BIM knowledge assessment: an overview among professionals

A survey on the AEC industry in Sao Paulo, Brazil

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The research goal was to evaluate BIM knowledge among professionals in order to delineate an overview concerning BIM adoption by the AEC industry of Sao Paulo, Brazil. The research method consisted of the application of a quantitative and qualitative online survey questionnaire. Results has shown the lack of adequately BIM trained personnel is still a significant constraint hindering a potentially wider adoption of the technology in the construction industry.

Keywords: *Building Information Modeling, BIM knowledge, BIM adoption, BIM professional education, AEC industry*

INTRODUCTION

Building Information Modeling (BIM) has transformed the Architecture, Engineering, Construction (AEC) industry and attracted increasing attention from researchers and practitioners (Zhao, 2017). In recent years, the field of study has consistently grown with more than 90% of papers being published under peer review in the last five years. In terms of BIM publications, the early ones were much simpler and more general (conceptual) than the current studies, which are more specific and focused on the application of tools and methods using case study methodology (Santos et al., 2017).

BIM has become a common process and technology used in the management of construction projects (Puolitaival and Forsythe, 2016). Considered as an innovative process and efficient technology, BIM is a collaborative approach, which manages project information from the early stages of design to construction, operation (facility management) and demolition (Donato et al., 2018).

BIM represents a paradigm shift for the AEC industry (Pauwels et al., 2017; Lu et al., 2017). Consequently, this paradigm shift represents an increase in the demand for trained professionals with BIM skills (Suwal and Singh, 2018; Zhang et al., 2018; Ahan and Kim, 2016). Despite the efforts from the AEC industry to implement BIM, the lack of trained professionals still presents a significant constraint (Barison and Santos, 2010; Becerik-Gerber, Gerber & Ku, 2011; Kocaturk and Kiviniemi, 2013). Although in the past decade, there have been significant advances in construction-related collaborative technologies, BIM implementation is a long path and depends on many aspects, such as the adequate methodology, trained personnel, the availability of technology and industry policies (Akintola et al., 2017).

The AEC industry in developing countries such as Brazil is still facing challenges in BIM implementation. The main obstacles are related to the need to change work culture and practices, the lack of understanding of the stakeholders 'roles and responsibilities, the lack of knowledge about processes and workflows and the highly investment in training and skills required for BIM (Olawumi, 2018; Mahalingam et al. 2015; Khosrowshahi and Arayici 2012; Singh et al. 2011; Hartmann and Fischer, 2008).

Given the field of study's relevance to the development of construction sector in Brazil, the research goal was to evaluate BIM knowledge among professionals in order to delineate an overview concerning BIM adoption in the AEC industry of Sao Paulo, Brazil with the purpose to answer the following research question: "What is the BIM level of maturity among professionals by the AEC industry in São Paulo, Brazil? " As additional contributions, this paper brings an understanding of BIM maturity stage in the AEC industry based on a BIM knowledge assessment among professionals in the labor market of Sao Paulo. We surveyed approximately six hundred individuals from the construction industry aiming to identify their level of BIM proficiency.

Our paper is structured as follows: Firstly, we introduce the research topic, research gaps and propose the research goal followed by the research question. Secondly, we contextualize the theoretical background, divided into three subsections: BIM adoption in the AEC industry, BIM professional education and BIM maturity levels. Thirdly, we outline our chosen research method including details of research stages and the developed survey questionnaire. Fourfly, we present data and sample, results and discussion. Finally, we conclude by presenting research goal achievements, research limitations and future works.

THEORETICAL BACKGROUND

BIM adoption in the AEC industry

Succar (2009) states that BIM is not just a technology, but also a project management tool and process consisted of all aspects, disciplines, and systems of a facility within a model, with which all stakeholders (owners, architects, engineers, contractors, subcontractors and suppliers) can collaborate more accurately and efficiently than traditional processes (Azhar et al, 2012). BIM promises an integration of information by combining geometric and non-geometric information in a comprehensive model that accommodate all aspects of construction (Koutamanis (2017).

