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An Assessment of the use of BIM to Enhance the Building Commissioning Process

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Building owners are aware of the benefits to be recognized by operating an efficient building. For project teams the process of verifying a building's performance based on the owner's requirement is one of the most difficult tasks they are faced with. As a result, many companies within the Architecture, Engineering, and Construction (AEC) industry are searching for new ways to improve the commissioning process (Cx). Building Information Modeling (BIM) as one tool to can make the process more collaborative is becoming an effective tool to ease the implementation of the commissioning process. In this paper, construction experts were surveyed regarding BIM and its application in the commissioning process. The 16-question survey showed that 74.0% of respondents had been involved with BIM on their past projects, and that 29.6% of respondents had utilized BIM during the commissioning phase. BIM and commissioning training was offered to 48.0% and 40.7% of respondents, respectively. The biggest challenges identified were a lack of collaboration when utilizing a new technology or software package (27.1%) and the respondent's perception of needing more training (22.9%). Respondents identified issues in "staffing and training" (40.7%) and "quality and management principles" (40.7%) as the most prevalent during the project implementation stage.

Key Words: Commissioning, BIM, Training, Sustainability, Construction.

Introduction

In recent years owners have begun to recognize the impact that their buildings and organizations can have amongst the built environment. One of the leading indicators of this is in relation to energy consumption. It has been found that commercial buildings can contribute up to 40% of the global energy consumed (Xiao & Wang, 2008). This statistic shows how great of an impact the architecture, engineering, and construction (AEC) industry can have on the global economy. A buildings mechanical, electrical, and plumbing (MEP) system are typically the highest energy consuming systems within a structure. When these systems work inefficiently major cost overages are likely to be realized. These cost impacts can come to fruition both during the construction process as well as when the building is operational. The Heating, Ventilating, and Air Conditioning (HVAC) system alone can account for 50% of a building's energy consumed (Xiao & Wang, 2008). HVAC issues tend to show up in the form of operational faults, poor equipment maintenance, improper installation during construction, and building management system (BMS) failures. When HVAC systems are not properly controlled or maintained they can account for as much as 30% of a buildings energy consumed overall due to the errors previously described (Zhang, 2017). While owners have recognized several of these potential pitfalls, many within the AEC industry are in search of ways to ensure that buildings perform as desired and are able to maintain efficient performance throughout the buildings lifespan.

While the AEC industry continues to strive towards a sustainable future there are many contributing factors affecting the performance of a building right now. One area of such concern is in relation to commissioning. It has been reported that nearly 6% of the net production value applied by project teams is used correcting process related damages discovered after the commissioning phase has been completed. However, this value can inflate to nearly 10% when the commissioning phase into this taken into consideration (Lohne, 2015). As buildings become increasingly complex it is critical that the project teams ensure that part of their goal is to reduce project waste in the form of redesign and coordination efforts which are typically not realized until a building is constructed or being tested for functionality. Building commissioning is an effective method to help ensure that a buildings equipment

and internal systems operate and perform as designed (Wu, 2017). The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) defines the commissioning process as a quality-based method which allows for owners to achieve a successful construction project (ASHRAE, 2005). However, it can be rather complicated to realize and understand how this can be achieved. Ultimately great team leadership and communication is key to a project's overall success.

There are many requirements and guidelines that ASHRAE recommends during a project's lifespan. Although, upfront planning during the design and construction phases serve as key drivers towards success. There is great emphasis placed on the execution of the construction buildout. During this phase it is suggested that the following team members be responsible for the project delivery: Owner's representative, the Commissioning Agent, design professionals, contractors, vendors, construction managers, and project managers (ASHRAE, 2005). Ensuring that a project has inclusion from these key members is paramount. Some of the recommended responsibilities of these team members include: review of submittals and shop drawings for compliance, ensuring the delivery schedule has room for functional performance testing, conformance with the basis of design and system manual, and development of a commissioning plan. The commissioning plan itself should clearly state how information will flow across all phases of the job, how information is documented, and how it will be distributed amongst all team members (ASHRAE, 2005).

