EXPLORING THE ROLE OF MODELLING, SIMULATION, AND VISUALISATION (MSV) IN INNOVATING HEALTHCARE ENVIRONMENTAL DESIGN

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There exists a global and national need for improved understanding of how innovative solutions can be developed and applied to the therapeutic design of new hospitals. This necessity is growing as National Health Service (NHS) infrastructures face challenges of: overcrowding; thermal energy use and comfort; lighting; hygiene and Health Care Acquired Infection (HCAI); and ventilation. These issues emphasise considerable need for change in the way hospitals are designed in order to become built environments that promote health, and enhance patient wellbeing, staff performance, operational efficiency and medical outcomes. This paper reviewed current literature and tools relating to advances in MSV technology, particularly in: 3 Dimensional (3D) Computer Aided Design (CAD); Building Information Modelling (BIM); Parametric Modelling and Environmental Simulation; Construction Simulation; Virtual Reality (VR); and Facility Planning and Design Simulation. Their applicability to healthcare environmental design was reviewed to identify: examples of good practice; evidence based solutions and current trends; and conceptualise a Virtual Health Promoting Environment (VHE) that integrates MSV tools for optimised building performance. It was discovered that MSV has an important role to play in facilitating innovation and stimulating change from traditional healthcare design approaches to new approaches that support healthcare environmental design aimed at increase in the evidence base and optimisation of performance within multiple environmental parameters.

KEYWORDS: Innovation; Modelling; Simulation; Visualisation.

INTRODUCTION

One of the questions addressed by this paper is, "how can innovation stimulate change from a traditional healthcare design approach to a more evidence based healthcare promoting environmental design approach – one that incorporates consideration for multiple parameters and impacts - and what role can modelling, simulation, and visualisation (MSV) tools play in this much needed innovative change?"

Innovation Technology (IvT) has been defined by Gann and Dodgson (2007, pp.10-11) as comprising three main types of technology platform: eScience, or Grid technologies; Modelling, simulation and visualisation; and Virtual and rapid prototyping systems. "Modelling, simulation and visualisation technologies, … evolved from CAD systems and benefited significantly from developments in the computer games industry". However, opportunities and reasons abound for MSV technologies to gain prominence within the planning, design and construction of healthcare buildings. In comparison to traditional approaches, the advent of MSV provides design professionals and teams with the opportunity to investigate, demonstrate and validate various solutions within a virtual environment. The benefits inherent in such an approach were identified by Gann and Dodgson (2007) and these include, the reduction in the cost and time required for various aspects of the building design and development process. It also integrates several stakeholders, including end users, industry, practitioners and regulators – through 3D visualisation - to effectively collaborate even during the early stages of the building design process. In further describing IvT and its current prominent role, Dodgson et al. (2005, p.8) stated that "Computer-based simulation and modelling is replacing the traditional, laborious drafting, physical testing, and model building approach to many design tasks". These physical testing and model building approaches represent traditional methods such as the use of Physical Mock Ups (PMU) for addressing specific assessment and validation requirements, but which is subject to limitations in its ability to incorporate multiple parameters in its assessments and validations. Computer based models, according to Dodgson et al. (2005), assist design tasks with diagnosing, analysing, verifying and optimising design. Advances in MSV technology offer many opportunities for a more integrated approach to the planning, design, construction and operation of healthcare infrastructure. This is intended for improvement in operational efficiency in order to engender clinical recovery and medical outcomes. Considerable information and knowledge is available about innovative design and construction of healthcare infrastructure. However, most of this information is fragmented and not easily accessible. The study disseminated in this paper is intended to help reduce such fragmentation, improve access and provide an excellent foundation on which subsequent research can be built on. The main methods used to gather the information include the following:

- The use of Literature Reviews: for the presentation of current Construction IT application of modelling, simulation and visualisation to healthcare infrastructure planning, design and construction.
- The use of Case Study Research: for the investigation, identification and collation of evidence of good practice in modern design and construction. The resultant information will be used to develop an approach that facilitates good knowledge transfer.

