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Enhancing decision making processes in early design stages: Opportunities of BIM to achieve energy efficient design solutions

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Abstract

Over the last decades, technological advancements were carried out with a great pace and that forced industries to drastic changes and paradigm shifts. These advancements provide new opportunities that arise with their new requirements. Due to some of these requirements, AEC industry unwittingly caused some crucial global issues which are gaining momentum exponentially, cannot be ignored anymore. The main reason of this situation is identified as many significant decisions which directly affect the performance of the building and the relationship of the building with natural and built environment are taken, even if there is no certain and valid information. The focus of the study is to discuss and evaluate the collected data and the obtained findings from previously implemented 5 case studies with 25 unique participants in a same context to re-evaluate and understand how BIM can help designers in the early stages of architectural design, most particularly in decision making processes. In addition, we also focus on investigating what opportunities it provides, what drawbacks it causes and what the user feedbacks about using the tool in these stages are. The focus of this study is not to offer an alternative way for traditional design practices but to explore if these kinds of tools have advantages for conceptual designing and/or design supporting. To achieve these aims, we have used quantitative (questionaire), qualitative (pure observation, participant observation, in-depth interviews and focus groups) and protocol analysis (retrospective analysis) methods.

Keywords
BIM, Decision making in design, Early design stage, Performance evaluation.

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1. Introduction

With the beginning of the Industrial Revolution and its subsequent World Wars, mechanical and electrical systems were invented and developed with a great pace and achieved technological advancements forced industries to drastic changes and paradigm shifts. While this situation provided new opportunities, it also directly affected the requirements of the era. Due to some of these requirements, an expeditious increase in AEC industry has started which has caused some crucial global issues in progress of time such as global warming, depletion of ozone layer, depletion of natural resources and so on. Researches show that AEC industry is directly responsible for this situation. For instance, all consumed energy of the United States used up by the buildings is 47,6% (Architecture 2030, 2017), while it is 40% in EU countries (The European Union, 2012). In the United States, when all other manmade immovable structures are included - things such as bridges, roads, dams, and ports - the raw materials consumed in the process of construction exceeds 75 percent of the total (Roodman et. al, 1995; Matos and Wagner, 1998). From another point of view, the construction in the United States consumes three times more raw material than all other economic and industrial activities combined (Smith and Tardiff, 2009).

Furthermore, the population of the world is expected to reach to almost ten billion by 2050 (United Nations, 2017). In a similar vein, during next twenty years, it is expected to be more than doubling the built environment (Krygiel and Nies, 2008). It is obvious that demanding for materials and energy is growing exponentially. On the other hand, according to the United Nations, the world can barely sustain a population of six billion at a middle – income consumption level, which we experienced in 1990s (United Nations, 2005; Smith and Tardiff, 2009). These facts show us that the world will not be able to meet these exponentially growing infinite demands in a short span of time. This situation leads us to be in a much more critical position which cannot be ignored anymore.

Numerous researches have shown that one of the most important reasons of this consumption is many essential decisions (building orientation, building shape, structural system, building envelope and so on) are taken at the early design stages without any valid and certain information (Gervasio et al., 2014; Granadeiro et al., 2013; Hong et al., 2000; Holm, 1993; Gratia and De Herde, 2003). These decisions which are taken with often inadequate information on the site, climate, geography also provide a basis for the final performance and the aesthetics of the final outcome. In order to find a solution to recent challenges, new BIM processes and capabilities have started to be developed and although they have been acknowledged as inadequate for the early stages of architectural design, they can have a huge potential to support these stages with their existing and potential capabilities.

The focus of this study is to discuss and evaluate the collected data and the obtained findings from the previously implemented 5 case studies with 25 unique participants in the same context to re-evaluate and understand how BIM can help designers in the early stages of architectural design, most particularly in decision making processes. In addition, we also focus on investigating what opportunities it provides and what drawbacks it causes, and what the user feedbacks about using the tool in these stages are. The focus of this study is not to offer an alternative way for traditional design practices but to explore if these kinds of tools have advantages for conceptual designing and/or design supporting. To achieve these aims, we have used quantitative (questionaire), qualitative (pure observation, participant observation, in-depth interviews and focus groups) and protocol analysis (retrospective analysis) methods that provided us to obtain a wide range of data.