Commissioning is typically viewed as a single task performed at the end of the job, but as mentioned above, it needs to be developed and implemented throughout all phases to ensure a proper product is delivered. This is a common misconception of commissioning as it is not merely a matter of handing over documents to the owner (Xiao & Wang, 2008). As stated, many think of the turnover process as being the main driver of the commissioning process: where teams compile maintenance manuals, drawings, and contract closures, and many other building system documentation related tasks (Schneider, 2016). The process is very labor intensive and can be very documentation oriented. Often the information in not effective and does not aid towards the operation and maintenance of the building (Wu, 2017). The increased complexity of buildings has led to the need for improved quality assurance measures to ensure value is delivered to the owner (Coyner & Kramer, 2017). Therefore, the AEC industry has placed great emphasis on the research and development aimed at improving the commissioning process (Wu, 2017). By ensuring that project teams have inclusion and are communicating properly an owner can become increasingly confident in the delivery process. Many different software applications and consulting firms are aiming their resources at tackling this problem and it can be seen in many different forms.

One of the most popular and up and coming methods helping to improve commissioning is Building information modeling (BIM). While a three-dimensional has been common for many years, today's BIM software can also help communicate pertinent information. By utilizing the model and the information within it, the BIM platforms can be leveraged to help close the gap between design and building performance. Although BIM programs typically focus on increasing a team's visual understanding of a building using a three-dimensional model, more emphasis needs to be placed on improving the project delivery process. Typical modeling software focuses on design only features, such as drawing creation (Aziz, 2016). For example, the incorporation of facilities management (FM) groups into the BIM process is currently not a primary focus of the industry since it does not guarantee the effective management of a buildings performance (Gerrish, 2017). However, this thinking is beginning to be a thing of the past as most modern-day BIM software is slowly adding features focused on taking a holistic approach towards building delivery and operations. One such item is the spatial coordination capabilities currently available to project teams. By simply incorporating information such as equipment access into the coordination phase architects can ensure that rooms have been properly programmed and ensure they encompass the required space for maintenance clearances or access routes.

Literature Review

Current State of Commissioning

According to Tseng (2005) one of the main concerns of the commissioning industry is that the quality of commissioning is beginning to fade. Recently a shortage of experienced commissioning experts within the industry has been recognized. As a result, many companies have been forced to utilize underqualified workers. For this reason, training should be of the upmost importance in order to make a long-term commitment to the commissioning

process. Tseng stresses that proper training cannot be achieved by continuing to only focus on short-term training sessions. He later goes on the state that the attendance of professional training seminars sponsored by associations such as ASHRAE are a way for industry leaders to improve commissioning (Tseng, 2005).

There is a major need for qualified workers who have a high level of experience from their time spent in the trade. However, the pool of an experienced labor force has not kept up with the pace of the market. This has thus created an industry wide need for a high trained and skilled workforce. In response over time is has become the norm to hire a third-party commissioning agent on most projects (Schneider, 2016). This person ensures that the owner and project team are getting someone who is properly trained and has experience leading the commissioning process. It is up to the construction trades to educate their owners and to collectively determine what the best approach is for each project.

Current BIM Software Applications

Recently there have been many government agencies that have promoted the use of BIM technologies as a way of improving the quality of construction project delivery (Abanda, 2015). For example, the United Kingdom has mandated that on publicly funded projects the use of BIM is implemented for design and operation management. The goal is that through these improved processes buildings will become more efficient as a result (Gerrish, 2017). For reason such as these many agencies are striving to utilize the latest software in order to improve their building's efficiency through improved collaboration. This is one of the main reasons that many different software groups have reacted and are now racing to become involved in this market sector. This has posed a series of crucial decisions that companies have had to make regarding software manufacturers in recent years. For instance, the US Department of Energy has published a comprehensive list of 417 energy software applications. It is also estimated that there are at least 150 BIM software programs available to the AEC industry (Abanda, 2015). Although there are many programs to choose from there are great advantages for project teams when incorporating different phases of the job simultaneously through one comprehensive model (Vysotskiy, 2015). BIM 360 Field is one program with this capability. The program has become a major player within the commissioning process and is widely used. The program provides project teams with the capability to "digitally collaborate on a building's physical and functional characteristics" and "deepens partnerships between architects, engineers, and the client" (Sattineni & Schmidt, 2015). Although new software like BIM 360 are transcending the industry through the ability to tie all phases of the project together it is mainly the programs ability to process information and properly distribute such knowledge through the cloud that has sparked its rise in popularity. By allowing team members to access information through a handheld device in the field teams can now recover hours previously lost from a lack of productivity.