As stated in BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors (Eastman et al., 2011), the benefits of BIM are well known: coordination and communication improvement, data management, analysis, simulation, construction productivity and facilities management. Nonetheless, BIM requires new strands of expertise for all disciplines compared to more traditional projects (Succar et al.,2013). Furthermore, there is a reluctance to change traditional practices and current procedures by the professionals in order to learn BIM.

Despite the rapid development of BIM, the effectiveness in the practice is constrained by the current contractual arrangements and traditional practices. In general, projects are more focused on individual benefits instead of the delivery of integrated project solutions (Migilinskas, 2013). BIM requires a significant change in the way construction businesses operate at almost every level within a building process (Arayici et al., 2011).

In summary, as an efficient technology and a disruptive process, BIM has changed not only the AEC industry's framework, but also the academic environment. Thus, AEC professional education has been searching for new alternatives that can improve BIM implementation in practice due to the considerable impact of BIM approach in the construction industry (Morton, 2012; Sacks and Pikas, 2013).

BIM professional education

The academic community has been searching for more effective teaching approaches that reflect the need for strong collaborative practices, as required by the increased level of design complexity, integrated delivery methods, and information modeling adoption in the construction industry. Although the issue of BIM in AEC education has attracted much attention in academic literature, little is known about what the current status of BIM in academia is (Becerik-Gerber, Gerber & Ku, 2011).

Several authors have proposed that BIM should be advertised through education or mandated by governments (Turk, 2016). To provide students with BIM skills as required by the current construction industry, many construction education institutions are introducing the concept in their coursework and hiring new faculty based on their expertise in BIM (Joannides, Olbina & Issa, 2012). Also, many schools now realize the potential of BIM applications as powerful teaching tools that help instructors to engage students with the class content, improving their learning experiences. Adopting and teaching BIM from the early stages of undergraduate education can provide future professionals with more experience with the technology (Irizarry et al., 2013).

However, the success of BIM adoption depends on a collaborative learning environment (Lindkvist, 2015). As stated by Mathews (2013), when experienced in a dynamic and collaborative learning environment, BIM brings better conditions to prepare the students to solve problems commonly experienced in the labor market. This teaching proposal conducts significant gains to the students' education, since it increases the level of cognition, learning and understanding of the design process.

Although many researchers suggest a pressing need on new alternatives based on collaborative practices, the adoption of BIM in a collaborative work environment has been little developed by institutions (Macdonald, 2012). Based on that, there is a continuous demand for professionals with BIM skills in virtue of the traditional and fragmented teaching practice. As a result, AEC schools have been looking for the development of integrated solutions for BIM in academia (Macdonald and Mills, 2011).

BIM maturity levels

BIM maturity denotes the basic abilities to perform BIM-related tasks efficiently rather than the actual attainment of the objectives expected from BIM deployment (Mahamadu et al., 2017). According to the BIM framework developed by Succar (2009), BIM maturity levels are: Pre BIM: Status of AEC industry before BIM implementation; BIM stage 1: object-based (modeling); BIM stage 2: model-based (collaboration); BIM stage 3: network-based (integration) and IPD: Integrated Project Delivery (the long-term goal of BIM implementation).

The usage of BIM is growing as technology matures (Turk, 2016). A study developed by Cao et al. (2015), has shown an overview of BIM practice through a decade in China and confirmed that BIM adoption has been clearly extended from the architectural design stage to the construction stage. Even though BIM has been continually expanding its functionality in the AEC industry since its inception in the 1970s, the implementation of BIM has not been fully exploited even in leading contexts. Mostly, there is a higher level of awareness of BIM in the UK, Canada, Finland and New Zealand then compared to developing countries (Ghaffarianhoseini et al., 2017).

