Overview of the State-of-Practice of BIM in the AEC Industry in the United States

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Abstract –

The Architecture, Engineering, and Construction (AEC) industry has undergone a significant and radical transformation in its design and documentation process as it evolved from the days of the drafting board to today's Building Information Modeling (BIM) process. As BIM remains the center of this transformation, it is important to keep both practitioners and academicians updated on the current state-of-adoption of BIM in construction projects. Thus, this paper presents the results of a BIM survey conducted on 125 respondents representing 83 companies located in the United States of America, United Kingdom, Netherlands, and Canada. The types of the targeted companies varied between Owner, Owner's Representative (OR), Architect/Engineer (A/E), General Contractor/Construction Management (GC/CM), Mechanical Contractor, Electrical Contractor, Sheet Metal Contractor, Plumbing Contractor, Fire Protection Contractor, Structural Steel Contractor, and Facility Manager. Findings of the paper elaborate on why companies are using and requiring BIM, why companies are not using and requiring BIM, and how BIM is being used by the different company types across the project lifecycle.

Keywords –

Building Information Modeling; BIM; AEC Industry; Construction Projects; Usage; Practices; Users; Construction 4.0; Construction Project Lifecyle

1 Introduction

The fourth industrial revolution, coined as Industry 4.0, has been reshaping the way work is done in the twenty first century, and the construction industry is no exception to this transformation [1][2]. The mapping of Industry 4.0 onto the Architecture, Engineering, and Construction (AEC) industry has been coined as Construction 4.0 – a radical transformation that is digitizing and industrializing the AEC industry using technology [3][4]. Major technologies such as augmented reality, robotics, big data, drones, and digital twins are being heavily investigated to increase their use across the construction project lifecycle [5][6][7][8][9].

One major component at the center of Construction 4.0 is Building Information Modeling (BIM). Studies that investigated Construction 4.0 have identified BIM as a major enabler for the construction transformation [10][11]. [4] noted that BIM is at the center of the construction industry transformation since it is the technology that interacts with every other Construction 4.0 technology. BIM has also laid down the foundation for construction firms to adopt a wide variety of technology because it incorporates people, processes, and technology [12].

Given its essential role in advancing the industry, the continuous investigation of BIM in the AEC industry is critical to keep both academicians and practitioners updated on the latest state-of-adoption of BIM in the industry [13]. This paper provides an overview of the state-of-practice of BIM surveying 128 construction practitioners on their rationale for using BIM and their perceptions on the usage and users of BIM across the construction project lifecycle.

2 Background

2.1 The Evolution of Construction Information Technology

Ever since humanity started building structures, there have been accompanying methods of drawing, sketching, and planning of these structures. The two-dimensional (2D) drawings for architectural purposes have been traced back to Ancient Egypt [14] and have evolved over the course of history to keep pace with the advancing complexity and ambition of the built environment.

The most common purpose of 2D construction and architecture drawings is the presentation and visualization of an as-yet unbuilt structure, communication of the designer(s) intentions, and instructions for later on-site work. The earliest known drawings of this type are Egyptian, as previously stated. The next evolution of construction documentation occurred in middle-ages Europe. During that time, construction was overseen in all aspects by a 'Master Builder' who would plan, manage, and execute a project for an owner or patron. To communicate the particulars of the design to that patron, the master builder would employ scale models [15]. The patrons, usually landed nobility, provided the funding for many of the most iconic structures we know today – the castles and fortresses of feudal Europe. However, the term 'construction documents' as currently used still did not yet exist. The master builder relayed instructions to the workers verbally or through demonstration, rather than disseminating plans and drawings. Many particularly complex aspects of the project were developed as full-scale mockups on site, using real materials.

