Integrated Modelling, Simulation and Visualisation (MSV) for Sustainable Built Healing Environments (BHEs)

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Abstract

The purpose of this paper is to explore the potential benefits of integrated modelling, simulation and visualisation (MSV) technology with a view to conceptualising a virtual built healing environment (VBHE) approach that supports sustainable built healing environments (BHEs). Through presenting an overview of BHE issues and benefits of using integrated MSV technology for solutions, this paper demonstrates the potential of using integrated MSV technology – including VBHE as a viable integrated MSV approach – in facilitating sustainable BHE design and assessment. This paper also identifies barriers to the full adoption of integrated MSV technology, and proffers ways of overcoming such barriers.

Keywords Built; Environment; Healing; Modelling; Simulation; Visualisation.

Introduction

The concept of the Built Healing Environments (BHE) has been given increased prominence over recent years, and there has been recognition of the relationship between patients' surroundings and their rate of recovery. There are many environmental factors that could contribute to patients' wellbeing and rate of recovery. These include thermal comfort, day lighting, acoustics, aesthetics, quality of space and place, ergonomics and accessibility, way finding, and air quality. The design of the BHE should be such that it enhances environmental quality for performance efficiency and well-being. For instance, BHEs must develop patient focused environments that enhance patients' health and recovery processes if they are to meet their intended aims (NHS, 2004). Integrated design and construction approaches have been used to develop hospitals with physical environments that have a positive influence on patients' health and recovery outcomes (Cox and Cox, 2000). Douglas and Douglas (2005) examined patients' perceptions of hospital environments and assessed the influence of the built environment on patients' health and well-being. The findings suggest that supportive built environments with good layout and accessibility can create an overall inviting, calming and engaging healthcare environment for patients and their families, thereby leading to improved patient recovery (Wendler, 1996).

Aim and Objectives

The aim of this study is to explore the potential benefits of integrated MSV technology with a view to conceptualising a VBHE approach that can support sustainable BHEs.

The objectives of this study are to:

- Explore the user benefits of integrated MSV technology, including CAD and BIM.
- Explore good practice in the use of BHE related purpose-built modelling and simulation, VR and DMUs.
- Conceptualise a VBHE approach that can support sustainable BHEs.

Methodology

The central methods used for data collection and analyses are:

- Review of BHE literature in order to explore BHE impacts and how these could be addressed by using advanced design and performance assessment solutions.
- Surveys of healthcare AEC related organisations based in the US, UK and Finland in order to explore the user aspects and benefits of using integrated MSV technology, including CAD, BIM, VR and DMUs for sustainable BHE design and assessment.
- Case study research in order to explore the user aspects and benefits of using VR and DMUs developed by this study's US and Finland based healthcare AEC related organisations.
- Purpose-built modelling and simulation assessment of the ability of integrated MSV technology to model, simulate and visualise sustainable BHE design and performance.
- Conceptualisation of a virtual built healing environment (VBHE) as an example of integrated MSV that supports sustainable BHEs.

Findings from the Review of BHE Related Literature: BHE Impacts and Possible Solutions

Lawson and Phiri (2003) compared the outcomes of patients treated in modern hospital wards with similar patients cared for in older hospital environments. The conclusions showed that refurbished wards had better recovery results and shorter times for the healing process. However, it is difficult to determine how much of this was associated with: the physical environment; improvement in healthcare service provision; or introduction of new technologies.

BHEs very much depend upon the design and construction of healthcare facilities that contribute to the quality of care and to the recovery process while promoting therapeutic goals and enhancing operational efficiency. Previous research has linked quality of care, and patient health and well-being with the physical characteristics of the healthcare environment (Douglas and Douglas, 2004 and 2005). More specifically, there is evidence that the physical environment of hospitals can affect the healing process, for example, by:

- Reducing the level of anxiety and stress (Beauchemin and Hays, 1998; Pattison and Robertson, 1996).
- Shortening recovery periods following surgery through better view of surroundings and the environment (Ulrich, 1984).
- Positioning of furniture to increase patient well-being (Sommer and Ross, 1958; Baldwin, 1985).
- Establishing links between built environments and patient recovery (Gabb, et al., 1992).
- Provision of appropriate space and conditions to decrease patient recovery time and maximise the use of therapeutic environments (Ewing, 2005).