This study consists of five main sections. We firstly review the the decision making processes in early design stages and its significance over the entire design process and the final product. We also review the literature on the early stages of architectural design and its significance within the scope of design cognition field. Later on, we concentrate on the BIM and discuss what capabilities BIM can offer for the early stages of design and how these capabilities can help us to challenge global issues that we are going to face. In the Case Study Implementations section, we present the previously implemented case studies. In that section we also express the research methods that have been used during the case studies and explain how we use these inputs and outcomes for this specific study. In the Findings section, we explain and evaluate the collected data of the previous implementations and discuss the findings of different studies in the same context to constitute an understanding for the focus of the study. In the last section, we discuss the findings of this study connection with the related literature in terms of decision making, building information modeling, energy efficient design and so on.

2. Decision making in early design and the potential benefits of BIM

2.1. Decision making in design

Decision-making can be described as a four-step process: searching the environment for problems, analysis and development of possible courses of action, choosing a particular course of action and implementation of the action (Sprague 1980; Simon 1960). It is a process choosing a preferred option or a course of actions from between a set of alternatives based on given criteria or strategies (Wang et al., 2004; Wilson and Keil, 2001) by identifying, gathering information, and assessing alternative resolutions.

From the design perspective, as design problems are usually open-ended, complicated, uncertain and ambigious, decision making process in design has a dynamic nature. Dynamic decision making is characterized by the following four features: a series of decisions is required to reach the goal, the decisions are interdependent, the state of the decision problem changing a consequence of the decision maker's actions and the decisions to be made in a real-time environment (Edwards, 1962; Brehmer, 1992). Dynamic decision making environment also requires two overlapping cognitive activities which track key variables for information, regarding present and expected conditions and the control, generation, evaluation and the selection of alternative actions (Lerch and Harter, 2001). Within this context, feedback is one of the most crucial features of dynamic decision processes. There are three decision support mechanisms that are commonly accepted and discussed in this regard (Gonzalez 2005; Arora, 2009):

- Outcome feedback refers to providing decision makers with feedback on the performance results of their decisions.
- Cognitive feedback refers to giving decision makers instructions on how to perform the decision task.
- Feedforward refers to providing decision makers with an environment to perform what-if analysis of potential decisions.

2.2. Early design stages

Design is identified as a process of generating new, valuable and desirable solutions by many researchers (Casakin, 2008; Woo, 2005; Buchanan, 2001; Galle and Kroes, 2014; Galle, 2011). It is also acknowledged as one of the most complicated cognitive process of human beings (Liu and Architecture Group, 1996; Akin, 1979; Oxman, 1996; Gero and Mc Neill, 1998) which is mostly accepted as a problem solving activity. Design problems usually have open-ended, wide-ranging, complicated and ambiguous characteristics (Pinch et al., 2010; Carmel-Gilfilen and Portillo, 2010). They are interacted with various criteria to generate design ideas and concepts (Casakin, 2008; Goldschmidt, 1989). Goel (1995) states that design problems are constituted of lots of different parts and elements, and these do not need to be logically connected. This makes design a cyclical process which is fed from the feedbacks of the ongoing process. To deal with these complicated and ill-defined problems, Alexander (1964) claims to separate design problems into smaller sub problems. Thus, it will be possible to obtain more defined problems which can be solved successfully with rationality (Goldschmidt, 2014).

In these stages, designers are also expected to decide on significant factors such as building orientation, building shape, structural system, building envelope and interior finishes with inadequate and indefinite information. These decisions which are taken with often inadequate information on the site, climate, geography, also provide a basis for the final performance and the aesthetics of the final outcome.

This situation makes early design stages important not only for the aesthetic and functional aspects but also for sustainability. In order to find a solution to this problematic situation and enhance early design processes, some researchers and practitioners have focused on developing new design tools and information management databases for meeting the new requirements of the current practices. In this context, BIM comes to the forefront with its current and potential capabilities.