In the Renaissance, projects grew larger and more complex, and the master builder spent more time off-site working through engineering problems in the 'office'. Eventually, early engineering drawings emerged. They served a twofold purpose – to communicate to experienced craftsmen what should be built, and to show a particular detail or section to the patron(s) for their approval [16]. The consequence of the master builder spending more time off-site was the creation of the superintendent position, as the project still required supervision on-site. Thus, the master builder assumed the new responsibility of coordinating communications between the patron (owner) and the superintendent, while making design changes. As construction continued to grow more complex, the various trades began to specialize – masons, carpenters, joiners, etc.

The Pharaohs of Egypt, the master builders of the middle-ages, the architects of the renaissance, and even constructors today all face a common problem: buildings are three dimensional, but documents are not. Thus, the use of 2D drawings and instructions in a 3D world requires multiple translations – from the initial concept in the designer's head, onto paper, and then into reality. As such, numerous efforts have been made to improve the quality of design drawings. These efforts are motivated by the need to reconcile planned solutions with practical implementations, poor communication between project parties, and inefficient scheduling of construction activities [17]. [18] postulated that the need for teamwork, flexibility, coordination, and communication in construction gave the industry a great potential to integrate Information Technology (IT). Froese has divided the innovations in IT into three eras [19][20]. The first era is comprised of "stand-alone tools that improve specific work tasks – Computer Aided Design (CAD), Structural Analysis, Estimating, Scheduling – which are all individual programs that each works on a single facet of the construction process". During the early 1980s, CAD became commonplace in architectural work and soon supplanted the drafting board as the most common method of producing drawings. This is because CAD allows for quick replication with a high degree of accuracy. Eventually CAD also supported 3D design, making it a more attractive and efficient option than hand-drafting [21][22]. The second era includes computer-supported communications (i.e. email, web-based messaging), and document management systems. The third era is where construction currently sits – "reconciling the first two eras into a unified platform wherein project teams can collaborate to produce a virtual model of all aspects of the construction project". A major problem faced during the early iterations of CAD was the lack of understanding of relationships between the spatial geometric objects and how these relationships functioned. For example, while drawings communicated that a beam is connected to a column, the number, size and placement of the bolts to connect it would not be communicated [23]. This problem was addressed in more modern iterations of CAD, and the inclusion of this process is commonly known as Building Information Modeling (BIM).

2.2 The Evolution of BIM

The concept of BIM can be traced back to 1962 when Engelbart presented a hypothetical description of computer-based augmentation system [24]. Later, [25] recognized the shortcomings of 2D drawings and developed a computer-based Building Description System (BDS) that arranges and connects the geometric, spatial, and property description of the various elements of a building into an actual 3D building. This system serves as a database that provides a single description of each building element and of its relation to other components in the building and can be used during design, construction, and operation. In addition, if change is needed, designers need to make the change to the element once and the drawings will be automatically updated. This system designed by [25] paved the way for the concept of Building Information Models, a term that was first introduced by [26].

BIM has transformed the traditional paradigm of construction industry from 2D-based drawing information systems to 3D-object based information systems [27][28]. For more than a decade, BIM has been one of the most important innovation means to approach building design holistically, enhance communication and collaboration among key stakeholders, increase productivity, improve the overall quality of the final product, reduce the fragmentation of the construction industry, and improve its efficiency [29][30]. One of the greatest benefits of BIM is its ability to represent in an accessible way the information needed throughout a project lifecycle, rather than being fragmented [31]. Being a shared knowledge resources through the project lifecycle, BIM centralizes information on a facility and acts as a “reliable basis for decisions” during the facilities’ lifecycle [32]. [33] defined BIM as “a technology that describes an engineering project consisting of intelligent facilities with their own data properties and parameter rules, in which each object’s appearance and its internal components and features can be displayed in the form of three-dimensional figures”.

BIM has been widely hailed as a successful innovation in the construction industry [34], with numerous competing products available on the market today: AutoCAD MEP, Revit® (Autodesk®), BIM 360™ Glue®, Navisworks® (Autodesk®), Sketchup (Trimble®), Synchro Bentley Systems, Graphisoft, and Nemeschek [23][35].