MSV tools were reviewed, particularly those relating to Three-Dimensional (3D) Computer Aided Design (CAD), Building Information Modelling (BIM), Parametric Modelling and Environmental Simulation, Construction Simulation, Virtual Reality (VR), and Facility Planning and Design Simulation. Their application to healthcare design and construction were reviewed.

The Built Healing Environment (BHE) research project has identified a link between impacts and patient recovery. The traditional approach to designing solutions to these impacts involves the use of 2D documentation, 3D physical models and Physical Mock Ups (PMU) such as the full-scale mock-up of a patient room for the Sacred Heart Medical Center at RiverBend, Oregon, United States of America (USA). This traditional approach has its advantages but is limited in its flexibility to incorporate multiple varying evidence-based design solutions, and it can also be cost intensive in its implementation. An emphasis on the adoption of new approaches such as the use of MSV technology and Digital Mock Ups

(DMU) is timely since the United Kingdom (UK) Government's policy interest is currently geared towards evolving a more innovative National Health Service (NHS).

Current research work involves improving the therapeutic design of new, and the assessment of existing healthcare environments through the use of MSV technologies that optimise performance within multiple environmental parameters, thus enhancing evidence based approaches. It also explores the development of a Healthcare Infrastructure Digital Mock Up Facility (HIDMUF) that provides a multi-parameter long-term financially beneficial evidence based approach to the design against impacts in the Built Health Promoting Environment (BHE), including those in NHS Trusts.

Tools for MSV of Healthcare Promoting Environments

One of the work packages (WPs) of our current research, Improving the Therapeutic Design of Healthcare Environments through the use of MSV, involves the 'determination of the human aspects associated with MSV technology use and its impacts on decision making'. Part of the review presented in this paper represents a study undertaken to identify some of the MSV tools currently being applied to healthcare design and construction, as well as the role their use has played in the work of some stakeholders. Knowledge acquired from this study will be applied in future work. Current literature and tools relating to advances in MSV technology were reviewed, particularly in: Three-Dimensional (3D) Computer Aided Design (CAD); Building Information Modelling (BIM); Parametric Modelling and Environmental Simulation; Construction Simulation; Virtual Reality (VR); and Facility Planning and Design Simulation. Their applicability to healthcare environmental design was reviewed to identify: examples of good practice; evidence based solutions; current trends; and conceptualise a Virtual Health Promoting Environment (VHE) that integrates MSV tools for optimised building performance.

These MSV tools have been evaluated by the first author (an environmental designer and architect) based on a study of relevant literature and software, and case studies of MSV application to healthcare building design and construction. These MSV tools will be eventually mapped in relation to human aspects (planned for the latter phase of the current research) but are categorised in this paper into the following:

- 3D Computer Aided Design (CAD) Tools: these include MicroStation, ArchiCAD, Bentley Architecture, and AutoCAD Revit Architecture Suite 2008;
- Building Information Modelling (BIM) Tools: these include Bentley BIM Technology, and Bentley Speedikon Architectural;
- Parametric Modelling and Environmental Simulation Tools: these include ECOTECT, and IES Virtual Environment (VE);
- Construction Simulation Tools: these include Synchro, and Asta Powerproject;
- Virtual Reality (VR) Technology Tools: these include Urban Sim, MultiGen Creator, Vega Prime, and Immersive Environments (VR theatres, Caves, Domes, Immersive workbenches, and Hemispherical screens); and
- Facility Planning and Design Simulation Tools: these include ProModel, MedModel, ED, OR and Process Simulators, and DataAnalyzer.

3D Computer Aided Design (CAD) Tools

Widely used 3D CAD tools include: ArchiCAD 11; MicroStation version 8; Bentley Architecture 2008; and AutoCAD Revit Architecture Suite 2008. Based on the MSV tools review, these 3D CAD tools were discovered to support: integration of design and work between internal and external teams; accuracy and flexibility in design; about 10% reduction in construction time wastage; about 3% savings on the cost of projects; time resource optimisation; Building Information Modelling (BIM); compatibility with other systems; visualisation of design; effective communication; and evidence based design (Graphisoft, 2007; Bentley Systems, 2007; Autodesk, 2007).

