Towards Evidence-Based BIM

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Abstract

Building information modeling (BIM) is widely used in the construction industry today. The development in this area constantly creates new opportunities to evaluate the properties of buildings by employing digital models. New simulation tools that can analyze a building in various ways have become available. As BIMs become more advanced, they tend to be applied earlier in the design process and can simulate the user's perception of the building in more detail. Consequently, with the development of new approaches for various properties, adequate BIM strategies that assist in depicting those properties, which can be evaluated by the emerging uses of BIM, should be developed. Accordingly, the aim of this study is to evaluate if and how an evidence-based design (EBD) approach can assist in the development of a BIM-strategy. Furthermore, we investigate how the initial steps of the EBD process, that is, finding and evaluating evidence, can be applied to decide the properties that should be identified and assessed, as well as what types of BIM uses should be rendered to represent these properties. To test such an approach, a case study on student housing was conducted in collaboration with researchers and MSc students from the Sustainable Building Information Management program at Jönköping University. Their aim was to investigate what type of properties/values should be relevant and could be rendered with BIM uses in order to evaluate these properties. In total, 15 students searched for and selected literature on relevant evidence for the student housing project and a simple framework for the levels of evidence were introduced and used to evaluate these evidences. Based on this case study, it is concluded that literature concerning different BIM uses can be found but training is needed in finding relevant scientific sources. Furthermore, working with EBD-BIM process a simplified guideline concerning the level of evidence needs to be developed.

Keywords: BIM, BIM-strategy, Evidence-based Design, Levels of Evidence

1. Introduction

Building information modeling (BIM) is becoming a well-established tool and an innovative methodology in the field of architecture, engineering, construction, and facility management (AEC/FM) (Zhou et al., 2017) and many benefits of its use have been reported e.g. (Borrmann, König, Koch, & Beetz, 2018; Eastman, 2018). The use of BIM will evolve further in the coming years (Ozturk & Yitmen, 2019; Pauwels, Zhang, & Lee, 2017) and there will be an accelerated development of new BIM uses, which will provide new ways to evaluate the properties of buildings by employing digital models. One of the promising directions of BIM is to facilitate various building simulations even in early stages of design (Eastman, 2018; Lee et al., 2012). Traditionally, design evaluation is performed manually by multiple domain-specific experts and is time consuming and expensive. With BIM, such tasks can be automated, resulting in more aspects of the building performance being evaluated in more detail and more alternatives being considered (Jalilzadehazhari, Vadiee, & Johansson, 2019; Sandberg, Mukkavaara, Shadram, & Olofsson, 2019). The development of BIM has raised a demand of strategies and plans for the application of BIM in projects. Consequently, a number of approaches to develop such strategies and plans have been proposed (CIC, 2011; Fischer, Ashcraft, Reed, & Khanzode, 2017; Kumar, 2015; Won & Lee, 2016).

One of the main tasks in these approaches is to identify the appropriate BIM uses to be adopted for the project considered. Although several structural approaches have been proposed (CIC, 2011; Kumar, 2015), there is a lack of methods relying on evidence that the BIM uses chosen will provide value to the project. This makes it possible for BIM uses to be applied for reasons other than their effectiveness, e.g., because they are profitable for the consultants.

To close this gap, a framework has been developed at Jönköping University that connects the process of light simulations and evidence-based design (EBD) (Davoodi, Johansson, Henricson, & Aries, 2017) called EBD-SIM. The term EBD has evolved from other disciplines, in particular, medicine, which has used an evidence-based model to guide decisions and practices in their fields. The most widely accepted definition of Evidence-Based Medicine (EBM) was introduced by Sackett et al. (Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996). Hamilton and Stichler (Stichler & Hamilton, 2008) adopted this definition to the field of the built environment, as follows:

"Evidence-based design is a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project." (p.3)

Interest in EBD has been growing extensively since Ulrich's publication (Ulrich, 1984) addressed the effect of views of nature on patients (Zhang, Tzortzopoulos, & Kagioglou, 2016). In the building industry, EBD has been applied mainly to the design of healthcare facilities, even though, due to the flexibility of this method, it can be adopted by other types of buildings such as offices, schools, sports facilities, etc. (Hamilton & Watkins, 2009; Muszynski, 2009). Proponents of EBD claim that it can help to enhance outcomes throughout all phases of design. As highlighted in the abovementioned definition, EBD is a process and it is impossible and not recommended to see the best available evidence as a fixed and static guideline to support design decisions (Hamilton & Watkins, 2009). Collectively, the EBD method is an evolutionary process that continuously improves and builds on previously generated and published evidence.