BIM has also evolved from the 3D modelling (object model) to further dimensions such as 4D (time), 5D (cost), and 6D (as-built operations) [36]. This evolution represents added information that is placed in the model and attached to intelligent objects [37].

3 Methodology and Research Questions

To provide an update on the perception of the AEC industry on the use of BIM, a survey was developed and distributed to the industry. Five stakeholders were targeted: Owner, Owner’s Representative (OR), Architect/Engineer (A/E), General Contractor/Construction Management (GC/CM), and specialty contractors (Mechanical Contractor, Electrical Contractor, Plumbing Contractor, i.e., MEP Trades). As a result, 128 responses were captured from all five stakeholders. Descriptive and statistical analyses were then employed to describe, summarize, and analyse the collected data to answer the following research questions:

1. Why are companies not using/requiring BIM?
2. Why are the companies using/requiring BIM?
3. What are the most common BIM practices and how do they vary between company types?
4. What is the usage of BIM for different construction stakeholders and how is this usage perceived by different company types?
5. Where is BIM used across the project lifecycle and how does this usage vary between company types?

4 Analysis

A total of 128 responses were collected from 83 different companies in the AEC industry.

4.1 Data Characteristics

4.1.1 Geographic Distribution

The bulk of the respondents (around 96%) were located in the United States of America (USA). Other respondents were located in Canada, United Kingdom, and Netherlands. Within the USA, most responses were collected from Wisconsin, California, Illinois, and Minnesota. Given that the bulk of the data was from USA, the remaining sections of the paper will encompass the analysis of the 125 USA data points.

4.1.2 Types of Companies

Respondents were asked to identify the type of their company among the following options: Owner, OR, A/E, GC/CM, and MEP Trades. The data was recategorized into the five types as shown in Figure 1.

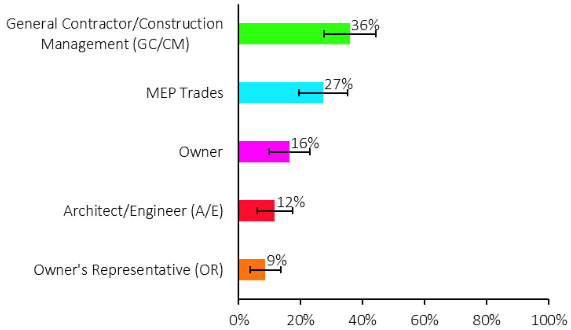

Figure 1. Breakdown of respondents by company type

4.1.3 Respondent Occupation

Respondents were asked to provide their job titles. Their responses were then categorized into one of the following occupations: Technologist, Field, and Top Management. Figure 2 shows the distribution of the respondents based on their occupation.

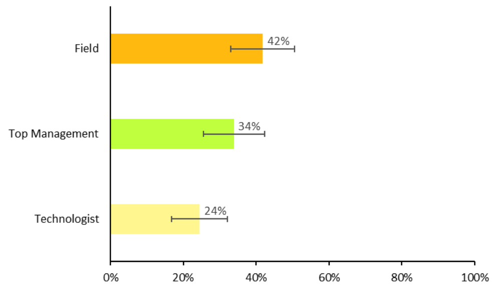

Figure 2. Breakdown of respondents by occupation

4.2 BIM Usage

4.2.1 Companies Distribution

The 125 responses were collected from the employees of 80 companies: 59 companies represent A/E, GC/CM, MEP Trades, or OR (Group 1), and 21 companies represent owners (Group 2). Out of the companies that belong to Group 1, 79% use BIM and the rest (21%) do not use BIM. Among the companies that belong to Group 2, 43% indicated that they require the use of BIM and 57% indicated that they do not. These numbers show that the dominant majority of companies use BIM despite it being only required by a slight majority of Owners.