RESEARCH METHOD

The research method consisted of the application of a quantitative and qualitative online survey questionnaire. According to Fink (2003), survey is a system of data collection with the purpose to describe, compare and explain knowledge, attitude and behaviour of a specific group of individuals. In other words, survey is understood as a research method which aims to collect data from a significant sample through a quantitative and statistical analysis of information from dozens or thousands of people (GIL, 2010). As reported by Forza (2002), a survey can be classified as exploratory, confirmatory or descriptive.

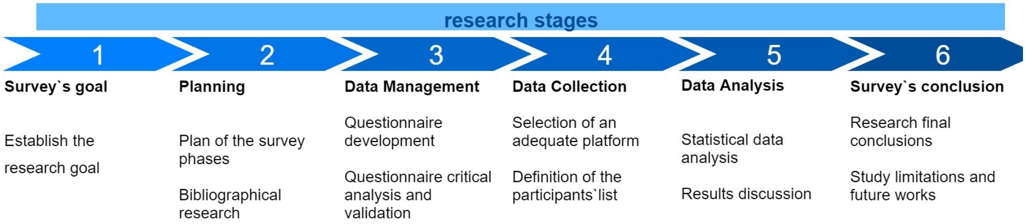

Figure 1
Research stages

This study is an exploratory survey, statistically analysed in order to obtain an overview about BIM knowledge among professionals in the AEC industry in Sao Paulo, Brazil

Research stages

Based on The Survey Handbook by Fink (2003), we developed our survey in six main stages as illustrated in Figure 1. First, we established the survey's goal. Second, we planned the study by conducting literature review about BIM adoption in the AEC industry, BIM professional education and BIM maturity levels. After the bibliographical research, the third stage (data management) focused on the questionnaire development, critical analysis and validation. The fourth stage concentrated on data collection by selecting an adequate platform for data collection, the definition of possible respondents and, lastly, sending the questionnaire to the respondents list. The fifth stage consisted of data analysis and results discussion. Finally, the last stage presented the research's final conclusions, research gaps and limitations and future works.

Survey questionnaire

The survey questionnaire consisted of 21 questions developed through a web-based platform. The questionnaire was designed to evaluate the level of BIM proficiency among professionals. The information requested from the participants was educational attainment, professional major, years of experience, previous BIM knowledge, the participant's self-evaluation of BIM level and their opinion about the role of academia on BIM teaching in professional education. The survey questionnaire used multiple-choice open questions which was based on four main categories: (1) BIM knowledge, (2) organization/company general information, (3) BIM adoption by the organization/company and (4) participant's educational attainment. The process of questionnaire designing was divided into three steps. First, we sent an initial version to be validated by professionals with expertise in BIM. Second, we updated the questionnaire and, finally, we defined the final version for the study.

DATA ANALYSIS AND DISCUSSION

Sample and data

Based on our research goal, we surveyed individuals from several professions related to the AEC industry in the market of Sao Paulo, Brazil. Data collection was completed under the condition of anonymity. Thus, it was not possible to determine if each completed survey represented a different organization. For data analysis, the sample was calculated by the software R 3.3.0 (R Core Team, 2017) considering the level of statistical significance (α) at 5%.

We collected 591 (≈15% response rate) answers in a sample of approximately four thousand individuals. The sample is non probabilistic and composed of professionals who have responded to the questionnaire on behalf of their companies. The participants were taken from a list of an online professional web-based platform. Data analysis showed a variance regarding the number of responses in each different question. Consequently, results' response rate varied according to each question. The sum of relative frequencies of the answers might not add up to 100 %, once more than one response was possible.

Results

Participants profile indicated that 49,5% of the respondents were architects, 45,6% engineers, 10,1 % professors, 5,2% consultants and 4,3% other position. In regard to years of professional experience in the field, one-third of the respondents (31,3%) declared having between 10 and 25 years of experience; 29,5% between 5 and 10 years, 18,3% more than 25 years, 17,7% between 1 and 5 years and only 3,2 % with less than one year of experience. Mostly, the participants are involved in the design phases, such as design development, management and coordination, instead of the construction and facility management phases.