Recent studies have shown that there are many advantages BIM technologies offer to companies but often there is little to no recommendation on how to implement them at many different project levels (Vysotskiy, 2015). Understanding the pitfalls of these technologies can allow for improvements of the industry's future (Sattineni & Schmidt, 2015).

Implementation and Training Challenges

Construction is a unique industry in the sense that each project team is faced with building a truly custom-built facility each time they begin a new project. Often there is a tendency to not properly capture lessons learned on past projects and mistakes are often carried over and repeated. Specifically, within construction organizations there is currently not a culture of learning that accounts for technology and people collectively (Ferrada, 2016). Companies are challenged when implementing technology since users often lack the appropriate BIM knowledge required (Lu, 2017). This can make an implementation challenging when working with such complicated software (Vysotskiy, 2015).

Commissioning currently has a shortage of qualified workers. While a new labor force is brought up through the ranks there is an increased focus on the training received by these new recruits. With the pace of today's construction projects, organizations have begun having trouble keeping up with their overall volume of work. Information can be complex, and often flows too fast for an individual to fully comprehend. By keeping different type of training material current organizations can help motivate their employees to learn. It's crucial that employees who are new to the AEC industry work together to collect and analyze information in a collaborative

manner (Reychav & Wu, 2015). Recent technologies such as BIM 360 Field have allowed for companies to utilize cloud data to analyze and process large amounts of data in real time (Zou, 2017). Many organizations are steering their efforts towards new training experiences that immerse employees amongst one another to ensure they are being fully exposed to the subject matter at hand (Reychav & Wu, 2015).

Methodology and Data Analysis

Data Collection Methodology

While the literature review conducted focused on different aspects of the AEC industry as it relates to sustainability, commissioning, BIM, training, and implementation. Most of the material found in review focused primarily on past performance or laws and regulations. Also found were many opinions on specific technology sectors or markets showing a potential to help spark industry change. Many of the authors focused their research toward alternative ways to improve both commissioning and technology in a separate manner. When speaking to commissioning specifically a majority of the literature spoke to the inexperience and a lack of understanding regarding the subject matter. While literature focused on BIM highlighted the broad spectrum of available software.
Taking into consideration the main focal points of the literature review a survey was then developed to help determine the current state of technology and commissioning within the AEC industry. The survey questions were kept simple in nature since some of those surveyed may have not ever had the chance to participate in the commissioning process. This may potentially be due to the fact participants could still very well be new to the industry, or maybe their job does not yield towards continued commissioning participation. Secondly the survey aimed to validate the efforts companies are currently taking to ensure their employees get the proper training to help implement the different software and processes currently available for BIM and Commissioning. The survey conducted was distributed via email and included current members of the AEC community all located within a similar geographical region. The survey also strived to obtain responses from industry members who worked for larger and more experienced firms as there was concern that many of the smaller firms may not have had the chance to gain experience with advanced AEC software packages. The survey was 16-questions and was sent out to 42 individuals that included: architects, owners, construction managers, consultants, general contractors, facilities management, and subcontractors. Of the responses collected 27 were received in the form of email while 3 copies were received via hand delivery. This resulted in a 64.2% response rate overall.

Analysis of Results

The survey began by evaluating the participant's role within the construction industry. The various positions held of the participants are depicted in the table below (see Table 1). The main contributors to the survey were as follows: 29.6% general contractors, 25.9% subcontractors, followed by 14.8% owner's representatives or construction managers, 7.4% architects, 18.5% responded as other, and lastly 0% represented the facilities management sector. The fact that no facilities management members of the industry responded to the survey was given special attention and reinforces the fact that inclusion of this group in the technology section is currently an uphill battle.