4.2.2 Respondents Distribution

Out of the 104 respondents who work for companies in Group 1, 87% indicated that their company uses BIM and 13% reported that their company does not. Among the 21 respondents who belong to companies of Group 2, 43% indicated that their organization requires the use of BIM and 57% indicated that they do not.

4.2.3 Reasons for Not Using and Requiring BIM

Respondents were provided with 6 frequently reported reasons for not using BIM, as shown in Figure 3. Out of the 14 respondents of Group 1 who reported that their companies do not use BIM, 64% reported that the high cost of implementation and the fact that BIM is not requested/required by owners are the main reasons for not using BIM. Only 7% of the respondents indicated that social and habitual resistance to changes is a driver for not using BIM. Respondents also had the option to provide other reasons for not using BIM. One respondent indicated that they still use CAD and another reported that their company manages designers who use BIM.

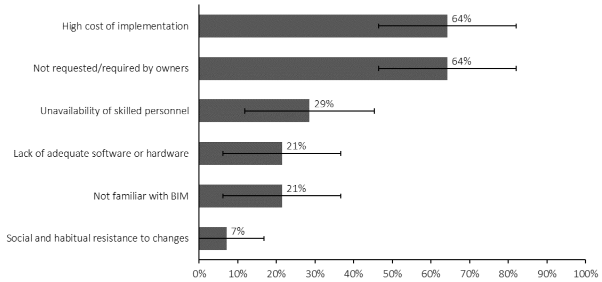

Figure 3. Reasons for not using BIM

Similar to the companies that do not use BIM, owners were given 5 reasons for not using BIM and were asked to select those they relate to them, as shown in Figure 4. Out of the 12 owners who reported that their company does not require the use of BIM, 33% reported that high cost of implementation is the main reason for not requiring BIM.

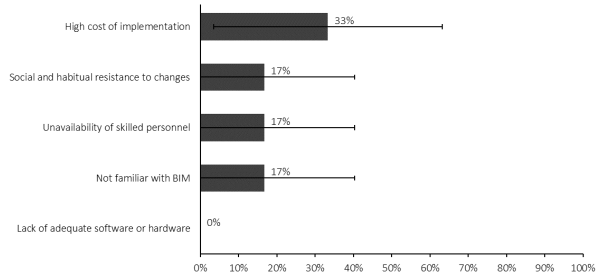

Figure 4. Reasons for not requiring/requesting BIM

Overall, it shows from Figures 3 and 4 that "High Cost of Implementation" is the biggest barrier for the implementation of BIM.

4.2.4 Initial/Ongoing Reasons for Using and Requiring BIM

Respondents who indicated that their companies use BIM were asked to the select the factors that impacted their initial decision to use BIM and the factors that impacted their company's ongoing use of BIM (shown in Figure 5).

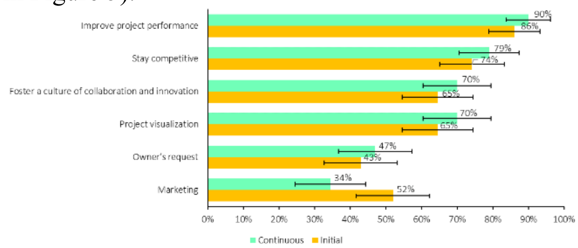

Figure 5. Reasons impacting company's initial and continuous decision to use BIM

Similarly, respondents who work for Owners were asked to identify the factors that impacted their initial and ongoing decision to require the use of BIM on their projects (shown in Figure 6).

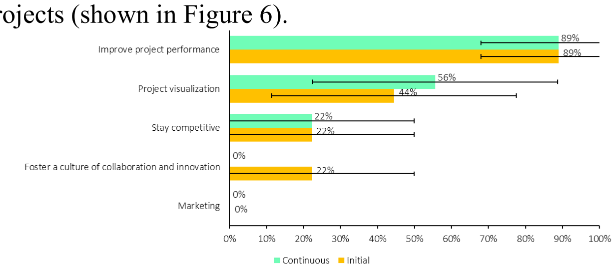

Figure 6. Reasons impacting company's initial and continuous decision to require/request the use of BIM

It can be noticed from Figure 5 and Figure 6 that most respondents, whether their company uses or requires BIM, indicated that BIM is vital for improving the project performance.