While (38%) of the respondents mentioned that BIM has been adopted by the firm that they represent, 62% answered negatively for BIM implementation. The main difficulties chosen related to BIM implementation from the given options were: (45,1%) high cost of training, infrastructure and company's organizational structure; (38,2%) lack of trained professionals; (31,9%) low reward from the client; (27,1%) software incompatibility and undefined cost of implementation; and (27,1%) long path for BIM implementation.

Regarding BIM skills for professional recruitment, 43,3% of the participants answered that BIM is not a required skill, 34,8% confirmed that BIM is a demanding qualification and 21,9% said it may be a previous prerequisite. Fifty-five point three (55,3%) of the respondents said that their companies were planning to implement BIM in a near future, while 26,6% were in doubt and 18,1% answered negatively.

BIM knowledge among professionals. Figure 2 shows the concept of BIM by the participants (professionals from the AEC industry in Sao Paulo). Only 586 of 591 answers were valid, since five participants did not answer the question. Participants were able to choose more than one answer. Therefore, all answers were added to the total of each chosen option. Sixty-eight point four per cent (68,4%) indicated BIM as a construction data management process; (52 %) a "project data management software"; (45,6%) a "project representation technology"; (45,4%) a "project data management software"; (34,3%) "all previous answers", (3,1%) "others", and (2%) "none" for the given options, as illustrated bellow.

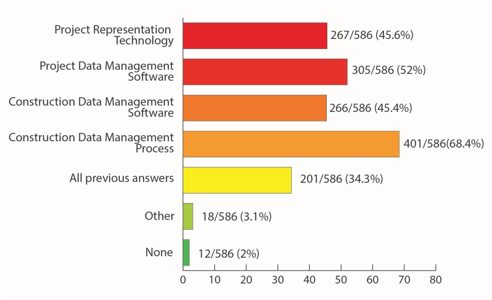

Figure 2
The concept of BIM understood by the participants

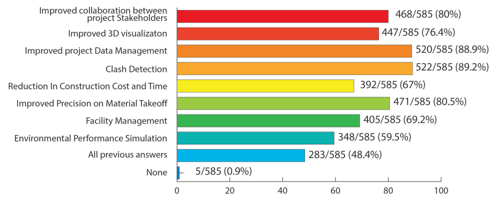

Figure 3
Participants 'opinion about the advantages of BIM

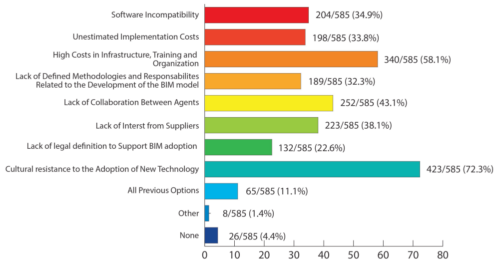

Figure 4
Participants 'opinion about the disadvantages of BIM

Participants were questioned about their opinion on the advantages and disadvantages of BIM implementation. The number of valid answers were 585 of 591. Firstly, Figure 3 illustrates the advantages of BIM chosen by the professionals. Eight-nine point nine per cent (89,9%) affirmed that BIM improves project data management and (89,2%) chose clash detection. The other benefits pointed by them were in sequence: (80,5%) improved precision on material take-off; (80%) enhancement of collaboration between stakeholders; (76,4%) improvement 3D visualization; (69,2%) facility management; (67%) reduction in construction cost and time; (59,5%) environmental performance simulation; (48,4%) choose all answers and (0,9%) none.