Advances in 3D CAD and BIM have been applied by architects from Anshen and Allen for the creation, effective collaboration and integration of the mechanical, structural, electrical and plumbing systems for the Mills-Peninsula Medical Centre in California, USA. The ArchiCAD 3D BIM model was also used in collaboration with NavisWorks for preconstruction clash detection simulation tests. MSV tools were applied in the design of three USA healthcare facilities, Mills-Peninsula Medical Centre, Heart Hospital, and Santa Clara Medical Centre, and advantages were observed. For example, according to Graphisoft (2007), the use of ArchiCAD improved the integration of systems, quality of 3D visualisation, evidence based design, and avoidance of resource wastage in the delivery of the Mills-Peninsula Medical Centre scheme.

Building Information Modelling (BIM) Tools

According to Autodesk, and Laiserin (2002), BIM is a tool – based on Three-Dimensional (3D), object-oriented, Computer Aided Design (CAD) – that is used by the Architecture, Engineering and Construction (AEC) industry. It is offered by several technology providers including Graphisoft, Autodesk, and Bentley Systems, and provides a representation of the building process in order to facilitate exchange and interoperability of information in digital format. Further, the American Institute of Architects (AIA) – in its definition of BIM – states it is a technology that is model-based and linked with a project information database.

These BIM tools include Bentley Speedikon Architectural, Bentley BIM technology, and ArchiCAD. Based on the MSV tools review, and according to Bentley (2007), BIM tools were discovered to support: integration of systems; improved construction documentation coordination; accelerated decision making during the design phase; enhancement of details during other phases; improved workflow; reduction in production time; collaboration between design and development teams; minimisation of resource wastage; cost savings; time resource optimisation; compatibility with CAD platforms; 3D Visualisation; effective communication; evidence based design; and promotion of the patient healing process.

Advances in 3D CAD and 3D BIM were used by architects from Escade for the creation of a hospital design in the Netherlands through utilisation of the Bentley Speedikon Architectural. This is a single architectural integrated BIM application for MicroStation, and it supports building design and construction documentation of new and existing structures. NBBJ used Bentley BIM technology for the design, documentation and 3D visualisation of the Moscow Medical Centre. Bentley (2007) described the Centre's scheme objectives as involving the design of a hospital that promotes the process of patient healing through the creation of friendly and operationally efficient experiences. There are also inherent opportunities that were identified for BIM to gain greater prominence in the AEC industry. However, for this to be actualised, there has to be an emphasis shift from traditional design presentation and preparation approaches to more evidence based and performance optimisation oriented approaches.

Parametric Modelling and Environmental Simulation Tools

Parametric Modelling and Environmental Simulation can be described as the use of object oriented CAD for the modelling and simulation of components within multiple real-world behaviours and environmental attributes to assess, evaluate and validate design solutions.

In its description of the ECOTECT building design and analysis tool, Crawley et al. (2005, p. 232) identifies that "ECOTECT is a highly visual architectural design and analysis tool…". It has the capability to link multiple performance analysis functions to a 3D editor and modeller, and its performance analysis functions include thermal, energy, lighting, shading, acoustics and cost aspects. Its 3D editing, modelling, and visualisation capabilities are advanced enough to incorporate varying degrees of volumetric and analytical complexities. Its volumetric and spatial analysis results can be visualised and real time animations can be created to reflect updates and changes to the building's response to its location, climate, and operational hours' characteristics. ECOTECT provides the opportunity for obtaining important performance feedback during the earliest stages of the building design process. It displays analytical results as standard graph and table based reports, however, such results can also be mapped over the building surfaces and within their spaces. During studies involving the use and review of ECOTECT by an environmental designer and architect, it was discovered to be a highly visual and interactive tool that supports:

- parametric modelling;
- performance analysis covering thermal, energy, lighting, shading, acoustics, resource use, and cost aspects within multiple environmental parameters;
- mapping of analysis results over building surfaces and within spaces;
- compatibility with EnergyPlus, Radiance, NIST FDS and ArchiCAD; and
- evidence based design improvements.

