **18**, 567--574.

Stanbridge, R. (2005), *Photogrammetry- a practical guide* [Homepage of Cathedral Communications Ltd], February 2005-last update, [Online]. Available: http://www.buildingconservation.com/arcticles/photogram/phtogram.htm [16 February, 2006].

Steed, A., Maccoll, I., Randell, C., Brown, B., Chalmers, M. and Greenhalgh, C. (2004) Models of Space in a Mixed Reality System, *8th International Conference on Information Visualisation*, London, England, 14-16 July 2004.

Wiedemann, A. (1997) Digital Architectural Photogrammetry for Building Registration. *International Colloquium on Applications of Computer Science and Mathematics in Architecture and Civil Engineering* (IKM97), Weimar.