PERCEIVING SPACE FROM MULTIPLE PERSPECTIVES FOR BUILDINGS USING BIM

Mohammad Mayouf[1], David Boyd[1] and Sharon Cox[2]

1 Birmingham School of the Built Environment, Birmingham City University, Birmingham B4 7XG, UK

2 School of Computing, Telecommunications and Networks, Birmingham City University, Birmingham B4 7XG, UK

The way that space is being perceived during the building design stage affects the way it is delivered. This becomes more complex when considering not only the geometric view of space, but also the building as a whole with all its uses. It is recognised that different users have different needs particularly as regards their use of space. It is proposed that building information modelling (BIM) can accommodate different perspectives on space held by the building design team, facility management team and building occupants. This paper investigates various views on the way that space is perceived from different perspectives. Data have been attained from a university building under construction in the United Kingdom using interviews with the building design team, and questionnaires with the facility management team and building occupants. The collected data demonstrate the complexity of space including the effect of 2D and 3D views on perceptions. The paper concludes with highlighting these different perspectives emphasizing the need for collaboration. Further work is needed to explore different space algorithms, which can accommodate these different perspectives in the BIM model. The paper provides an initial basis towards understanding the problematic nature of space from a holistic approach and its implications of the way it is being perceived.

Keywords: building information modelling (BIM), multiple perspectives, space visualisation.

INTRODUCTION

Buildings in their nature are fundamentally complex environments and because of this, it is often claimed that buildings do not perform as anticipated. The way the built environment is perceived can affect the delivery of several aspects within the building (Vischer 2008). Space is considered as one of the complex aspects involved in the core design of buildings. This complexity becomes apparent when looking back at the ambiguous nature of the concept of space (Dovey 2010). There are many aspects within the building that are affected by space such as layout, utilisation and spatial planning. BIM has supported the geometric coordination and visualisation of these aspects through smart object modelling and the integration of different building systems in one single model. However, in keeping with Vischer's (2008) built environment theory, which identifies building use and user as critical design determinants of buildings, a BIM model should serve all stakeholders' needs. Different stakeholders have different requirements and this require multiple perspectives in space perception to be included in BIM environments. BIM model

[1] Mohammad.Mayouf@bcu.ac.uk

can help to identify these different perspectives as it provides a user-friendly tool for collaboration to understand the needs and requirements of different user groups. This paper explores the different perspectives of the building design team (BDT), facility management team (FMT) and building occupants (BOs). Data are collected from FMT and BOs separately by asking them questions about a BIM model of an educational building under construction. Data have also been obtained from BDT using semi-structured interviews. The analysis of this data highlights the different ways in which these groups perceive space, emphasizing the complexity of space.

OVERVIEW ON SPACE COMPLEXITY

Space as a Complex Aspect

The study of space is complex where form and function of the building plays the main role in determining how space should function, be laid out and utilised. The term 'space' began to emerge in the discipline of architecture by the end of the 19th century with volumetric theories and continued with aesthetic theories (Dovey 2010). In volumetric theories, space is described as 'enclosure space' (Hensel et al. 2009) and aesthetic theories describe space as the 'aesthetic effect of architecture on subjects' (Holt-Damant 2005). Ching (2007) has identified several factors that affect the architectural space:

- Function of architectural spaces at different time.
- Amount of human-oriented (ergonomics) characteristics of the building space.
- Method of locating the vital and critical areas in the buildings.
- Independency of the building spaces.
- Density of the building spaces.

In modern architecture, it is claimed by Forty (2000) that space appears to be a homogeneous concept, partly because architects consider space via representations (abstract space) rather than experiencing space by living it (lived space). However, Hensel et al. (2009) pointed out that bridging the gap between lived and abstract space will result in another level of complexity, stopping any change from current practice. Therefore, it can be realised that the concept of space is complex and its trans-disciplinary nature increases its complexity.

Space Planning in Buildings and BIM

Space planning is considered to be one of the initial steps during the preliminary design process of the building (Duffy et al. 1976; Autodesk 2013). Guidelines have been developed for various building types such as: educational buildings (Stanford University 2009), office buildings (Duffy et al. 1976), hospitals, etc. There are many elements involved in space planning such as flexibility, efficiency and consistency. Furthermore, spaces in a building can be identical, unique or defined based on the client's requirements to perform a particular function. Bitrafan et al. (2013) have described space based on functionality where spaces are divided into three different types: flexible spaces, adaptive spaces and single functional space. This distinction between spaces becomes important when methods such as spatial planning take place. Spatial planning is a branch of space planning and can be described as the distribution of human ergonomic arrangement of objects in a space (Douglas 1996). However, the planning of space becomes more complex when all building systems are involved during the design process, which require an effective tool that can manage these different systems effectively.