Construction Simulation Tools

According to Synchro, in iBIM-UK (2008), Construction Simulation is described as the 4D Planning and Visualisation of construction schedules. Firstly, it involves the importation of a created 3D model into a 4D Planning software such as Synchro. Secondly, a construction schedule created in software such as Asta, Priamvera or MS Project is imported into the 4D Planning software. Thirdly, the individual tasks on the construction schedule are linked to the corresponding geometry on the 3D model. Fourthly, a 4D view of the time line of the construction program over time can be played back or forward and watched as a visualisation. These Construction Simulation tools include Synchro, and Asta Powerproject as identified earlier. The review of these tools by an environmental designer and architect included participation at a National User Forum, interviews, meetings, a workshop, and demo trials, which were all informative on various aspects of the tools' capabilities. These revealed that the construction simulation tools support: 4D simulation; 4D problem solving; 4D collaboration; project visualisation; bid visualisation; coordination and scheduling management; integration of design, procurement and delivery schedules; flexible management systems; cost savings; time resource optimisation; compatibility between systems; communication between clients and professionals; efficient planning; and avoidance of scheduling problems (Ormerod and Williams, 2008; Scurr and Williams, 2007).

Virtual Reality (VR) Technology Tools

Virtual Reality – otherwise known as VR – can be described as a computer simulated environment of a real or imagined system that permits users to immerse themselves and interact within the created VR environment in order to assess, evaluate and validate impacts and solutions to multiple scenarios in real time.

Virtual Reality (VR) Technology tools include Urban Sim, MultiGen Creator, Vega Prime, and Immersive Environments (VR theatres, Caves and Pseudo Caves, Domes, Immersive Workbenches, and Hemispherical Screens). Based on the review of the Antycip VR software – and work and facilities of the Advanced Virtual Reality Centre (AVRRC) – these VR tools and facilities were discovered to support: real-time interaction; optimised 3D Visualisation; collaboration between design and development teams; building performance measurement; and evidence based design (Kalawsky and O'Brien, 2008; Mould, 2007).

Facility Planning and Design Simulation Tools

Facility Planning and Design Simulation can be described as the creation and development of a computer representation of a system for the evaluation of several parameters related to its product characteristics, equipment capability, facility capacity, and operational and occupancy performance in order to support forecast scenarios.

These Facility Planning and Design Simulation tools include ProModel, MedModel, ED Simulator, OR Simulator, Process Simulator, and DataAnalyzer. A review of their capabilities revealed that they support: scenario testing; system behaviour analysis; parametric modelling; performance measurement; data analysis; accurate modelling of patient flow, staff scheduling and facility layout; conceptual planning and coding assistance; collaboration with other consultants; and evidence based design (ProModel, 2007).

The Virtual Health Promoting Environment (VHE): The Role of the Healthcare Infrastructure Digital Mock Up Facility (HIDMUF)

The Virtual Health Promoting Environment (VHE) is an emerging concept that applies the benefits inherent in the use of modelling, simulation and visualisation technology – in the form of MSV Inputs and MSV Outputs – towards solving healthcare infrastructure design and performance problems. It involves the integration of the capabilities and constituents of the virtual healthcare infrastructure to rectify the problems existent in the built healthcare infrastructure. The Built Health Promoting Environment (BHE) – and the non-digital and traditional methods usually employed in its design and assessment – are subject to physical limitations in terms of upgrade, adaptability and flexibility; they are indeed victim to the constraints of their physical surroundings. However, the VHE – and the Digital Mock Up methods employed in its design and assessment – do not have such limitations as the BHE, and they provide the opportunity for seamless assessment, evolution, demonstration, validation and documentation of healthcare building design and performance optimisation solutions.