The concept of designing therapeutic environments is not new (Francis et al., 1999). However, relationships between environmental stimulus and response are complex and not fully understood (Canter and Canter, 1979). According to Gesler et al. (2004), the therapeutic environment of hospitals relates to their physical, social and symbolic design. Therefore, the aim should be to develop facilities that are efficient, accessible to users, and promote occupancy well-being (Gesler et al., 2004).

Researchers in design and architectural disciplines have demonstrated that people are sensitive and responsive to the stimuli that they receive from the built environment (Beer and Higgins, 2000; Francis and Glanville, 2001; Hosking and Haggard, 1999). Researchers in the US and UK have studied the various impacts of the built environment on patient health, well-being and recovery from illness thus demonstrating how the design of healthcare environments can affect clinical and health outcomes (Ulrich, 2003; Pattison and Roberton, 1996; Beauchemin, 1996). Various studies (Hilton, 1985; Keep, 1980; Rubin and Owen, 1998) have demonstrated that the design of the built environment can help to reduce anxiety, the need for palliative medications, tiredness, and disturbance.

Clinical Outcomes for BHE Occupants (Patients and Staff)

Ulrich et al. (2004) identified and reviewed more than 650 rigorous scientific studies pertinent to understanding how the design of acute care hospitals affect patient outcomes. They showed that the conventional ways that hospitals are designed heightens stress, erodes safety and worsens outcomes. More positively, they asserted that the level of stress, risk and ineffectiveness is unnecessary as improved design of physical settings can be important in reducing stress, making hospitals safer, more healing and better places to work (Ulrich et al., 2004). Gross et al. (1998) also reviewed literature on the impact of the physical environment in which treatment occurs, on both the treatment process and its outcomes. Gross et al. (1998) proposed the merging of user-friendly architectural and environmental design components to create an integral healing environment. For example, a model of psycho-environmental approach to psychiatric hospital design was suggested in order to provide an important and effective tool in the pursuit of a humane and efficient containment and reduction of severe psychopathology. Douglas and Douglas (2004) also studied the attitudes and perceptions of patients to the built environment of hospital facilities and concluded that they prefer a hospital that is welcoming and a homely space for themselves, as well as their visitors.

Reduced Noise Improves Patient and Staff Outcomes

Research has shown that hospitals and many clinics are noisy environments (Aaron et al., 1996) with levels far exceeding World Health Organisation (WHO) guidelines. There are many potential sources of noise in hospitals and clinics such as overhead paging, pneumatic tubes, trolleys, medical equipment, staff voices and roommates (Blomkvist et al., 2005). A second reason why healthcare buildings are too noisy is that many surfaces, including ceilings and floors are hard and sound-reflecting, thereby enabling noises to echo, linger and travel over large areas and into patient rooms (Ulrich, 2003). Several studies have demonstrated that noise can worsen patient outcomes, for example, causing sleep loss, elevated physiological stress, increased blood pressure (Blomkvist et al., 2005) and higher frequency of rehospitalisation (Hagerman et al., 2005). Excessive noise can also reduce the quality of the working environment. Doctors, nurses and other healthcare workers may be subjected to increased levels of stress and annoyance, increased perceived work demands and reduced speech intelligibility, which all lead to a reduction in the quality of care being provided (Blomkvist et al., 2005).

Research indicates that the key to achieving a quiet healthcare building is found mainly in the appropriate design of the physical environment, not in modifying organisational culture or staff behaviour (Ulrich, 2003). Ulrich et al. (2004) identified important design measures for the reduction or elimination of noise through the provision of single-bed rooms; the installation of high-performance sound-absorbing ceiling tiles or panels that sharply cut noise propagation; and replacing overhead paging with quite systems.