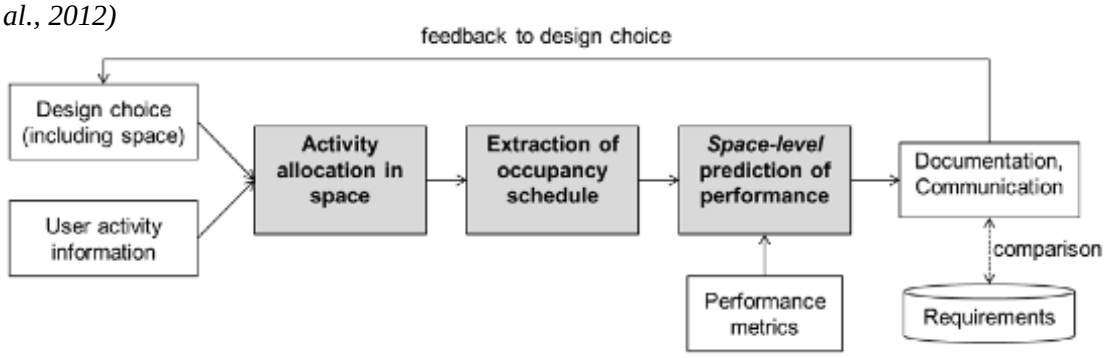
BIM has supported the integration of these building systems providing an interdisciplinary data platform where information can be shared, updated or modified. BIM forms a reliable basis for decisions, providing a shared digital representation of physical and functional characteristics of any built object (Volk et al. 2014). This has resulted in a more accurate layout of space, effective space utilisation and better space visualisation (Porwal and Hewage 2012). BIM uses parametric modelling and this had led researchers to propose improved design solutions (Eastman et al. 2011), which serve a particular need. This is because BIM can manage semantic information on building components and spaces. Jeong and Ban (2011) proposed computational algorithms to evaluate design solutions using Space Syntax based on recognising building information. Li et al. (2014) have used BIM models to extract building geometries to support the functionality of an add-on to enhance the accommodation of escape of occupants trapped in building fires.

Perceiving Space and BIM

Space perception can be composed from the properties and relationships of objects in space with respect to direction, size, distance, and orientation. In an environment, object relations can be described in terms of a Euclidean coordinate system (Richards 1975). The 3D environment provides this Euclidean framework for our perception of spatial relations. Loomis et al. (1992) stated that in the study of visual space, it has been assumed that an observer has an internal representation of surrounding physical space, and then attempts to measure the properties of visual space to establish how well various properties of physical space are preserved in the mapping to visual space. The complexity of visual space can be looked at using in-depth psychophysical procedures, but for the purpose of this paper, this depth will not be considered. However, understanding the complexity is important when designing space using BIM.

BIM is suggested to be a collaborative tool where divergent perspectives could be accommodated to achieve better design solutions (Sabol 2008). Currently, 3D and 4D simulation (e.g. Navisworks) using BIM models have enhanced users' understanding of the design allowing a third person view to support users' in obtaining a sense of scale, but this navigation is relatively simplistic (Khemlani 2008). There are some recent research attempts where end-users and facility management teams have been involved. For example, Lee and Ha (2013) have proposed a BIM-based tool for residential buildings to meet different customer needs. The solution proposed a customer interactive building information modelling (CIBIM) tool, which would allow customers to be involved in decision-making. It was found that collaboration using the tool helped to meet customer needs for the optimum use of space. Kim et al. (2012) have formalized activity-space-performance relationships to improve the accuracy of space performance analysis (see figure 1). Furthermore, Shen et al. (2012) proposed a user activity simulation and evaluation method (UASEM) that aimed to enhance the user's visual experience of the built environment, but did not explore whether such simulations have an impact on improving design solutions. Previous work has therefore researched space from the use and utilisation point of view rather than understanding the way that different parties perceive space. Moreover, understanding these different perceptions from multiple perspectives may contribute to a more holistic view of space. This research is going to consider how both FMT and BOs perceive space using BIM models.