The VHE will, through high-specification processors, process MSV Tools Input – consisting of 3D CAD, BIM, Parametric Modelling and Environmental Simulation, Construction Simulation, VR, and Facility Planning and Design Simulation tools – and develop MSV Tools Output that optimise design and performance. This system layout of high-specification processors, AEC related MSV Tools Input, MSV Tools Output, high-resolution projectors, ancillary hardware and software, and VR will constitute the Healthcare Infrastructure Digital Mock Up Facility (HIDMUF) currently being developed by the authors.

The HIDMUF (refer to figure 1) aims to enhance therapeutic design of healthcare environments – by facilitating the Virtual Health Promoting Environment (VHE) – based on multi-parameter assessment and performance optimisation. Its system layout will comprise of high-specification processors, AEC related MSV Tools Input – consisting of 3D CAD, BIM, Parametric Modelling and Environmental Simulation, Construction Simulation, VR, and Facility Planning and Design Simulation tools – and MSV Tools Output, high-resolution projectors, ancillary hardware and software, and VR display component. The VHE will involve exploring complementarities between these multiple parameters and establishing the feasibility of establishing an integrated approach. The developed integrated approach – incorporating parameters that include air quality, aesthetics, lighting, acoustics and thermal comfort – will be used for assessment, evaluation and validation of various healthcare environmental design impacts and solutions, as well as forecasting of future scenarios.

Also, current research at Purdue University's Regenstrief Center for Healthcare Engineering, Envision Center for Data Perceptualization, and Division of Construction Engineering and Management in the USA have focused on developing an immersive virtual reality mock up for the design review of hospital patient rooms. According to Dunston et al. (2007), a scarcity of evidence-based design principles and practices for patient-centred healthcare environments was identified. This necessity justified the objective of researchers at the Purdue University Regenstrief Center for Healthcare Engineering to develop a Virtual Reality (VR) mock up of a hospital patient room for the exploration of environmental design impacts on its behaviour, processes and safety, and the efficacy of its design solutions. Key to the importance of the VR patient room mock up is its high level of interactivity that facilitates the evaluation of its designed space as a therapeutic environment. Healthcare practitioners provided positive feedback on the mock up's performance and this has further justified the objective of the researchers at Purdue University to develop additional VR mock ups for other hospitals.

The current and proposed use of digital mock ups and virtual environments described in this paper demonstrate an emerging trend towards the adoption of new approaches. Since innovative solutions can be complex and involve several facets, the traditional use of physical mock ups to support these can be cost intensive. However, the emergence of MSV technologies provide a platform for cost effective visual alternatives that are flexible, upgradeable, performance optimisation driven, and equipped for evaluation and validation of multiple healthcare building design parameters, impacts, solutions and scenarios.