Table 1

Job title of respondents

Question 1: What best describes your role?		
Available Responses	**Answers Received**	**Percentages Received**
Architecture	2	7.4%
Owner or CM	4	14.8%
Cx Agent	1	3.7%
Subcontractor	7	25.9%
General Contractor	8	29.6%
Other	5	18.5%
Totals	27	100%

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The second question of the survey polled respondents to assess their work experience. It was found that 14.8% of respondents had a high level of experience. These individuals were those who had more than 30 years of service in the AEC industry. The next group which also had a high level of experience were those with 21 to 30 years of experience. This demographic accounted for 18.5% of the people polled. The majority of the respondents fell within the 3- to 30-year time frame making up 51.8% overall. There were 25.9% who had 11 to 20 years of experience while another 25.9% had 3 to 10 years of experience total. Lastly there were 14.8% participants who had 0 to 3 years in the industry. While the respondents with little to no experience may have acquired knowledge of the latest technology through their education, it was expected that some of them may have limited exposure to commissioning. The table below further illustrates the types of questions asked of survey participants overall (see Table 2).

Table 2

Breakdown of Questions Given to Survey Participants

Phases of Questions	
Question(s)	**Description of Question**
1 – 2	Role & Experience in AEC Industry
3 – 7	Involvement (BIM & Commissioning)
8 – 11	Training & Available Standard Forms (Commissioning & BIM)
12	Rate Level of Agreement (Commissioning)
13 – 16	BIM (Programs, Challenges, Implementation, and Benefits)

The experience factor was addressed through the third question of the survey where participants responded whether they had been involved in the commissioning process or not. It was found that 56% had in fact been involved with the process through their work experience. Finding out the experience level of the participants was an important factor taken into consideration with the other findings of the survey. Next respondents were asked if they had ever been involved with BIM on any of their past projects. The survey found that 74% of respondents had been involved. The participants who answered the previous question affirmatively were then asked if these BIM technologies were ever used during the commissioning process. It was found that 40.0% of those who responded to the previous question had utilized BIM during the commissioning phase. This value was higher than what was expected. This may be since most of the participants emailed worked for larger firms who may generally have more exposure than others who may work for smaller firms. Although technology is not new to the BIM, using the technology for the efforts undertaken during the commissioning process is a fairly new process on construction projects.

For the sixth question of the survey, participants who had previously responded that they had used BIM on past projects were then asked to rank their overall experience. They were asked to use a rating scale ranging from 0 to 10. The average score received from the industry members was a value of 7. This question helped provide insight towards how the industry perceives BIM and its current capabilities. This was a key point that the survey wanted to seek out from industry members. This helped reinforce findings such as those discussed in the literature review section. The survey then asked if respondents had ever used a mobile device to access project documentation. It was found that 88.9% had used a device to access project documentation while onsite regarding question seven.

The next phase of the survey aimed to assess the level of engagement that companies put forth regarding commissioning and BIM. Survey participants were asked whether their employer had provided them with proper training in the past. If so, respondents were then asked to elaborate further to help clarify if readily available training resources or material available to them for daily use. Of those surveyed, 40.7% had commissioning training offered to them, while another 40.7% responded said that they had not, and lastly 18.5% responded that this question was not applicable to them. A total of 44.4% responded that commissioning material and resources are readily available to them, 33.3% stated they are not, and 22.2% responded that the question was not applicable. When asked the same two questions regarding BIM 48.1% responded that their employer had provided training, 33.3% replied that they had not received any proper training, and 18.5% stated that this question was not applicable to them. The final question of this section asked whether the participants companies had made training material available to them as it relates to BIM. In response of those surveyed 40.7% stated that they had BIM material available to them, 33.3% stated that they did not, and 25.9% felt that the question was not applicable to them.

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Next, the survey asked participants to rank their levels of agreement towards a series of statements regarding commissioning. The available statements were to be ranked on a scale of 0 to 10. The available selections came directly from the literature review section and can be seen for reference in Figure 1.

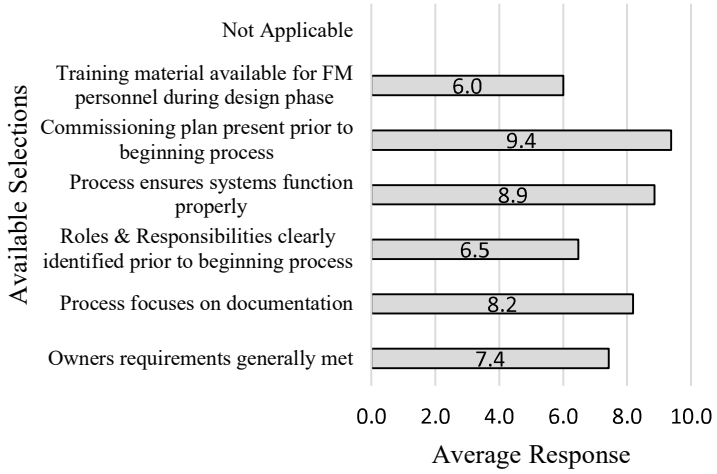

Figure 1: Level of agreement towards commissioning.