2.3. BIM and the potential benefits for early design stages

National Institute of Building Sciences (n.d.) defined BIM as a model and process: "A building information model is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward. A basic premise of Building Information Modeling is collaboration by different stakeholders at different phases of the life-cycle of a facility to insert, extract, update or modify information in the model to support and reflect the roles of that stakeholder".

Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design (GSA, n.d.). This integrated, parametric, intelligent and object-based virtual model provides an environment to obtain abstract forms of representations, inferences, work and time schedules, analyzes, simulations, and so on. By this way, BIM enables the creation, generation and management of all numeric and non-numeric data coordinately, collaboratively, coherently, synchronously, and in a computable way from the conceptual design to the end of the building's life (Krygiel and Nies, 2008; Garber, 2009; Deustch, 2011; Eastman et al., 2011). The characteristics and capabilities of BIM are discussed with many reports and publications in both industry and academic settings (Eastman et al., 2008; Azhar, 2011; buildingSmart, n.d.; AGC, n.d.).

In spite of the fact that BIM offered unique capabilities during the drafting and construction processes, it was regarded as being inefficacious as an early design environment for a short time before. Particularly for the past 10 years, BIM has been able to meet the capabilities of the other CAD tools commonly used in the industry and has reached a level of competitiveness with them for early stages of architectural design. Today, BIM stands out with its 'intelligent and parametric modeling capabilities' and 'simulation, analysis and inference capabilities' when comparing with conventional CAD tools in terms of early stages of architectural design process. As it was mentioned in the previous sections, the intent of developing BIM as an early design environment is directly related to the recent global challenges which AEC industry are obligated to face. Studies show that the difficulty of evaluating the performance of the building in the early stages of design has made the products generated to be inadequate in achieving the desired performance (Schlueter and Thesseling, 2009). Regarding studies which investigate how to achieve more sustainable design approaches, the necessity of evaluating sustainability criteria from the initial stages of design has been determined (Attia and De Herde, 2011). With BIM, even in the early stages of architectural design, designers can begin to work on models to analyze and redesign their designs according to the performance and efficiency criteria using specific pre-defined presumptive data without requiring any advanced engineering knowledge.

Since many important building-related decisions have not yet been taken at the early design process, the capability to analyze and simulate the geometric (mass) design models of the BIM tools is a distinguishing feature, which is one step ahead of conventional design tools. In this context, the passive and active strategies identified by Krygiel and Nies (2008) for the sustainable BIM approach are reduced and sorted according to the possibilities BIM can provide in the early stages of architectural design: building orientation, building massing, solar and shadow analysis, daylighting analysis, conceptual energy modeling, potential renewable energy analysis.

In brief, it is emphasized that taking advantage of essential information about design task in early design process is useful and crucial. BIM environment with its information processing capability operates as an improved design support tool with powerful drafting and modeling features, performance simulations and visual analysis feedbacks. These feedbacks are beneficial as visual and numeric outcomes of the design which enable the evaluation of the designed mass to improve it. Then, the design relies on the functional, aesthetic, sustainable realities and the subjective judgements of designers. In this section, we have studied the current realities of early stages of architectural design and building information modeling by literature review, and then, we have explained why and how we need BIM in these stages.

3. Case study implementations

Over the last years, we have implemented 5 case studies with 25 unique participants to investigate the opportunities and drawbacks of BIM environment in the early stages of architectural design. Participants were consisted of undergraduate and graduate students of various architecture education programs of Istanbul Technical University. Some of these case studies have been published (Cavusoglu, 2015a; Cavusoglu, 2015b; Cavusoglu and Cagdas, 2017).