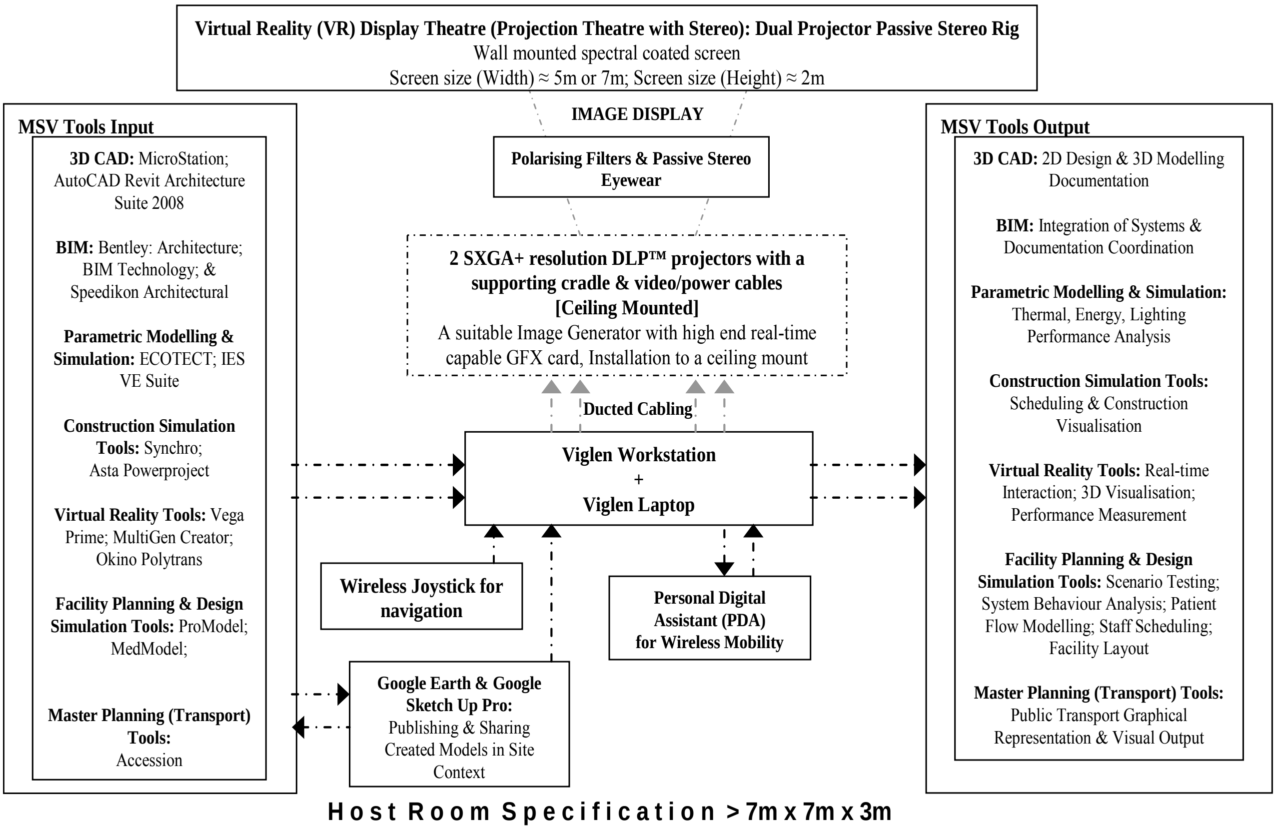

Figure 1: The Healthcare Infrastructure Digital Mock Up Facility (HIDMUF) that facilitates the VHE.

CONCLUSION: THE ROLE OF MSV TOOLS IN SUPPORTING INNOVATION IN HEALTHCARE ENVIRONMENTAL DESIGN

Based on the evidence presented in the studies reviewed, it was discovered that the application of MSV technology to the design of the healthcare environment facilitates the development of innovative methods, as well as solutions. It also offers opportunities for an integrated approach to the planning, design, construction and operation of healthcare built environments. Since the conceptualisation, development and operation of healthcare built environments involve complex and diverse processes, new approaches that integrate these processes offer opportunities for improvement in the planning, design, construction and operation of healthcare built environments. Although it is accepted that innovative solutions are complex and involve several facets of complexity, it is also important to appreciate that the traditional use of physical mock ups can be expensive. However, it has been discovered that the recent advances in MSV technology provide a cost effective, more visual and evidence based alternative when compared to the more cost intensive traditional approaches. Healthcare built environments that are designed with specific reference to the needs of patients, staff and visitors have been shown to deliver positive outcomes. MSV technology and its tools can effectively support the design of such healthcare built environments that cater to occupant needs and medical expectations within multiple environmental parameters.

These MSV tools were discovered – based on a review by an environmental designer and architect – to play a crucial role that supports innovation in healthcare built environments by:

- providing an evidence base that aids planning for designing integrated delivery and operation;
- facilitating effective decision making for multiple stakeholders through visualisation and simulation processes; and
- integrating processes and systems for effective collaboration and decision making.

As stated earlier, MSV technology provides an integrated approach to the planning, design, construction and operation of healthcare infrastructure, and it also offers opportunities for improvement in operational efficiency in order to engender clinical recovery and medical outcomes. MSV can support innovation and stimulate change from traditional healthcare design approaches to new approaches that support healthcare environmental design aimed at increase in the evidence base and optimisation of performance within multiple environmental parameters.

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