Improved Patient and Staff Safety

Ulrich et al. (2004) suggested that patient and staff safety can be improved by reducing risk from airborne and contact-spread infections. Ulrich (2004) suggested that the installation of alcoholbased gel dispensers at bed-side, for example, next to staff movement or work paths, and directly within their visual fields can increase hand-washing rates.

A clear advantage of single-bed rooms compared to multiple-bed rooms relates to the reduction of airborne transmission through air quality and ventilation measures (Williams et al., 1988 and 1989). These include filtration, negative room pressure to prevent a patient with an aerial-spread infection from infecting others or creating positive pressure to protect an immuno-compromised individual from airborne pathogens in nearby spaces (Williams et al., 1988 and 1989). Multiple-bed rooms are more difficult than single-bed rooms to decontaminate thoroughly after a patient leaves (Ulrich et al., 2004). They exacerbate the problem of multiple environmental surfaces acting as pathogen reservoirs that can potentially spread infection via environment-patient or environment-staff-patient contact sequences (Ulrich et al., 2004).

Floor Layout Design Affects Staff Fatigue and Time for Patient Care

Poor design of floor layouts can erode patient safety by increasing staff fatigue and stress, forcing nurses to spend much of their time engaged in wasteful 'hunting and gathering' activities such as fetching supplies, and greatly reducing the amount of time staff have for monitoring patients and delivering direct care. Hendrich et al. (2004) showed that floor layouts with decentralised nurse charting/observation stations sharply reduce staff walking, and markedly increase patient care time, especially when supplies are also decentralised and close in proximity to patient rooms.

A Room with a View and Daylight Exposure

Different investigators have reported that patients hospitalised for severe depression have considerably shorter stays if they are cared for in comparatively sunnier rooms in contrast to shaded or dim rooms (Benedetti et al., 2001; Beauchemin and Hays, 1996). A study of surgical patients also established that those assigned rooms with higher daylight exposure reported suffering less pain and actually took 20 percent fewer higher dosage pain medication (Walch et al., 2005).

There has been research into healthcare settings which demonstrate that visual exposure to nature can quickly and effectively lower physiological stress (for example, reduction of blood pressure) and improve emotional well-being. For instance, surgery patients with window views of nature compared to a brick building wall required fewer potent pain doses following surgery (Ulrich, 1984). Simulations of nature (nature art, virtual reality) can effectively distract patients, and thereby reduce pain and discomfort in persons undergoing procedures such as bronchoscopy, chemotherapy or burn dressing changes (Diette et al., 2003). Cortvriend (2005) identified that factors influencing recruitment of hospital staff include location, car parking and transport links, and family-friendly ward/patient areas. Furthermore, Cortvriend (2005) reported that open nursing stations result in staff spending more contact time with patients and are able to observe patients more easily.

Single-Bed Rooms Work Better than Multiple-Bed Rooms

Based on a varied body of research, it is clear that single-bed rooms have several major advantages over multiple-bed rooms or open bays (Ulrich et al., 2004). As noted earlier, these benefits include lower risk for hospital acquired infection and far less noise. Other documented advantages are much better patient privacy and confidentiality, better communication between staff and patients and superior accommodation for families (Ulrich et al., 2004). Single-bed rooms also reduce patient transfers between rooms, thereby reducing costs and medical errors (Hendrich et al., 2004). Multiple-bed rooms have been shown to generate more patient transfers than single-bed rooms because of incompatibility amongst roommates (Ulrich, 2005). There is also evidence of patient care units with single-bed rooms that do not require higher nurse staffing or increased nurse/patient ratios compared to multiple-bed units (Hendrich et al., 2004). Lawson and Phiri (2000) studied two National Health Service (NHS) hospitals and reported that 93 percent of patients in single-bed rooms stated that they: preferred them over multiple-bed rooms; had shorter hospital stays; required fewer analgesics; and were more satisfied.