Secondly, Figure 4 illustrates the disadvantages listed by the professionals: (72,3%) indicated cultural resistance to the adoption of new technology; (58,1%) high costs in infrastructure, training and organization; (43,1%) lack of collaboration between stakeholders; (38,1%) lack of interest from suppliers; (34,9%) software incompatibility; (33,8%) unestimated implementation costs; (32,3%) software lack of defined methodologies and responsibilities related to the development of BIM model; (22,6%) lack of legal definition to support BIM adoption, and (11,1%) chose all given options.

BIM professional education among professionals. In consonance with the research goal, participants were invited to answer questions related to their professional education. First, (71,9%) participants considered their level of BIM knowledge at the end of their undergraduate program insufficient, (14,7%) intermediate, (8,9%) good and (4,4%) advanced, as illustrated in Figure 5.

Second, participants were asked about the role of academia in the professional education concerning the usage of BIM in the AEC industry. The majority of the respondents (78,5%) admitted that the AEC academia has an important representation in BIM education; (11,2%) of them were in doubt; (7,3%) do not believe that the AEC institutions are responsible for introducing BIM into their professional education and (3%) said that they do not have knowledge about it, as shown in Figure 6 below.

Third, Figure 7 shows from where the participants have acquired BIM knowledge. The number of valid answers were 462 of 591. Thirty-six point eight per cent (36,8%) answered that they had learned BIM in a graduate program; (29,2%) in an undergraduate program; (19%) from practice; (3,5%) from training courses; (3%) from self-learning; (5%) had contact with BIM from academic events and (3,5%) from specialized media.

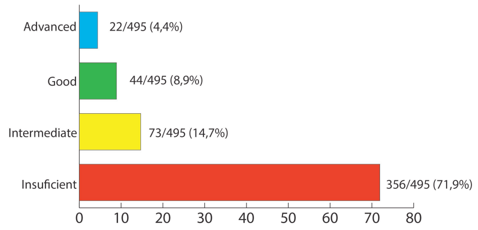

Figure 5
Participants 'opinion about their level of BIM knowledge at the end of undergraduate program

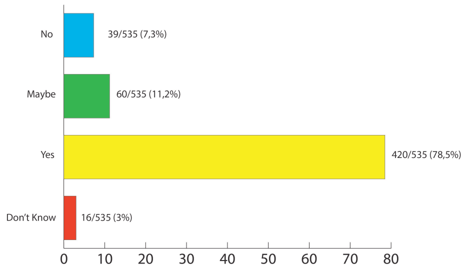

Figure 6
Participants 'opinion about the role of academia in the professional education

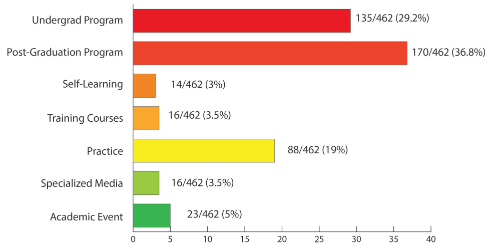

Figure 7
From where the participants have acquired BIM knowledge

DISCUSSION

Findings have shown an overview of BIM knowledge among approximately six hundred professionals in the AEC industry of São Paulo in Brazil. Most of them classified their level of BIM proficiency as insufficient at the conclusion of their undergraduate education. Consequently, participants answered that their BIM knowledge where obtained predominantly from a graduate program (36,8%) instead of (29,2%) of the them said that they have learned BIM while enrolled in an undergraduate program. Professional education was indicated as a relevant reason for the lack of BIM knowledge among practitioners. According to the participants, academia has an important role on BIM education.

For Ghaffarianhoseini et al. (2017) the lack of BIM skill and experience is a major concern. Many BIM users attribute the low return on investment to the users' level of experience and BIM engagement. Accordingly, the most significant reason for not adopting BIM pointed out by the participants was cultural resistance to the adoption of new technology (almost 73% of the answers). The other ones were high costs in training and software; lack of demand and stakeholders' collaboration; lack of defined methodologies and responsibilities related to the development of BIM model and interoperability issues.