4.2.5 BIM Practices: Overall Industry Usage

Thirteen BIM practices (shown in Figure 7) were identified, and respondents were asked to identify their company's level of use of each practice. As seen in Figure 7, between 20% and 55% of respondents indicated that these practices are not used within their organization, while the rest reported their organization uses these practices. Notably, Clash Detection was reported to be the most used BIM practice with 80% of respondent using it. It was followed by Visualization (79% use it and 21% do not), design collaboration (77% use it and 23% do not) and understanding constructability (77% use it and 23% do not). Environmental Analysis was the least BIM practice used, with only 45% of the respondents using it.

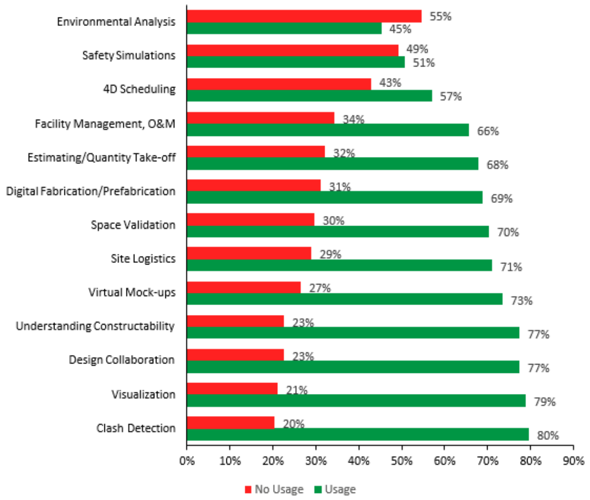

Figure 7. Usage/No Usage distribution of BIM Practices

Respondents who have indicated that their company uses a given BIM practice were subsequently asked to rate their level of usage on a scale from 1 (very low) to 5 (very high). The respondents' overall average level of usage of each BIM practice is displayed in Table 1 indicating that, on average, Clash Detection has the highest level of usage in the industry (4.20) and Safety Simulation has the lowest (2.09). The cluster analysis performed on the 13 BIM practices, showed that Clash Detection, Design Collaboration, Visualization, and Understanding Constructability have, on average, the highest level of usage in the AEC industry.

Table 1 Clustered table of the ranked BIM practices based on their average level of usage

BIM Practices	Overall Average	Clusters
Clash Detection	4.20	Cluster 1
Design Collaboration	4.09	
Visualization	3.78	
Understanding Constructability	3.70	
Space Validation	3.42	Cluster 2
Virtual Mock-ups	3.20	
Digital Fabrication/Prefabrication	3.06	
Site Logistics	2.87	
Estimating/Quantity Take-off	2.84	
4D Scheduling	2.41	Cluster 3
Facility Management, Operation & Maintenance	2.26	
Environmental Analysis	2.17	
Safety Simulations	2.09	

4.2.6 BIM Practices: Usage Per Company Type

The average level of usage of the BIM practice was then broken down by company type and shown as a heatmap in Figure 8. The darker the color the higher the average level of usage of BIM.