All participants indicated that they were familiar with at least one well-known CAD tool to use it as drafting, modeling and designing tool. On the other hand, they had no or little experience about using BIM and energy modeling. For this reason, since participants had no or little experience about BIM related concepts which would be used in these studies, a series of theoretic and practical lessons had been given to the participants. We started these lesson series with giving a lecture about general concepts of BIM and its importance for AEC industry. At that moment, our focus was not about using BIM in early stages of architectural design but describing why BIM gain importance in a short span of time in AEC indusrty and what opportunities it provides. After informing the participants about these general concepts, we started to give applied courses for using BIM particulary for basic operations such as drawing and modeling geometric forms and also understanding the non-geometric features of the environment. At the last sessions of these lesson series, we concentrated on using BIM in early stages of architectural design. While we were focusing on mass modeling and conceptual energy analysis features of the environment, we also gave theoretical courses about the main principles of sustainable building design.By this way, we tried to provide an adequate basis for participants to achieve a successful research process within a limited time.

Design tasks of these implementations had different complexities which varies from 'designing a single function building form' to 'designing a multi-purpose functional building which has functional, contextual and sustainable requirements that must be considered'. To achieve the expected results, we have used quantitative (questionaire), qualitative (pure observation, participant observation, in-depth interviews and focus groups) and protocol analysis (retrospective analysis) methods that led us to be able to obtain a wide range of data. During these studies, we have examined the BIM in terms of efficiency evaluation of different roles of the tool, software evaluation criteria and design cognition, most particulary how using BIM in early design stages affects decision making processes of the designers.

On the other hand, in consideration of the previous case study implementations, we took a step back and re-evaluate all these processes in this study. We reconsidered all the collected data and the obtained findings from these studies to study and discuss all together within the same context.

4. Findings

4.1. Efficiency evaluation of BIM's roles in early design stages

During the case study implementations, we determined 5 main roles for the BIM environment that contribute to the early design stages. These are design exploration, 3D modeling, parametric modeling, energy modeling and decision support system. The participants were asked to vote these capabilities from 1-10 points through their own experience and to explain the reason why they had evaluated the capabilities in this way. The average results for each role are given below in Figure 1.

Design Exploration. The participants have a consensus on that BIM environment is not as good as traditional sketching and physical modeling for design exploration and triggering creativity. On the other hand, they also indicated that starting the design process within sketching environment and then improving the concept design in BIM is a very effective way of working without being obligated to sacrifice any important aspects of early design stages. It is understood that BIM environment offers lots of unique capabilities that supports the designer in early design stages in comparison with other CAD tools but still cannot compete with sketching environment in terms of design exploration.

The main problem we observe in the case is that the analyzing capabilities of BIM led the participants to improve their designs they developed before. From this moment on, we notice that the design process is starting to evolve from an intuitive desing approach to a systematic design approach. In other words, after starting the analyzing and evaluating process in BIM, almost none of the the participants tried to develop an entirely different concept models. So it can be discussed that using BIM in creative design process may cause fixiation so that the participants tended to focus solely on one solution and tried to improve it.

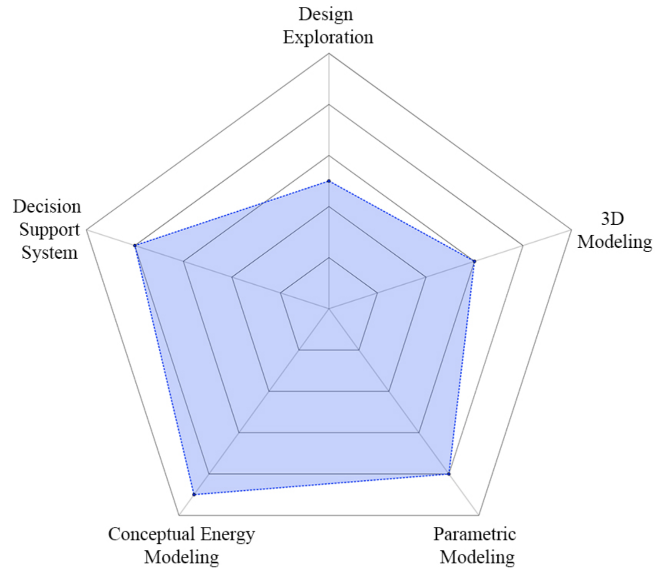

Figure 1. *Graphical representation of questionnaires average results.*

3D Modeling. Almost all users found the BIM's capabilities equal or better than the traditional CAD tools for 3D modeling. But, while we were investigating the participants' feedbacks on 3D modeling capabilities of the tool, we found a contradictory situation that some participants voted very high, but others voted low. When we thoroughly investigated this situation, we understood that the participants who had a better command with the tool, were able to do what they wanted easily which directly led them vote higher. On the other hand, the participants who were not able to use the tool fluently voted lesser.