There are a number of EBD-frameworks described in the literature and a literature study together with an investigation of the different frameworks can be found in (Davoodi et al., 2017). The frameworks can be categorised into three types: 1) conceptual frameworks about EBD processes in general, 2) frameworks that strengthen EBD by integrating knowledge from other disciplines, and 3) frameworks based on EBD in a specific domain (Davoodi et al., 2017). Davoodi et al. (2017) found that the frameworks of type 1 was most suitable for the development of EBD-SIM due to the need of a general conceptual framework when integrating simulations. Two literature references ((Malone et al., 2008) and (Hamilton, 2003)) describe a conceptual framework (Type 1) illustrating an EBD process in 'general'. Hamilton et al. (Hamilton, 2003) proposed a four-level conceptual model of evidence-based design practice wherein each subsequent level increases in research rigour. The focus of the first and second level is for gathering, analysing, assessing, and generating evidence, and the two next levels deal with how to share the newly generated evidence.

The framework developed by the Center for Health (2015) was identified as the most suitable for integration with computational modeling because it gives a holistic picture of the EBD process by breaking it down into eight steps involved in different stages of construction projects (see Figure 1). This makes it possible to investigate the integration of computational modeling in each step of the EBD process. The aim of the selected EBD framework was to integrate EBD into different stages of a typical building design process. The Centre for Health Design (CHD) EBD framework contains eight steps for: (1) definition of key goals and objectives; (2) finding sources with relevant evidence; (3) critical interpretation of relevant evidence; (4) creation and innovation of EBD concepts; (5) development of a hypothesis; (6) collection of baseline performance measures; (7) monitoring of design and construction implementation; and (8) measurement of post-occupancy performance results. It is important to note that, while the steps appear linear, the EBD process is fluid and the steps can be repeated in different phases of the project, and the EBD is a continuous process, as shown in Figure 1. The CHD framework has influenced the work by Joseph et al., (2014), who strengthened the EBD knowledge base by developing standardized post-occupancy evaluation (POE) tools.