Figure 1: Proposed Framework to Enhance Accuracy of Space Performance Analysis (Kim et al., 2012)



APPROACH

In a construction project, different stakeholders have different requirements and as the input from these stakeholders is not the same, then this can lead to contradiction during the design. This will also result in different views of space, which is the subject of this research. Multiple perspectives on the way that space is being perceived was explored from the perspectives of the BDT, FMT and BOs on an university building that is currently under construction. Data have been collected using semi-structured interviews with the BDT and open-questionnaires with the FMT and BOs.

From the BDT, three interviews were conducted with the project director, BIM coordinator and building designer (BIM manager). These individuals were selected based on their vital role in space planning and layout. They were involved in the development process of the BIM model and monitored changes that occurred throughout the construction process. Data were collected individually from the BDT using semi-structured interviews to capture a richer image of BDT's view of spaces in buildings. The questions were put in the context of the selected case study (under construction university building) to reflect upon recent experiences with BIM and how it had been utilized in relation to space and its related aspects.

From the FMT, the facility manager and building services supervisor were selected for the study, because these different roles may affect the way they view spaces within buildings. The questionnaires were designed to explore the familiarity of both FMT and BOs with building plans (2D drawings) and space related problems that they have experienced.

A number of building occupants were chosen to participate in the study, which involved showing them a navigation through BIM models using Autodesk Navisworks followed by questionnaires about the experience. It is important to acknowledge the lack of familiarity of both parties (FMT and BOs) with the BIM models, and thus a quick brief was provided to obtain meaningful data.

The purpose behind using interviews for BDT unlike FMT and BOs, where questionnaires were used, is that the BIM model has been developed by the BDT, and thus getting their views on space using interviews would be sufficiently useful to compare it with the way that FMT and BOs see space. It was necessary to navigate FMT and BOs through the BIM model to get their views on different spaces and the way they perceive it. Throughout the navigation process, prompts about different spaces were given because some 3D components did not have an adequate level of detail and to increase the consistency of the feedback collected from both parties (FMT and BOs).

RESULTS

This section presents the responses from the interviews with the BDT and questionnaires from the FMT and BOs. Table 1 shows the different perspectives from BDT, FMT and BOs derived from the questions. It is important to note that the table only represents a summary of the comprehensive responses received. These comparison criteria comprised of three parameters: defining space, what is important in a space and what issues are associated with a space.

Table 1: Different Perspectives on Space from BDT, FMT and BOs.

	BDT	FMT	BOs
Defining space	Normally confined by the design of the building and defined by four sides with single or multiple accesses and designed to perform a particular function.	An owned area by the client and defined by what facilities are in it.	An environment that allows me to perform a certain task or daily job comfortably.
What is important in a space?	Size, route access, communication and collaboration between staff, thermal comfort, and internal air quality (IAQ).	Number of occupants, movable facilities, and temperature.	Arrangement of objects (facilities), route access, thermal comfort, lighting (sun and artificial).
What are the common issues faced in a space?	Functionality, space layout, space efficiency and facilities layout.	Noise level, ownership of the space, functionality of the space, and maintenance.	Accessibility, privacy, noise level, control of temperature, and flexibility of space.

For the purpose of the paper, a selected space from the case study, which was shown during BIM model navigation to the FMT and BOs, will be used to demonstrate the differences in perception between FMT and BOs. The structured information charts identify the entities and attributes related to that particular space where 2D and 3D views are assigned to them based on the responses from the FMT and BOs. The charts in Figures 2 and 3 present the way that FMT and BOs perceive space.

Figure 2 and Figure 3 interpret the responses from FMT and BOs using entities and attributes based on the responses from FMT and BOs. To demonstrate better understanding of the way that space is being perceived, the research is proposing that a particular space has number of properties, where the hierarchy of these properties is presented as entities and attributes. Each entity/attribute is associated with 2D, 3D or no view reflecting the participants' perceptions.

Figure 2: How One of the Spaces from the BIM Model Navigation was Perceived by the FMT.