BIM Practice	Average Level of Usage				
	A/E	GC/CM	MEP Trades	OR	Owner
Clash Detection	3.64	4.56	4.38	3.14	3.33
Design Collaboration	4.55	4.09	4.13	3.33	3.88
Visualization	4.18	4.05	3.41	3.83	3.33
Understanding Constructability	3.90	3.74	3.77	3.57	3.11
Space Validation	3.78	3.13	3.68	3.67	3.38
Virtual Mock-ups	3.90	3.31	2.70	3.43	3.25
Digital Fabrication/Prefabrication	2.50	3.00	3.45	2.50	2.25
Site Logistics	2.50	3.58	2.04	2.14	2.71
Estimating/Quantity Take-off	2.70	3.18	2.54	2.33	2.57
4D Scheduling	2.25	2.92	1.84	1.50	1.50
Facility Management, O&M	1.80	2.36	2.15	2.17	3.00
Environmental Analysis	2.56	2.03	2.50	2.25	1.67
Safety Simulations	2.33	2.14	2.33	1.80	1.20

Figure 8. Heatmap of the average level of usage of BIM practices by company type

The analysis showed that the average level of usage of the different construction companies is similar for the following BIM practices: Design Collaboration, Visualization, Understanding Constructability, Space Validation, Virtual Mock-ups, Digital Fabrication/Prefabrication, Estimating/Quantity Take-off, Facility Management, O&M, Environmental Analysis, and Safety Simulations.

While for the three remaining BIM Practices, it was shown using the Kruskal-Wallis test and its post-hoc Conover-Iman non-parametric test that for:

- Clash Detection: GC/CM have a significantly higher average level of usage than MEP Trades.
- Site Logistics: GC/CM have a significantly higher average level of usage than OR and Owners, and MEP Trades have a significantly higher average level of usage than OR.
- 4D Scheduling: GC/CM have a significantly higher average level of usage than MEP Trades.

4.2.7 BIM Stakeholders: Overall Industry Perceived Usage

The use of BIM by 10 stakeholders (listed in Table 2) was investigated. More than 50% of respondents reported that, in their opinions, inspectors do not use BIM and 63% indicated that workers also do not use BIM. Conversely, the usage of BIM is reported to be mostly uniform between 70-78% for other stakeholders with project managers reported to be most users of BIM.

Respondents who have indicated that a particular stakeholder uses BIM were asked to rate this stakeholder's perceived level of usage of BIM on a scale from 1 (very low) to 5 (very high). The respondents' overall perceived average level of usage of BIM of each stakeholder is illustrated in Table 2 indicating that, on average, "Architects/Engineers" have the highest perceived level of usage (3.91), followed by "Project Managers" (3.51). "Project Executives" (2.08) and "Inspectors" (1.90) have the lowest perceived level.

Table 2 Clustered table of the ranked stakeholders based on their average perceived level of usage of BIM

Stakeholders	Overall Average	Clusters
Architects/Engineers	3.91	Cluster 1
Project Engineers	3.51	
Project Managers	3.00	Cluster 2
Superintendents	2.75	
Foremen	2.71	
Owners/Owner's Representatives	2.42	Cluster 3
Workers	2.35	
Facility Managers	2.24	
Project Executives	2.08	
Inspectors	1.90	

4.2.8 BIM Stakeholders: Perceived Usage Per Company Type

Each stakeholder's level of usage was then broken down by company type and is illustrated as a heatmap in Figure 9. The darker the color the higher the average level of usage of BIM.

	Average Perceived Level of Usage					
BIM Users	Average	A/E	GC/CM	MEP Trades	OR	Owner
Architects/Engineers	3.91	4.36	4.17	3.52	3.71	3.63
Project Engineers	3.51	3.73	3.57	3.26	3.43	3.88
Project Managers	3.00	2.73	2.98	2.94	3.29	3.50
Superintendents	2.75	1.67	2.76	3.10	2.29	3.00
Foremen	2.71	2.17	2.49	3.19	1.80	3.00
Owners/Owner's representatives	2.42	2.11	2.41	2.17	3.00	3.29
Workers	2.35	2.33	2.13	2.81	1.50	2.40
Facility Managers	2.24	1.89	2.21	2.07	2.43	3.29
Project Executives	2.08	1.89	1.92	2.10	2.60	2.71
Inspectors	1.90	1.75	1.89	1.69	2.20	2.40