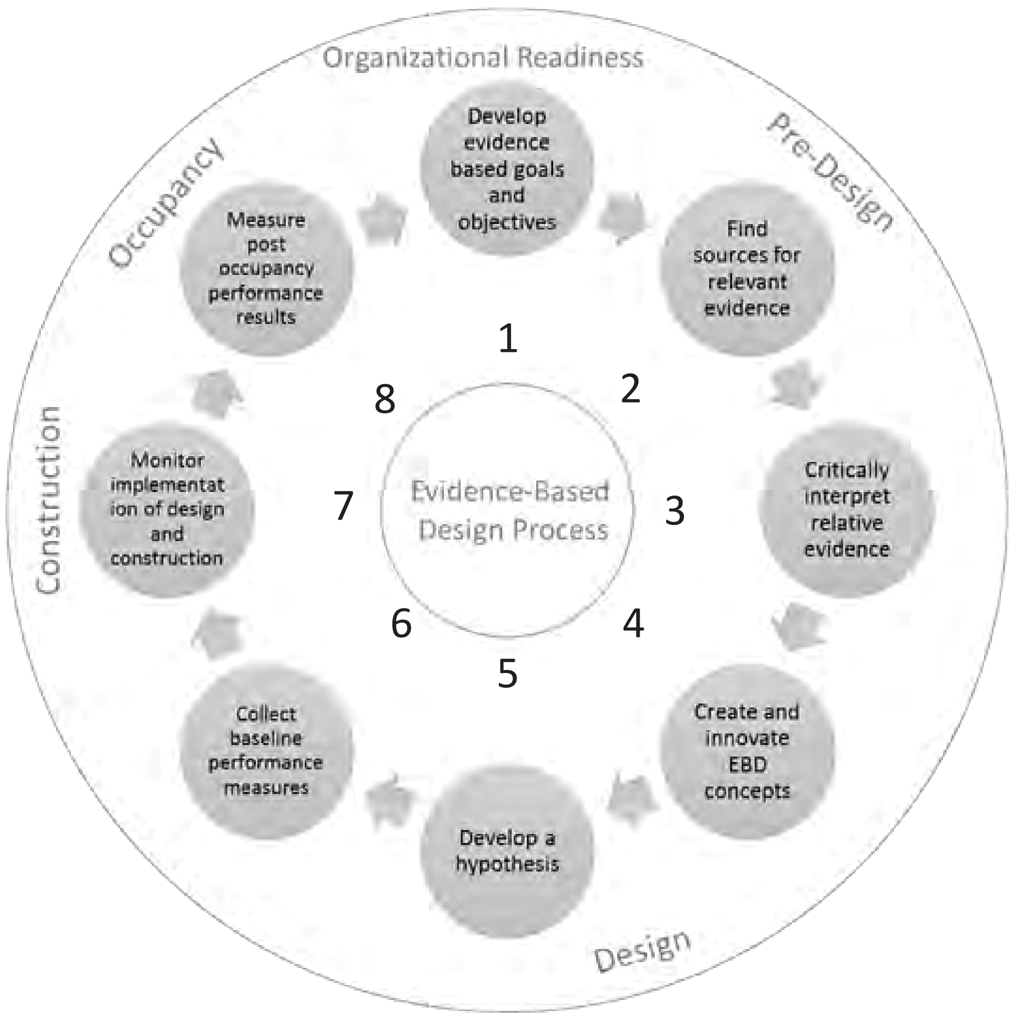

Figure 2: The EBD process ((Joseph et al., 2014)

The aim of this study is to further develop the EBD-SIM framework toward a framework for evidence-based BIM (EBD-BIM).

It was noticed that one of the barriers in adopting EBD in the building design process with computational modeling is the limited amount of evidence sources (including both literature and example projects) that can be readily used by the design practitioners (Davoodi et al., 2017). To investigate this barrier, we decided to investigate the reachability of evidence sources in the area of BIM, focusing on the first two CHD's steps: (1) definition of key goals and objectives and (2) finding sources with relevant evidence. There are also two similar tasks connected to the development of a BIM strategy: 1) to identify the appropriate BIM uses and 2) to find sources with evidence relevant for these BIM uses.

2. Method

A case study on student housing was conducted with MSc students from the Sustainable Building Information Management program at Jönköping University with the aim of investigating the initial CHD's steps, described above, for a building project of a student residence on a plot near the university. In total, fifteen students, divided into five groups, searched for and selected literature on relevant evidences. The students have received their bachelor's degree from different universities in Europe, Afrika and Asia and they before this case-study got an introduction to literature reviews by the personal at the university library and had conducted two exercises containing search for scientific literature.

The students preformed two tasks connected to values:

V1) definition of key goals and objectives;
V2) finding of sources for relevant evidence;

and two tasks connected to BIM uses:

B1) to identify the appropriate BIM uses and
B2) to find sources with evidence relevant for these BIM uses

The tasks were performed in similar manner by primarily searching for evidences in the literature. To help them starting this process the researchers gave lectures concerning regulations and values relevant to student housing. Having this the students started to search for literature concerning values, to answering the value tasks V1 and V2. After that they started to perform the tasks related to BIM uses, B1 and B2. This was mainly performed by conducting a literature search having the values as input. This exercise resulted in a report, from each group, that documented 10-20 values and related BIM uses together with a discussion concerning the sources of evidences found. The reports were assessed by the researchers and the level of evidence (LOE) were evaluated.

In the planning of this case-study, some guidelines for the LOE were investigated (Pati, 2011) and, although these guidelines reduced the need for scientific rigor, validity, and reliability, it was concluded that they were still too complicated for the students to follow. Instead, the researchers developed a simplified "levels of evidence" framework to evaluate the evidence. The levels were as follows:

1. Common understanding
2. Stated by a company
3. Scientific papers
    a) Can be performed
    b) Verified (measurable value)
    c) Validated (value is received (POE))

The first and lowest level was named "**Common understanding**" meaning that the only evidence provided is arguments confirming that the BIM use considered provides values to the project. The second level was named "**Stated by a company**," meaning that companies have stated, mostly on their websites, that the BIM use considered provides value. The third and last level, named "**Scientific papers**," indicates evidence found in scientific papers. In this category three sub levels were provided. Scientific papers that focused on showing a possibility, an exploratory study, was categorized in the **3a** level named "Can be performed". In the second sublevel **3b** the scientific papers show a BIM use but also indicate how the result form this BIM use can be verified. An example of this is a paper describing light simulations and how these simulations can be verified by measuring illuminance in the final building. At the third sublevel, **3c**, the scientific papers should also include a Post Occupancy Evaluation (POE) that validate that the expected value was also received.

As an incentive for the students to find evidences on a high level the grading of the exercise included the LOE they provided.

3. Result

Table 1 show the result from the students' efforts in number.