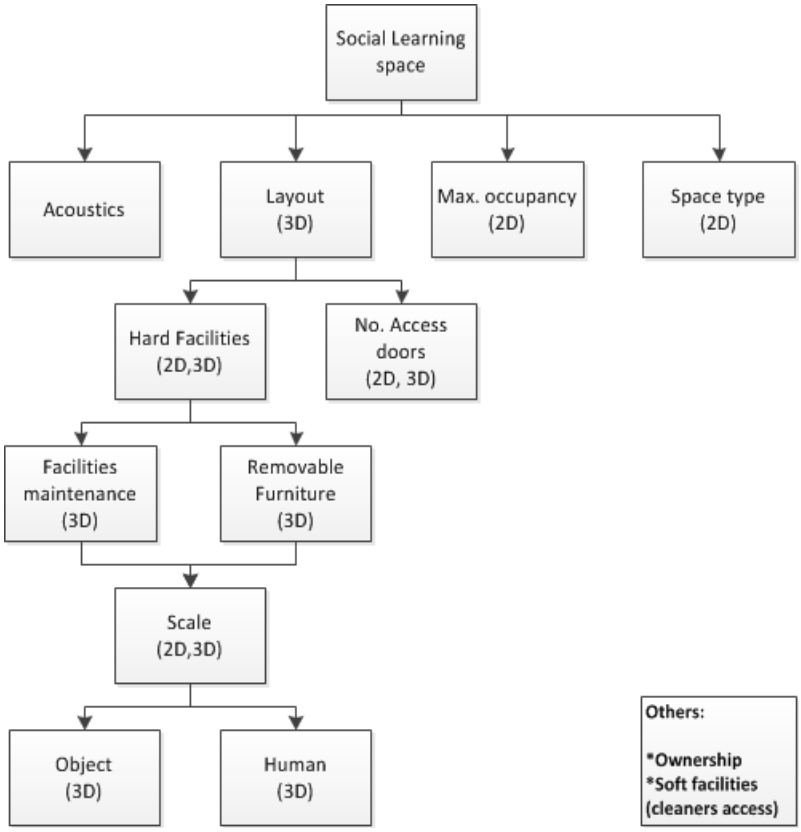
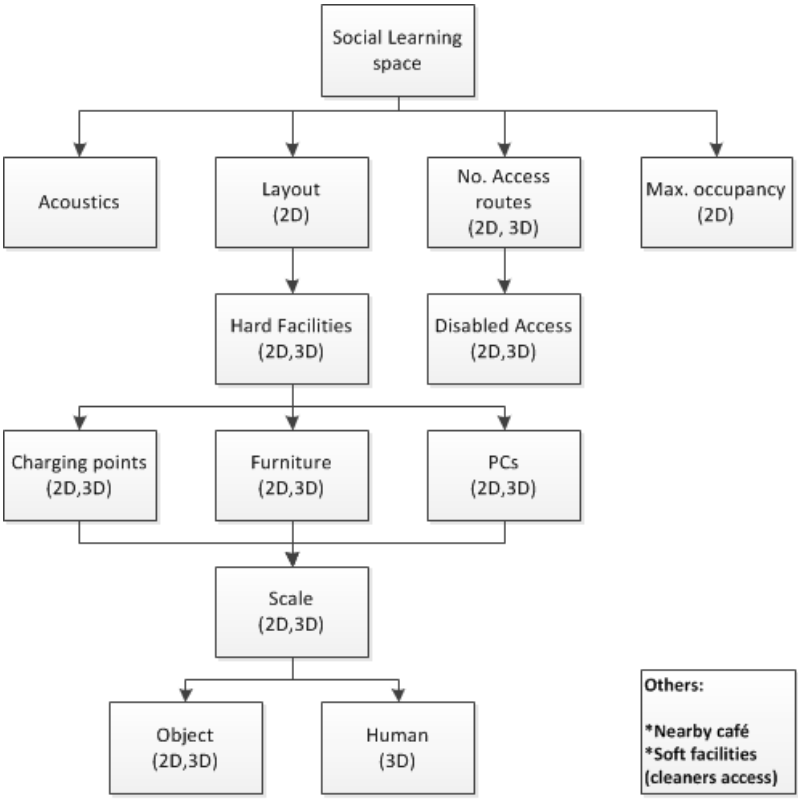


Figure 3: How One of the Spaces from the BIM Model Navigation was Perceived by the BOs.



DISCUSSION

The results presented in the previous section have provided an overview of the way space is viewed and perceived from different perspectives. This section discusses how space is defined and understood by BDT, FMT and BOs in order to gain insight towards understanding the nature of space from multiple perspectives. Differences of how space is perceived in 2D and 3D environments from the FMT and BOs from the above figures are also considered.