Discussion: Benefits of Innovative Design Solutions for Sustainable BHEs

The financial benefits of appropriately designed environments, though implicit, are far reaching and can result in the following:

- Improved medical outcomes.
- Reduced stress within the working environment.
- Reduced occurrence of infections.
- Reduced intake of expensive analgesics.
- Improved job satisfaction for employees, including fewer staff absentee rates and higher staff turnover.

Innovative design and construction solutions can lead to economic, social and environmental benefits associated with the provision of new or improved services, as well as decreasing the cost of existing services. This also applies to healthcare where innovative solutions can help to create appropriate healing environments, reduce costs, improve affordability and reduce risks. More innovative design and construction solutions for healthcare infrastructure are needed to satisfy increasing demands for better healthcare provision and sustainable high quality BHEs. The direct improvement of patient healing processes and recovery rates is partly due to using advanced design solutions. However, user behaviour has been identified as a barrier. A key user behaviour that has been identified to be in need of change is the reliance on the use of only traditional approaches in the design of BHEs. For example, the use of Physical MockUps (PMUs) and non-digital design methods are constrained in their ability to: model multiple parameters; and simulate multiple scenarios.

Findings from the Exploration of the Benefits of Using Integrated MSV for Sustainable BHE Design and Assessment

Surveys of healthcare AEC related organisations based in the UK, US, and Finland were undertaken in order to explore the user aspects and benefits of using integrated MSV technology for sustainable BHE design and assessment. These were done as part of the Engineering and Physical Sciences Research Council (EPSRC) funded project, entitled *Improving the Therapeutic Design of Healthcare Environments through Modelling, Simulation and Visualisation (MSV)*. This EPSRC project is part of the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) award with grant reference number EP/DO39614/1.

The surveys sought to find answers to the following specific questions:

- What type of CAD, BIM, and MSV technology do several healthcares AEC related organisations use in planning, design, construction, representation, and assessment of BHEs?
- What are the user benefits of several healthcare AEC related organisations' use of CAD, BIM, and MSV technology?

Findings from Surveys of US Based Healthcare AEC Related Organisations
Surveys were undertaken of several US based healthcare AEC related organisations in order to explore the user aspects and benefits of using integrated MSV technology for sustainable BHE design and assessment. These surveys resulted in the following findings:

- 89 percent of them use some form of MSV technology in undertaking their work directly or in collaboration with MSV skilled sub-contractors.
- 11 percent of them do not use some form of MSV technology but work with a number of healthcare related AEC organisations that do.
- 67 percent of them use 3D: CAD; BIM; and visualisation technologies.
- 33 percent of them use Autodesk AutoCAD software, and also use Autodesk Revit to support their BIM related tasks.
- 44 percent of them use 3D CAD and modelling software, including: Autodesk 3d studio Max (3ds Max), VIZ, and Maya; and SolidWorks.
- 22 percent of them use Google SketchUp, and also use VR technologies that include a virtual OR 3D program, and a VR theater for rear projection of large-scale 3D images (either passive or active stereo).
- 11 percent of them use Google Earth, and also use simulation software, including Fluent for computational fluid dynamics (CFD) and validation of HVAC concepts.

The use of MSV technology such as Revit, AutoCAD, 3ds Max and SketchUp by TAYLOR have benefited them in the sense that they have been able to more accurately represent a project using BIM. According to McGill (2008) of TAYLOR, their use of MSV technology has been beneficial because they have been able to resolve problems ahead of construction, enabling them to minimise their field conditions, thereby coming up with better solutions and not have the field dictate the solution.