Parametric Modeling. Other than the geometric modeling, the participants stated that they took advantage of working with a model which constitute its elements parametrically connected. In regard to our observations, this situation actualises in two ways:

BIM provides an environment where users are able to constitute a parametric connection on 2D/3D models while they can still manipulate the model manually. In this way, it offers a way of working which provides an environment that users can work totally manual, parametric, and also parametric with manual transformations. In one of our implementations, participants were able to continue their design development processes with these parametric design capabilities of the tool. Mostly, they tackled with the problem of constituting true parametric connections while most of them had no parametric and algorithmic thinking foundation. Because of this reason, we ignored the parametric design capabilities of the tool for this series of implementations.

On the other hand, in all of our implementations, participants used the parametric foundation of the environment for taking inferences via calculations and schedule capabilities such as floor area schedules classified by different functions, building masses and zones. All participants found this useful and expressed that it gave them a chance to handle the geometric and non-geometric inputs much more easier and effective.

Conceptual Energy Modeling. Almost all participants even the ones who were experienced some troubles using the BIM found conceptual energy modeling as the most powerful and useful capability of the environment. We observe that conceptual energy modeling directly contributes two important factors. Firstly, it supports the designers not only with its text based and visual analysis feedbacks to obtain better design solutions in terms of performance output but also provides them a self learning environment to design sustainable solutions with the way of trial and error problem solving method.

Decision Support System. Firstly, we met the same situation here in common with the evaluation of 3D modeling that some of the participants voted higher than the others voted lesser. The reason is again same with the 3D modeling evaluation that is directly related with the command of the tool. On the other hand, based on our observations and the participants' feedbacks within the interviews and focus group meetings, BIM environment provides a lot of capabilities to its users in terms of decision supporting. But more importantly it has a suitability to be developed as a better decision support system. Over the last years, there have been a lot of new tools which have been dedicatedly developed for enchancing decision support processes in early design stages. This has made BIM environment much more efficient within this perspective. Along with this, we notice that the participants voted fairly higher in the subsequent implementations when compared with the first ones.

Overall Evaluation. As a summary of the criteria we found out that BIM could not be able to provide a good environment for design exploration. Moreover, it needs more flexibility for 3D modeling capabilites in terms of ease of use and user friendliness which were started to be developed nowadays. Having a parametric foundation serves great with both geometric and non geometric inputs of the process. In addition to being parametric, conceptual energy modeling capability provides a great environment to test and evaluate the developed design model without any expert engineering knowledge. All these capabilities provide a solid foundation for BIM in terms of being a decision support system. Recently, new capabilities and tools have been developed to take BIM's decision support role a step further which aims to enhance cognitive processes of designers while they are analyzing and evaluating the design models.

It is important to underline that even the BIM tools have new opportunities for the early design stages, we still have to educate and improve ourselves to be able to adapt to this new approach. As it is a well known general issue for BIM, we also experience and observe that the need of adopt the cultural shift for BIM is a must to get efficiency from it. In early stages of design, this cultural shift is not only about improving the command of the tool but also gaining knowledge about related concepts, improving computational thinking and analytic reasoning skills.

During the implementations, even it was not our target to observe BIM as a learning environment, we determine that the participants who lack command with the sustainable design principles were using the tool with trial and error method to understand which analysis input and output affected the design in what way. By this way, they figured out the lack of command issue and constitute a new way of working for themselves. This situation shows us that BIM provides an effective environment for learning, teaching and practicing the sustainable design. In a similar vein, BIM not only enhances the analytic reasoning and evaluation skills of designers, but also provides an environment for improving them.