Space as a Complex Aspect

The findings provided in table 1 demonstrated the different views with regards to space in buildings. As expected, the BDT defined space from a geometrical view, where space is described as an enclosure space confined by building components (e.g. walls). The BIM manager (project architect) has emphasized the complexity of space due to his role managing the central BIM model where all building systems are integrated. The project director and BIM coordinator explained that the nature complexity of spaces arise from different requirements from the client, where this becomes problematic when changes occur during the construction process. The FMT, described space as a property whose identity is defined by type of the facilities in it. There are two implicit findings from this definition: first, the FMT's view of space is driven by the management of space in the building, and second the team had limited involvement in the development of BIM models. These findings have many major implications for space design, which need further exploration but are outside the scope of this paper. Lastly, building occupants described space based on their personal needs, which is a sensory response based on their role. However, their definition of space as a 'comfortable workplace' was associated with the other building aspects such as temperature, which supports the literature findings about space and its effect on various building aspects.

The initial findings from these three perspectives have demonstrated that space is yet to have sufficient and clear definition that satisfies different views. One way to simplify this conflict about space is to understand the spatial relationships between the components, which are important to the different stakeholders (Motamedi et al. 2014). The use of BIM models should enhance the way of capturing knowledge about these relationships in buildings, which is the case for FMT and BOs. On the other hand, it is also important to acknowledge that terms such as functionality, flexibility and accessibility are complex and influenced by many factors such as policies or building type, but for this paper, they are described within the context of a university building.

Perceiving Space in 2D and 3D Environment

Bouchlaghem et al. (2005) pointed out that development of 3D modelling has been driven by architectural design. In other words, the shift from 2D to 3D was mainly to allow architects to visualise and immerse themselves in their designs. However, during navigation of the BIM model in this study, both 2D and 3D models of the environment were provided to explore the stakeholders' differences in perception. The FMT claimed that they preferred the layout in 3D whilst BOs suggested that it is clearer to represent the layouts in BIM's 2D environment. The FMT stated that the 3D view of layout would allow them to identify the space needed for maintaining the facility(s) in that space. Other authors have used 3D components to visualise the asset condition during construction and operation phase through the use of colour-coding (Hammad and Motamedi 2007).

The occupants also preferred the 2D view for route finding in and out of the space as well to identify their own workplace. Although it may logically seem that occupants are more likely to understand 3D environments more easily (Smith and Tardif 2009), findings from this research showed that they preferred to see aspects such as layout in a 2D environment. In addition, some space related aspects from BOs' perspective such as occupancy level cannot be currently represented in a 3D environment. Although 3D avatars have been claimed to improve the users' understanding of space and activities (Shen et al. 2012), this research shows that understanding the scale aspect for both FMT and BOs was problematic and contradictory in terms of the way they referred to it. This was critical for the FMT when referring to what facilities are fixed or removable where this could only be visualised effectively in 3D environment. The BOs had many queries with regards to human to object scale, as they wanted to see the space in use. This can be somewhat contradictory to what BIM is supposed to provide in terms of clarity and visualisation as a virtual reality (VR) environment but highlights the needs of BOs.

To sum up, the representation of spaces through their entities and attributes (figure 2 and figure 3) will support the BDT in terms of understanding different requirements by FMT and BOs. This needs to be incorporated in the way space is being modelled using BIM models during the design stage. It also promotes collaboration at an early design stage (Choi et al. 2013) with facility managers and end-users to obtain more efficient design solutions.

CONCLUSIONS

BIM provides a good visualisation of space, but the way space is perceived from different perspectives can be contradictory and problematic. The literature has identified several efforts by researchers to optimise design solutions for space. In addition, it was emphasized how BIM played an important role in terms of visualising the space and use of semantic information to enhance spaces in buildings. The use of BIM to facilitate the different perspectives on the way that space is perceived will allow the involvement of the participants (FMT and BOs), which will gain a richer design of spaces in buildings. The analysis of these different perspectives may provide a means to re-establish the social aspects of space and to consider it as a heterogeneous concept, which is influenced by the interdisciplinary world of involved stakeholders. This can also have a positive impact on space performance of the building, which can serve different needs. The mystery of 2D and 3D in terms of their contribution to solve needs and address the requirements for stakeholders needs further research. This research suggests that 3D is not the only way to solve built environment complexities related to the perceptions of space.

REFERENCES

Autodesk (2013) Lesson 1: Area and Space Planning, available at: http://bimcurriculum.autodesk.com/lesson/lesson-1-area-and-space-planning (accessed: 30 April 2014).