According to Schwartz (2008) of Cosentini Information Technologies (a department within Cosentini Associates), Cosentini Associates have delivered 3D modelling services for several years using MSV technology such as AutoCAD, Revit, Autodesk VIZ, and Fluent. Cosentini has designed MEP, IT and Mission Critical systems for healthcare projects, including Bellevue Hospital, Memorial Sloan Kettering and New York Presbyterian. Cosentini (2008) has always been excited by the ability of MSV technology to assist their engineers in the design process and communicate to their clients a clear visual understanding of what a project will look like and how it will function once constructed. In their experience, this facilitates collaborative project development, and a design process and project that are highly detailed and more cost-effective. MSV technology was identified to have assisted Cosentini in engineering design. It did this by supporting the undertaking of advanced calculations, and maintaining project coordination and quality control between design teams. It permitted easier visualisation of complex models for quicker detection of possible system interference between objects. Furthermore, MSV technologies have assisted Cosentini with performing CFD and Finite Element Analysis, and energy simulations. It was identified that MSV technology also provided Cosentini with the ability to create 3D architectural spaces for ergonomic studies, and animated walkthroughs for their clients.

The emerging need for BIM was identified by Mueller (2008) of BERCHTOLD Corporation. For instance, BERCHTOLD was inundated with many requests over six months in order to provide Revit compatible models for architects and equipment planners in the US. BERCHTOLD has also developed a virtual OR 3D program that is used to develop concepts with the client as a stakeholder. It provides BERCHTOLD with the ability to conveniently insert equipment and human models in an operating room space and then modify various views and animations in order for the client to understand the relationships between the various booms and lights in the space. It was identified that BERCHTOLD's approach of showing the equipment in an operating room through the use of MSV related technology such as a 3D virtual OR program – as opposed to the traditional method of using a 2D floor plan – made clients understand the space much better and provided them with confidence in the final design. It also supports effective consultation and decision making with the whole hospital OR team that helps eliminate problems occurring after equipment has been installed. Project elevations developed by BERCHTOLD using MSV technology such as SolidWorks were identified to provide clients with an understanding of the spatial relationships, and guidance in production and inspection after approval.

This study identified that Purdue University's Regenstrief Center for Healthcare Engineering, Envision Center for Data Perceptualization, and Division of Construction Engineering and Management use MSV technology such as VR and DMUs. According to Dunston et al. (2007 and 2008), their use of VR and DMUs was identified to provide opportunity for significant improvements in patient care and patient centred healthcare facility design. It supports the assessment of the impacts of several design decisions and solutions on patients such as the choice of room layouts, construction materials, soundproofing options, and medical equipment placement. Their use of VR and DMUs was identified to be more favourable than the current industry use of PMUs that are expensive to build, and are less flexible in addressing multiple variable environmental related parameters.

Findings from Surveys of UK Based Healthcare AEC Related Organisations

Surveys were undertaken of two UK based healthcare AEC related organisations, and these are MJ Medical, and the Advanced Virtual Reality Centre (AVRRC), which is based at Loughborough University. These surveys were done in order to explore the user aspects and benefits of using integrated MSV technology for sustainable BHE design and assessment. These surveys resulted in the following findings.

According to Salmon and Gibson (2009) of MJ Medical, k*ey* design and decision making MSV technology such as BIM are a keen interest of MJ Medical. This interest includes BIM's role in improving the responsiveness of BHEs to issues and scenarios related to sustainable design and development, future need and refurbishment changes (Salmon and Gibson, 2009). MJ Medical (2009) identified that managing and incorporating several technical and clinical information are major challenges of BHE design and equipment planning. Therefore, it designed intricate database systems and a unique web-based stakeholder update tool that meet the information management needs of the most complicated BHE and equipment related projects (MJ Medical, 2009). This has enabled MJ Medical (2009) to provide precision and accuracy in the work it undertakes using its technical resource that include:

- A Project Database.
- An Equipment Database.
- An Equipment Library Database.
- An Online Stakeholder Update (OSU).
- COre Hospital BRiefing Alignment (COHBRA).

However, user behaviour, particularly client reluctance to support the use of MSV technology in BHE projects has been identified by MJ Medical as a major obstacle. As stated earlier, a key user behaviour that has been identified to be in need of change is the placing of too much reliance on the use of only traditional approaches in BHE design and assessment.