Figure 9. Heatmap of stakeholders' reported level of use of BIM by company type

The analysis of this heatmap using the Kruskal-Wallis non-parametric test showed that respondents working for different types of companies have, on average, similar perception of the level of usage of BIM of stakeholders except for the following:

- Architects/Engineers: GC/CM reported a higher level of usage of BIM by Architects/Engineers that what was reported by MEP Trades.
- Superintendents: GC/CM and MEP Trades reported a higher level of usage of BIM by Superintends than what A/E reported.
- Foremen: MEP Trades reported a higher level of usage of BIM by Foremen that what was reported by GC/CM.

4.2.9 BIM Phases: Overall Industry Perceived Usage

The use of BIM was investigated throughout the seven construction project lifecycle phases: Planning, Design, Pre-Construction Planning, Construction, Commissioning, Operation and Maintenance, and Decommissioning. The perceived usage of BIM throughout these phases varied among respondents. Between 20% and 48% indicated that BIM is not used in a particular phase, while the rest reported the use of BIM in a certain phase. Notably, 80% of the respondents believe that BIM is used in the design phase and 48% of the respondents reported that BIM in not used in the Decommissioning.

Respondents who have indicated that BIM is used in a phase were asked to rate the perceived level of usage of BIM on a scale from 1 (very low) to 5 (very high). On average, respondents reported that BIM has a high level of usage in the Design, Pre-Construction Planning, Construction, and Planning phases and a low level of usage in Commissioning, Operation and Maintenance and Decommissioning (Table 3).

Table 3 Clustered table of the ranked project phases based on the average perceived level of usage of BIM in each phase

Phases	Overall Average	Clusters
Design	3.97	Cluster 1
Pre-Construction Planning	3.83	
Construction	3.77	
Planning	3.36	
Commissioning	2.29	Cluster 2
Operation and Maintenance	2.04	
Decommissioning	1.78	

4.2.10 BIM Phases: Average Perceived Usage per Company Type

The perceived level of usage of BIM throughout the lifecycle of a construction project was then broken down by company type as shown in Figure 10. The analysis of this heatmap using Kruskal-Wallis showed that all company types have a similar perception of the level of usage of BIM in each of the seven phases of the lifecycle of a construction project.

	Average Perceived Level of Usage				
Phases	A/E	GC/CM	MEP Trades	OR	Owner
Design	4.55	4.07	3.63	4.00	4.00
Pre-Construction Planning	3.64	3.91	3.91	3.14	4.00
Construction	3.36	3.88	3.94	3.14	3.63
Planning	3.36	3.54	3.13	3.67	3.22
Commissioning	2.55	2.39	2.21	2.00	1.88
Operation and Maintenance	2.10	2.10	1.89	2.14	2.13
Decommissioning	2.00	1.77	1.76	1.83	1.50

Figure 10. Heatmap of the average level of usage of BIM throughout the lifecycle of a construction project by company type

5 Conclusions and Future Works

The results of the questionnaire showed that while 72% of A/E, GC/CM, MEP Trades, and OR use BIM, only 43% of Owners require the use of BIM on their project. Respondents whose companies don't use or require BIM reported that high cost of implementation is the biggest barrier for implementing BIM. On the other hand, respondents whose companies use or require the use of BIM indicated that BIM is vital for improving project performance. Out of 13 identified BIM practices, Clash Detection, Design Collaboration, Visualization, and Understanding Constructability were reported to have, on average, the highest level of usage. Architects/Engineers and Project Managers were reported to be the stakeholders with the highest level of usage of BIM and Owners/Owner's Representatives, Workers, Facility Managers, Project Engineers, and Inspectors to be the stakeholders with the lowest level of usage of BIM, on average. In addition, it was shown that BIM has, on average, a high level of usage in each of the Design, Pre-Construction Planning, Construction, and Planning phases and a lower level of usage in Commissioning, Operation and Maintenance, and Decommissioning phases.

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