On other side, the survey suggests that the notion of BIM as a data management technology prevails among the respondents. Participants have recognized that the main improvement brought by BIM is the increment on project data management capacity and clash detection. Furthermore, when asked to pick a more accurate definition of BIM, most of respondents indicated that BIM is a construction management process.

Additionally, participants were asked about their opinion on alternatives to expand the implementation of BIM in the AEC industry in Brazil. From the given options the most selected were the ones related to the need to implement measures that increment the value of BIM adoption for final client; also the need to include BIM into curricula in the AEC schools; reduction of cost implementation and regulation of normative and laws from the government. Turk (2016) suggests that the lack of tools and knowledge and culture reasons should be studied from the perspective of economics and organizational science.

Concerning BIM adoption among professionals, we observed that BIM has been more used by architects than engineers among those that answered the survey. Which may be a consequence of the adoption of BIM as a modeling tool among architects. Also, there was no evidence that firms with more experience were prone to the implementation of BIM. Moreover, BIM has been adopted by firms related to the design's development and management. However, we noticed that three-dimensional (3D) modeling has been the main implementation of BIM (approximately 90%) when compared to other types of modelling such as 4D (cost), 5D (time), 6D (facility management and 7D (sustainability).

CONCLUSIONS

This research has achieved the purpose of creating an overview of the level of BIM knowledge among professionals in the AEC industry in Sao Paulo, Brazil. Based on the survey's results, we conclude that there is a need for strong collaborative practices, as required by the increased level of design complexity, integrated delivery methods, and BIM adoption in the AEC industry. Due to the increase of design complexity, professionals must be able to deal with more collaborative and multidisciplinary solutions. BIM adoption requires a significant change by the AEC firms such as software, hardware, training, process, and business investments for developing future BIM capabilities.

The demand for BIM education is high (Ahn and Kim, 2016). In the Brazilian context this reality is not different. However, besides the implementation of BIM disciplines in undergraduate and graduate programs, education institutions must have a closer relation with the AEC industry to understand the demands of design and construction firms. This way, education institutions can propose new learning and research opportunities to the AEC community, incrementally introducing as a fundamental concept during the design, construction and management phases.

The adoption of BIM by the AEC industry requires a broader framework of laws and regulations to structure the use of the technology throughout the chain of services and professionals involved in the building process. The participation of academic institutions is a fundamental phase not only offering the necessary knowledge during professional education but also as a research hub, functioning as a resource to AEC industry in general. On the other end of this spectrum, laws and regulations are important mechanisms that need to be implemented fostering a business environment in which the incremental management of building data becomes a valuable condition throughout the construction industry.

Another important aspect to be observed is how BIM is seen by the survey respondents when it compared to the way BIM has been used as a technology in the industry. As discussed earlier, most of the respondents understand that the biggest improvement brought to the industry by BIM as a data management technology. However, to a larger group of respondents, BIM tools are used as 3D modeling tool which is a limited interpretation of this technology not contributing for the structuring of the industry. Also, the interpretation of BIM as a 3D Modeling tool do not bring any advancement for AEC industry, keeping the technology isolated as a design tool and far away from the notion of building data management.

Finally, it is also important to mention that this study has some limitations. First, data analysis was based on respondents' perceptions which can be impacted by some bias. Second, we apply non-probabilistic sample, and hence, the results are not generalizable. Third, the sample was not stratified by different profession, sector, firm size and country; thus, these variables could not be investigated. These limitations can lead to future works that includes the understanding of BIM knowledge among different professionals, sector, country and firm size. At last we end this paper addressing the research question which has driven of this study. Based on the notion of BIM maturity level proposed by Succar (2009), we suggest from our findings that the BIM level of maturity is between Pre BIM and BIM stage 1 (object-based modeling) in the AEC industry in Sao Paulo, Brazil.

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