Table 1: Result from all the groups

Group	1	2	3a	3b	3c	SUM
1	0	2	3	2	8	15
2	1	2	10	0	3	16
3	7	7	1	0	0	15
4	0	11	0	1	0	12
5	0	3	4	2	2	11
Sum:	8	25	18	5	13	69

As can be seen from *Table 1* the different groups documented between 11 to 16 different values/BIM-uses. The number of values/BIM-uses documented were 69 in total. The result from the evaluation of the sources of evidence in the documentation, concerning the LOE, is shown in the different columns. The students found scientific papers for 36 (52%) of the values/BIM uses. 18 of these were in the category "Can be performed", five in the category "Verified (measurable value)" and 13 in the category "Validated (value is received (POE))". For the other 33 (48%) values/BIM uses the sources of evidence were categorized as "Stated by a company" 25 (36%) or "Common understanding" 8 (12%).

Table 2 contains the result for the of the student groups with the highest level of evidence (LOE).

Table 2: Result from Group 1

Goal/Value	BIM Use/Software	LOE
Adequate size of rooms	Design authoring (Audit and Analysis tools): Solibri	3c
Organized site layout	Site Utilization Planning: Infraworks FormIt	3c
Adequate lighting	Daylight analysis: Velux Lighting analysis: Dialux	3c
Adequate indoor temp	Energy simulation: IDA ICE	3c
Good acoustic quality	Noise simulation tool: EASE focus	3c
Air quality	Wind analysis: CFD Autodesk	3c
Indoor recreation and soc area	space management Model checking: Solibri	3c
Building maintenance	Building (Preventative) Maintenance Scheduling	3b
Cost affordability	Cost Estimation (Quantity Take-Off): VICO, RIBiTWO	2
Energy performance	Facility Energy Analysis: IDA ICE	2
Security system	Design Review: Solibri	3a
Accessibility	Design Review: SolibriSolibri	3b
Internal housing facility	Design Review: dRofus	3a
Fire safety	Design Review: Solibri	3c
Zero emission building	Sustainability (LEED) Evaluation: Revit	3a

As can be seen from *Table 2* the group found 15 values/BIM-uses and in the LOE-column the result from the evaluation concerning the level of evidence is shown. From this column it can be concluded that the group found scientific papers for 13 (87%) of the values/BIM uses. Three of these were in the category “Can be performed”, two in the category “Verified (measurable value)” and eight in the category “Validated (value is received (POE))”. For the other two values/BIM uses the sources of evidence were categorized as “Stated by a company". No values/BIM uses had the sources of evidence categorized as “Common understanding ".

Table 3 show the result from the other groups.

Table 3: Result from Group 2, 3, 4 and 5

Group 2			Group 3		
Goal/Value	**BIM Use/Software**	**LOE**	**Goal/Value**	**BIM Use/Software**	**LOE**
Room size	Solibri	3a	Access to public transport	ArcGis, Grass Gis, Rhino, Google Map Transit	2
Internal housing asset	dRofus	3a	water and wastewater	MagiCAD, BIM 360 OPS	2
Accessibility	Solibri	3a	materials quality and durability	Tekla, Rhino, 3D Max + Revit	2
Parking space management	Park CAD 4.0	2	entertainment and sport environment	dRofus	1
Residential critical areas	dRofus	3a	energy efficiency	MagiCAD, Energyplus	1
Interior and exterior appearance	Lumion 8	3a	indoor air quality	Energy Plus	1
Internet facility	iBwave design	3a	accessibility	SMARTreview APR	1
Space cost	VICO Office	3a	safety	solibri	2
Safety	MassMotion Software	3c	visual comfort	Velux, Light analysis Revit , Radiance	3a
Maintenance scheduling	ARCHIBUS v.23	1	space comfort	solibri, dRofus	2
Reachability	ArcMap	3a	accommodation costs	autodesk quantity takeoff,	2
Acoustic comfort	EASE FOCUS	3a	acoustics	Unclear	1
Visual comfort	Velux Daylight Visualizer IDA ICE	3c	furnishing	Unclear	1
Thermal comfort	IDA ICE	3c	green area	various kinds of gis tools	2
Indoor air quality	CFD	3a	smart building	Unclear	1
Wastewater management	Revit MEP Plugin	2			
Group 4			**Group 5**		
Goal/Value	**BIM Use/Software**	**LOE**	**Goal/Value**	**BIM Use/Software**	**LOE**
Optimal site location	SITE ANALYSIS – LOCATION	2	Cost	Cost Estimation (Quantity Take Off)	3a
SUSTAINABILITY EVALUATION	SUSTAINABILITY EVALUATION	2	Conductive Location	Site Analysis	2
SPACE COSTS	COST ESTIMATION	2	Fire Safety	Disaster Planning	3a
THERMAL COMFORT	SUSTAINABILITY EVALUATION	2	Sanitary Quality	BIM Use: Building (Preventative) Maintenance Scheduling & Asset Management	3b
Light efficiency	LIGHTING ANALYSIS	2	Acoustic Comfort	Engineering Analysis (Structural, Lighting, Energy, Mechanical, Another) & Code Validation.	3a
Sizing acoustic protection	ACOUSTICS	2	Energy Use and Performance	Facility Energy Analysis	3c
ACCESSIBILITY	PROGRAMMING	2	Visual Comfort	Lighting Analysis	3a
AIR QUALITY	BUILDING SYSTEM ANALYSIS	2	Thermal Comfort	Use Sustainability / LEED Evaluation	3c
SAFETY	DISASTER PLANNING	2	Internal Living Space Wide Area	Space Management and Tracking	2
MAINTAINABILITY	ASSET MANAGEMENT	2	Having Privacy Occupants	Space Management and Tracking	2
ENERGY CONSUMPTION	FACILITY ENERGY ANALYSIS	2	Accessibility	Space Management and Tracking	3b
SPACE EFFICIENCY	SPACE MANAGEMENT & TRACKING	3b			