The Advanced Virtual Reality Centre (AVRRC) uses VR such as those related to immersive environments, including: VR theatres; caves and pseudo caves; domes; immersive workbenches; and hemispherical screens (Kalawsky and O'Brien, 2008). According to Kalawsky and O'Brien (2008) of the AVRRC, these VR tools support AVRRC's: real-time user-environment interaction; 3D visualisation; collaboration between design and development teams; and evidence-based design (EBD). AVRRC's use of VR has permitted it to immerse users into real-time interactive VR environments in order to evaluate design and decision making solutions (Kalawsky and O'Brien, 2008).

Findings from Surveys of Finland Healthcare AEC Related Organisations

Surveys were undertaken of two Finland based healthcare AEC related organisations, and these are VTT Technical Research Centre of Finland, and STAKES (now part of the Finnish National Institute for Health and Welfare). These surveys were done in order to explore the user aspects and benefits of using integrated MSV technology for sustainable BHE design and assessment. These surveys resulted in the following findings.

Capturing user needs is the most critical part of maximising the value of the end product as it relates to ensuring effective requirements management whereby requirements are well defined, set and validated (Porkka, 2008; and Porkka and Huovila, 2008). This is necessary in order to appropriately identify exactly what the user needs, and that any proposed solution efficiently meets these requirements (Porkka, 2008; and Porkka and Huovila, 2008). VTT developed a tool, known as EcoProP for the systematic management of building project requirements for both new and existing buildings (Porkka, 2008). According to Porkka (2008) of VTT, EcoProP was developed in order to fulfil the following:

- Validation of the quality of an end result.
- Whole-life costing.
- Benchmarking.
- Capturing user needs at the early stage of a project.
- Design brief creation for building in use performance.
- Comparative studies.
- Informative reports to support decision making.

Desired solutions can then be designed based on the derived specified performance requirements (Porkka, 2008). EcoProP was used in the HospiTool project that sought to bring together spaces and users in order to achieve a user-oriented hospital space (Porkka and Huovila, 2008).

Just like VTT, STAKES also has interest in the development of user-oriented hospital spaces. STAKES considers EBD an effective tool in the achievement of good quality living and care environments. It also considers EBD improvements – through enhancement of innovation, technology and services – as essential in order to guarantee good quality care environments.

Findings from Case Study Research of VR and DMUs Developed by US and Finland AEC Related Organisations

Case study research was undertaken by this study in order to explore the user aspects and benefits of using VR and DMUs developed by this study's US and Finland based healthcare AEC related organisations, that is, VTT and STAKES, and Regenstrief Center for Healthcare Engineering.

The HospiTool Project by VTT and STAKES

The HospiTool project by VTT and STAKES sought to bring together spaces and users in order to achieve a user-oriented hospital space (Nykänen and Kotilainen, 2008). The HospiTool project also sought to find answers to the issue of whether BHE providers and designers actually understand user needs (Nykänen and Kotilainen, 2008). According to Nykänen and Kotilainen (2008) of VTT and STAKES respectively, the HospiTool project used a VR environment alongside EcoProP in order to:

- Generate user feedback.
- Determine user needs.
- Derive specified building project performance requirements.
- Systematically manage building project performance requirements with the assistance of EcoProP, and design desired solutions based on the derived specified performance requirements.
- Ensure compliance with the determined requirements.
- Validate design solutions and their conformity to user needs and performance requirements using the VR environment.

Even though the created virtual space is just an illusion, it permitted users to: go into it; experience it; move in it; and interact with it (Nykänen and Kotilainen, 2008). Nykänen and Kotilainen (2008) envisage that in the future:

- The mobility and ease of use of VR will improve.
- VR will increasingly be supported by BIM.
- The ability to add virtual elements to reality will exist.
- The ability to add real elements to VR will exist.
- User involvement in BHE design will be enhanced through the use of VR throughout a BHE's whole-life.