The literature review encountered many articles that listed various software available to the construction community. So much so that there were hundreds of programs to ultimately choose from. The programs selected for question 13 were those that had strong talking points within the articles researched. As shown in Figure 2, the programs that the survey respondents were able to choose from included file sharing software, BIM 360, Cx Alloy, Google Docs, Bluebeam, PlanGrid, other, and not applicable. File sharing programs such as Dropbox and Box were the most selected available option with a 96.3% selection rate followed closely by Bluebeam at 74.1%. Bluebeam allows for users to access the Studio function which acts like a FTP or jobsite server but allows for its users to complete detailed markups with ease. The use of some of the less popular programs such as BIM 360 was also assessed, indicating that 59.3% of the respondents had used this software. Google Docs came in at a position very similar to the BIM 360 applications with a 51.9% rate. Both BIM 360 and Google Docs help projects collaborate between team members and looks to be increasingly utilized on among the industry. Rounding out the mid-range responses was the software application PlanGrid at 44.4%. The survey results yielded a 29.6% rate for the choice of "Other". Lastly a program tailored specifically for commissioning called CxAlloy rounded out the list of available programs with a 22.2% response rate.

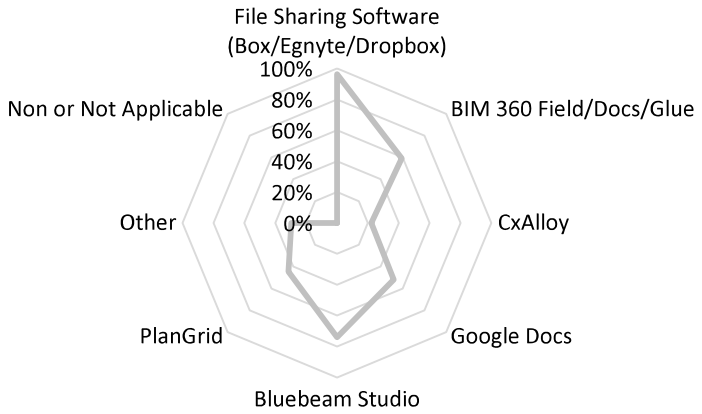

Figure 2: Level of use of different construction software.

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BIM implementation can present many challenges. Many potential issues can arise with respect to training, company business models, project obstacles, and a lack of collaboration to name a few. Of these available choices participants were ask to select all of the challenges they have experienced in the past. If participants had not been a part of a BIM implementation effort they were able to select "none or not applicable" as an option as well. There were 48 selections made overall with the most selected option being a lack of collaboration when utilizing a new technology or software package which came in at 27.1%. The next most selected challenge was that participants felt they did not receive enough training; this item came in at 22.9%. Surprisingly quite a few of those surveyed selected that the question was not applicable to them. This selected resulted in a 16.7% selection rate. Next 14.6% of the participants selected that there can be too many barriers to overcome making the process overwhelming. Lastly the survey found that a poor business model accounted for 10.4% of the selections and implementing too much at one time came in with an 8.3% selection rate.

While the previous question sought to determine the current challenges within the industry as it relates to BIM the next question focused on the implementation process. Participants were asked to check all issues that have applied to them in their past experiences. Leading the charge of the issues encountered during implementation was staffing and training which received a 40.7% response rate. Quality and management principles captured the same response rate of 40.7% (see Figure 3). It should be noted that once again a large majority of those who responded stated that BIM had little to no applicable value to them. Although 33.3% did reply that financial restriction played a role during the BIM implementation process. This can often be a major factor when owners and contractors begin to select available software. The final two factors depicted by the survey were BIM requirements as it relates to laser scanning or clash clearances coming in at 22.2%. Finally, with the lowest selection rate, data security requirements seemed to play the smallest role during BIM implementation while only attributing 11.15 to the responses received.