Bitarafan, M, Hosseini, S B, Hashemi-fesharaki, S J and Esmailzadeh, A (2013) Role of architectural space in blast-resistant buildings. "Frontiers of Architectural Research", 2, pp. 67 – 73.

Bouchlaghem, D, Shang, H, Whyte, J and Ganah, A (2005) Visualisation in architecture, engineering, and construction. "Automation in Construction", pp. 287 – 295.

Ching, F (2007) "Architecture: Form, Space, and Order". 3ed. Hoboken: John Wiley.

Choi, J, Choi, J and Kim, I (2013) Development of BIM-based evacuation regulation checking system for high-rise and complex buildings. "Automation in Construction" (In Press).

Dovey, K (2010) "Becoming Places: Urbanism/Architecture/Identity/Power". London: Routledge.

Douglas, J (1996) Building performance and its relevance to facilities management. "Facilities", 14(3/4), pp. 23-32.

Duffy, F, Cave, C and Worthington, J (1976) "Planning Office Space". London: Architectural Press.

Eastman, C M, Teicholz, P, Sacks, R, Liston, K (2011) "BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors". Hoboken: John Wiley & Sons Inc.

Forty, A (2000) "Words and Buildings: A Vocabulary of Modern Architecture". London: Thames & Hudson Ltd.

Hammad, A and Motamedi, A (2007) Framework for lifecycle status tracking and visualisation of constructed facility components, "Proceedings of the 7th International Conference on Construction Applications for Virtual Reality", Penn State University, pp. 224 – 232.

Hensel, M, Menges, A and Hight, C (2009) "En route: Towards a Discourse on Heterogeneous Space in Architecture". John Wiley & Sons.

Holt-Damant, K (2005) Celebration: architectonic constructs of space in the 1920s' In: Leash, A. and Matthewson, G. (Ed.), "The 22nd Annual Conference of the Society of Architectural Historians Australia and New Zealand", pp. 173 – 178.

Jeong, S K and Ban, Y U (2011) Computational algorithms to evaluate design solutions using Space Syntax. "Computer-Aided Design", 43, pp. 664 – 676.

Khemlani, L (2008) Autodesk Navisworks, available at: http://www.aecbytes.com/review/2008/NavisWorks2009.html (accessed: 2 June 2014).

Kim, T W, Kavousian, A, Fischer, M and Rajagopal, R (2012) Improving Facility Performance by Formalizing an Activity-Space-Performance Model, Stanford: Centre for Integrated Facility Engineering (CIFE).

Lee, S and Ha, M (2013) Customer interactive building information modelling for apartment unit design. "Automation in Construction", 35, pp. 424 – 430.

Li N, Becerek-Gerber B, Krishnamachari, B and Soibelman, L (2014) A BIM centered indoor localization algorithm to support building fire emergency response operations. "Automation in Construction", 42, pp. 78 – 89.

Loomis, J M, Da Silva, J A, Fujita, N. and Fukusima, S. S. (1992) Visual Space Perception and Visually Directed Action. "Journal of Experimental Psychology: Human Perception and Performance".

Motamedi, A, Hammad, A and Asen, Y (2014) Knowledge-based BIM-based visual analytics for failure root cause detection in facilities management. "Automation in Construction", 43, pp. 78 – 83.

Porwal, A and Hewage, K N (2012) Building Information Modelling (BIM) partnering framework for public construction projects. "Automation in Construction", 31, pp. 204 – 214.

Richards, W (1975) Handbook of Perception. Academic Press, Inc.: New York.

Sabol, L (2008) Building Information Modelling & Facility Management, "IFMA World Workplace".

Shen, W, Shen, Q and Sun, Q (2012) Building Information Modelling-based user activity simulation and evaluation method for improving designer-user communications. "Automation in Construction", 21, pp. 148 – 160.

Smith, D K and Tardif, M (2009) "Building Information Modelling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers". Hoboken: John Wiley & Sons.

Stanford University (2009) Stanford University Space and Furniture Planning Guidelines. Stanford University: Stanford.

Vischer, J C (2008) Towards a user-centred theory of the built environment. "Building Research and Information", 36(3), pp. 231 – 240.

Volk, R, Stengel, J and Schultmann, F (2014) Building Information Modelling (BIM) for exisiting buildings – Literature review and future needs. "Automation in Construction", 38, pp. 109 – 127.