DMU by Regenstrief Center for Healthcare Engineering

Research at Purdue University's Regenstrief Center for Healthcare Engineering has focused on the development of a DMU for the design review of hospital patient rooms. According to Dunston et al. (2007), it was necessitated by an apparent knowledge gap in areas related to EBD for patient/user-centred BHEs. Just like the HospiTool project by VTT and STAKES, the DMU developed by Purdue University's Regenstrief Center for Healthcare Engineering also supports: user interactivity with the created virtual environment; validation of design solutions; and conformity to user needs and performance requirements.

Just like the HospiTool project by VTT and STAKES, the Regenstrief Center for Healthcare Engineering's DMU is also an illusion based on reality, which in this case are actual rooms in the Bariatrics and Obstetrics department at St. Vincent Indianapolis Hospital. Pilot studies were undertaken whereby selected participants were used for unstructured demonstrations which generated positive feedback. The Regenstrief Center for Healthcare Engineering states that its future plans include the development of a library of generic objects for rapid populating of DMUs in order to contribute to sustainable BHE design and assessment.

Findings from the Purpose-Built Modelling and Simulation Assessment of Integrated MSV to Facilitate Sustainable BHEs

Purpose-built modelling and simulation assessment were undertaken of the ability of integrated MSV technology to model, simulate and visualise sustainable BHE design and performance.

These involved the interface of Activity Data Base (ADB) data of a single-bed room for the elderly with BIM, and parametric modelling and environmental simulation digital tools in order to develop purpose-built models and undertake simulation assessment of their environmental performance against sustainable design parameters and what-if scenarios.

The purpose-built models of the single-bed room for the elderly had the same volume specifications, but had weather data of 57 locations in 13 countries. The purpose-built modelling and simulation assessments were undertaken in order to: explore the impacts of microclimates on BHE purpose-built models; and demonstrate that integrated MSV technology can support the assessment and prediction of sustainable BHE design and performance.

Discussion

The key user aspects and benefits associated with the use of integrated MSV technology includes its support for:

- Efficient conceptualisation, development and communication of BHE design ideas.
- Development of VR environments and DMUs for advanced BHE design solutions and evaluation of user requirements.
- BHE performance prediction; and sustainable BHEs.

As beneficial as integrated MSV technology is to users and stakeholders, there is still reluctance on the part of several users – especially clients – to support its use on BHE related projects. Their belief is that it will escalate project budgets, delay project delivery timelines, and they are also unsure and perhaps unconvinced of the benefits of integrated MSV technology to actual BHE performance and management. Their concern is whether the benefits of integrated MSV technology at the design stage could also be achieved at the post-occupancy stage in order to improve actual BHE cost and performance. However, healthcare AEC related organisations and professionals need to consistently demonstrate evidence of the benefits of using integrated MSV technology at the BHE design and post-occupancy stages. This is important in order to overcome the barrier of user reluctance to embrace and support integrated MSV technology use for sustainable BHE design and assessment.

Conclusion: The Virtual Built Healing Environment (VBHE)

The VBHE concept suggests that even the BHE itself could be a ‘patient’, and an effective way to ‘diagnose’ its impacts and ‘prescribe’ design solutions for its efficient performance is through the use of integrated MSV technology.

The BHE and the PMU traditional method used in its design and assessment have limitations because they are subject to the constraints of their physical environment. However, the VBHE does not have such physical limitations, and even supports user interactivity for: efficient evaluation of user requirements; prediction of BHE performance; and sustainable BHEs.

The evidence generated by this study suggests that the use of integrated MSV technology in BHE design and performance assessment can support sustainable BHEs. Therefore, the VBHE is a viable concept. The use of integrated MSV technology for BHE design and assessment provides the necessary flexibility and robustness, which are required for assessments involving multiple variable parameters and what-if scenarios. Integrated MSV technology permits the study of alternate approaches, optimisation of design choices, and maximisation of performance efficiency. Furthermore, integrated MSV technology benefits include reduction in the cost and time required for various aspects of the BHE design and performance assessment process.

The reluctance of users and clients to fully embrace and support the use of integrated MSV technology for sustainable BHE design and assessment can be addressed by consistently demonstrating evidence of the benefits of using integrated MSV technology at the BHE design and post-occupancy stages.

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