4.2. Efficiency evaluation of BIM environment in terms of software evaluation criteria

In this section, we discuss how the participants evaluated the environment in terms of software evaluation criteria. We determined 8 criteria for evaluating the environment which are capabilities, developability, ease of use, effectiveness, flexibility, functionality, learnability and online education sources. The participants were asked to vote these criteria from 1-10 points through their own experience and to explain why they evaluated the criteria in this way. The results as an average for each role are given below in Figure 2.

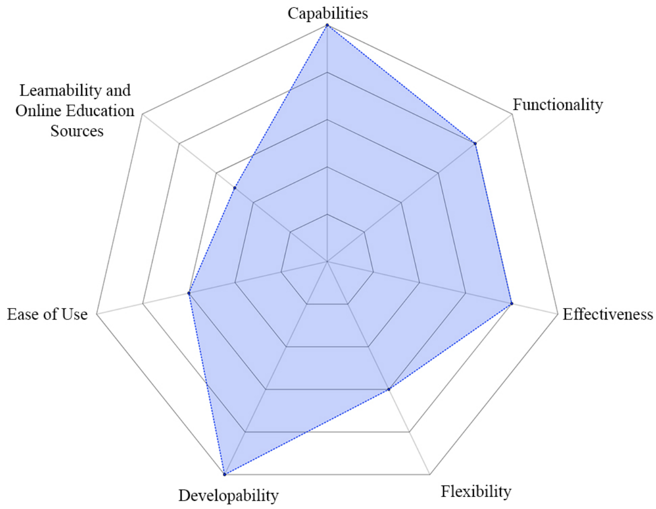

Figure 2. *Graphical representation of questionnaires average results.*

Almost all the participants indicated that the varied capabilities of the environment are useful and helpful. This situation directly contributes a positive effect to effectiveness and functionality of the environment. The participants stated that they were able to analyze and evaluate some design parameters which they were obligated to ignore in their early design activities. Moreover, they expressed that there are also a lot of potential capabilities which can be developed to make BIM a much more efficient environment for early design stages. The main point of their remarks were focusing on the capabilities based on new analyzing and evaluation features which can enhance the environment particulary in for decision making aspect.

On the other hand, some of the criteria relatively has lower points in our questionaire. In interviews and focus group discussions, it is understood that some of the participants were not able to gain enough command with the tool. They underlined that tool had to show progress in terms of the ease of use and flexibility. In addition, they asserted that the online education sources were not enough in both quantitative and qualitative manner which directly affected the learnability of the tool.

However, from the first day of our implementations up to today, following the popularity of using BIM based capabilities in the early design stages, there has been an immense progress to overcome these mentioned and also unmentioned issues. Educational institutes and professional organizations were initiated online education programs to develop designers' technical, theoretical and practical knowledge of BIM and sustainability in early design stages. Furthermore, new BIM based environments and capabilities are being developed for analyzing the concept model with different aspects and helping the designers' evalution processes with new features. Within this context, we detect that while the powerful features of the environment are still being developed, the weaknesses are also being developed to a much more better position. In a similar vein, we observe that the participants who participated the subsequent implementations marked higher votes when compared with the previous ones.

Based on our observations, interviews, focus group discussions and the results of the questionaire, we detect that the environment provides very powerful capabilities for the early design stages. In addition, the basis of BIM provides an environment where a lot of other tools or features can be developed. For that reason, we think BIM will continue to gain importance for early design stages especially as a decision support system which enhances designers' cognitive activities with supporting them its capabilities.

4.3. Evaluation of decision making processes in BIM environment

Kerstholt and Raaijmakers (1997) discusses that the decision maker needs to have an accurate model of the related elements and their temporal characteristics. By this way, they can control and predict the current and future states of the process which enable both feedback and feedforward mechanisims. With the capability of object oriented modeling where elements are parametrically connected to each other with involving all numeric and non numeric information, BIM provides an environment to obtain feedbacks and feedforwards from the design model through computing all the related information and serving them as a meaningful outcomes such as text based and visual based analysis reports and simulations. By this way, BIM provides a basis to the participants where they track the information about their key variables of design task interpretations and use it to handle, generate, evaluate and select between the design alternatives. It is also accepted that decision making has 6 important steps to follow which are constructing the problem, compiling the requirements, collecting the information, comparing the alternatives, considering the factors and commiting to a decision and improving it. We also observe that BIM environment is able to support designers in all these phases with its aforementioned capabilities.