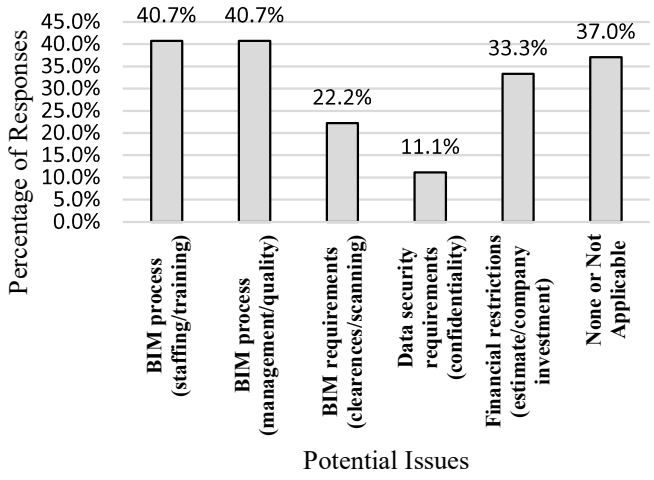

Figure 3: BIM implementation issues.

Lastly the survey asked participants to check all options that applied regarding the benefits encountered when utilizing BIM at their company. There were 61 items selected by the survey participants. Of the responses 36% said BIM helped with the early detection of errors. Next were understanding design and the improvement of construction sequencing with 28% and 21% respectively. 8% felt it helped track progress as it relates to time and cost of the job. Lastly 7% said that question 16 was not applicable to them or that they did not see any benefits.

The survey's main objective was to determine the different levels of engagement participants currently have in relation to newly developed software package, BIM, and commissioning within the AEC industry. By allowing the respondents to provide answers based upon their own individual experiences the literature review process was able to go through a proper validation process. The 16 questions given to the audience echoed the past observations and research made by a wide range of professionals. Within the closing statement a comparison is made between the relationship of the survey participants experiences and the literature reviewed.

SUMMARY AND CONCLUSION

In this paper, a group of industry practitioners were surveyed about the significance of using Building Information Modeling (BIM) and other collaborative technologies in the building commissioning (Cx) process. Special care was taken to ensure that the surveyed group was representative of the industry, that respondents had substantial experience in the industry, and that the survey included a broad spectrum of responses from different sectors of the industry. As a major finding and consistent with the literature, the survey results echoed the necessity of incorporating the commissioning process early in the construction phase. Early incorporation of new technologies such as cloud-based software, BIM, and commissioning will improve efficiency and help drive progress of the AEC industry.

The survey results also indicated that a large proportion of the respondents (74%) had been involved with BIM on their past projects, and that 29.6% of respondents had utilized BIM during the commissioning phase. The survey showed that a significant group of respondents had BIM (48.0%) and commissioning training (40.7%), yet the delivery and reach of the training should be improved. This is reflected on the respondents' perception that the biggest challenges identified were a lack of collaboration when utilizing a new technology or software package (27.1%) and the respondents' perception of needing more training (22.9%). Many BIM users did perceive that the industry does not spend enough time collaborating with these programs, which may be an indicator that participants could still be working in silos separate from one another. The survey showed that a lack of training or depth of training may be one of the leading indicators to why this is happening currently. At the same time participants assessed their use of new software and perceived that new software can help improve their communication and understanding of design and that it can also help industry members detect errors earlier in the construction process. Since BIM is still a relatively new software and may not be practiced heavily amongst all AEC members, specifically in less populated areas, emphasis should be placed on survey outreach moving forward. Additionally, as software helping to aid in the commissioning process is better recognized and understood the level of detail in the survey questions asked should be redefined to be more in depth.

Finally, the main point proven in the research was that both building commissioning and BIM strive to improve collaboration for project teams. The literature review found that in past years these two subjects have taken separate linear paths apart from one another. However, by increasing the speed in which information is shared through platforms such as newly created applications and cloud based software, supplementing BIM technologies with these additional platforms has the potential to help streamline communication and collaboration for an end goal of enhancing the budging commissioning process.

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