It can be seen in *Table 3* that the different groups focused on different LOE. Group 3 and Group 4 found just one scientific paper for the values/BIM uses. Group 3 also used “Common understanding " as their main sources of evidence while Group 4 used sources of evidence categorized as “Stated by a company" mainly. Group 2 and Group 5 found sources of evidence in different categories. In this table the terminology is directly copied from the reports of the students. This makes it possible to see the variety of terminology used by the different groups, both for Goal/Value and for BIM Use/Software. It also shows the difference in the type of terminology used, e.g. that some of the groups just give the name of the software in the BIM Uses/Software column and other groups the BIM use.

4. Discussion and Conclusion

It was observed in an earlier study by Davoodi et al. (2017) that one of the barriers in adopting EBD in the building design process with computational modeling is the limited amount of evidence sources (including both literature and example projects) that can be readily used by the design practitioners. Accordingly, we developed a case-study for MSc students at the Sustainable Building Information Management program at Jönköping University, wherein they were asked to find literature needed to conduct the first two steps in the CHD framework. A little more than half of the sources found by the students were scientific papers (36 of 69, 52%) and a little less than half (33of 69, 48%) were considered as nonscientific sources. The difference between the groups results of finding evidences were noticeable and the percentage of sources being scientific papers differed from 7% to 87% between the groups. It is rather obvious that two of the groups focused on sources of evidence in the two lowest categories. *Table 2* shows the result from the group that had the highest level of evidence and this group did not find scientific papers for two of the value/BIM use. Having the values/BIM-uses for these two it is rather obvious for the researchers that there are scientific papers available also concerning these values/BIM uses. From *Table 3* it is rather obvious that two of the groups focused on sources of evidence in the two lowest categories. There was also a large variation between students regarding the sources of evidence found, only three of the students had scientific papers for all the values/BIM uses and eight of the students found scientific papers for more than half of the values/BIM uses which they were responsible for. This indicates that scientific literature concerning different BIM uses can be found but the students on master level still show limited training in finding relevant scientific sources. The same can probably also be stated for most people working in the AEC/FM industry and to be able to implement an EBD-BIM process training is needed. However, in the same way as some of the students went through this extra effort to obtain a higher grade, an incentive is needed to establish this as a way of working in professional practice.

In the planning of the case-study, some guidelines for the level of evidence were investigated (Pati, 2011) and, although these guidelines have been simplified regarding required level of scientific rigor, it was concluded that they were still too complicated for the students to follow. From the results, it can be concluded that, working with EBD-BIM process, a simplified guideline concerning the level of evidence needs to be developed.

The students were introduced to literature containing terminology of values (Annerstedt et al., 2012) and BIM uses (CIC, 2011),yet the result shows a great variety of terminology used by the different student groups. An explanation is that the literature found by the students contains a variety of terminology and students have not understood the difference between value, BIM use and software and the importance of using these standard terminologies. For EBD-BIM to be practically useful the use of classification/standard terminology concerning values and BIM uses is needed be disseminated.

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