From another perspective, Kleinmuntz (1985) distinguished two different strategies which are action-oriented strategies and judgement-oriented strategies. Action-oriented strategies are used as decision makers who apply their actions and observe their effect on the system and proceed depending on the observed effect. On the other hand, judgement-oriented strategies are used as decision makers first try to reduce the uncertainty of the problem by requesting information and then apply their actions. During the implementations, we experienced that the participants were mostly using action-oriented strategies. They were taking decisions, applying actions and observing their effect on the model and proceeded improving design by this way. In contrast to this situation, based on our observations, we think that BIM is also suitable for the judgement-oriented strategies, especially if the design problem could be structured and framed as more rational subproblems.

In conclusion, we want to underline that 5 different case study implementations with 25 unique participants and a specific BIM environment are not sufficient to generalize the outcomes. Moreover, as most of the users had no or little experience with BIM and sustainable design principles but just learned the basics of them for that specific implementations, it is not fair to evaluate their votes as a precise input. Associated with this, as we have discussed before, we notice that the participants who have better command with the tool, tended to vote pretty higher than the others. It is obvious that we need to carry out further implementations with more participants who have better proficieny with the tool and sustainable design principles to comprehend better the current situation of the tool in early design stages. But still, the findings show how well BIM environment provides a foundation for early design stages, also where it is facing problems and what the underlying reason of this problem is.

5. Discussion and conclusion

The main objective of the study is to observe and explore what opportunities BIM can offer in early design stages particulary in decision making processes. During the study, we also investigate how the participants evaluated BIM as an early design stages environment in terms of the roles of BIM and software evaluation criteria.

Due to the ongoing devastating incidents, considering the performance criteria in the early stages of design to achieve a better performative buildings become obligatory. The perspective of Foqué (2010) accords with this situation as he expresses that 'intuitive thinking and rational thinking are not oppenents; they are the twin poles between which the artist structures reality'. He also asserts that architecture must take advantage of both science and art (Foqué, 2011).

As technology has evolved over the years, lots of new digital design tools have been started to be developed with a great pace. With the emergence of new technologies, new design approaches and way of working opportunities are shaping the way we think, make decisions and design. From this perspective, BIM does not only signify an environment or a tool but also a way of working. BIM's ability to store, inference and analyze the data related to the building serves as a modeling and decision support environment for designers in early design stages. In addition to its decision support capabilities, it offers a real time object oriented modeling environment where all the design model parametrically connected to each other with all numeric and non numeric inputs. By this way, designers can continue to design while they are considering both aesthetic, functional and also sustainable factors within a cyclical design process (Azhar et al., 2009). Within this context, BIM comes to the forefront with its current and potential capabilities as a decision support system for early design stages.

Kymmell (2007) describes the basic concepts of human action and interaction as being interwoven with each other as visualization, understanding, communication and collaboration, and explains how the direct and indirect features of BIM have fed these four concepts. It is now possible to consider many different factors in the early design stages which are often overlooked or difficult to assess nowadays. Kymmell explains the contribution of BIM through the phrase "a picture is worth a thousand words" as follows: "then how much will a 3D model be worth, or a movie of a timed sequence of events?"

In a similar vein, Miller (1956) has shown that short-term memory of individuals is limited to 7 ± 2 elements during data processing. Because of the assumption that design moves made during a problem-solving action are the representations of the minds at that moment they are considered to be connected to each other in the range of 7 ± 2 moves (Goldschmidt, 2014). Thus, as Kymmell points out, the building information model and all the inferences derived from it help designers to search for a more effective design by playing a reminder and decision support role for many design criteria that are prone to ignoring in the conceptual design process and disappearing from the working memory.

In conclusion, BIM offers many benefits to its users not only for drafting and construction processes but also for early design stages. It may have a way to become a better design tool and a decision support system. But, as we have discussed before, it already has very powerful capabilities that enhances decision making processes particularly for sustainable expectations of design.

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