DESCRIPTIVE ANALYSIS OF CONSTRUCTION SCHEDULING DATA TOWARDS AUTOMATION OF 4D BUILDING INFORMATION MODELING

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Civil Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2019

Urbana, Illinois

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ABSTRACT

The integration of construction planning and scheduling into Building Information Modeling (BIM) workflows is still evolving. The common workflow to integrate the fourth dimensional (4D) of BIM still relies on the ability of manually linking construction activity tasks with 3D BIM-based objects. This process is arduous and requires high levels of accuracy and strong communication between design and construction trades. Identifying the corresponding objects and its tasks could even be a more complex process in large projects. Although this 4D BIM procedure tends to be troublesome, the benefits of completing it are various: project visualization, project monitoring and controls, construction safety, etc. Different efforts for leveraging its uses and application have been released, nonetheless there are a lack of studies focused on the analysis of the two main variables entailed within 4D BIM towards its automation: construction schedules and 3D BIM-based objects. This study is intended to cover this gap.

Analyzing the relation between construction scheduling data and BIM-based objects provides an opportunity to identify ways to fully-automate 4D BIM under a systematic approach. Therefore, this research includes a comprehensive diagnosis of the current construction planning and scheduling, and 4D BIM practices in the industry. This diagnosis has been elaborated based on a survey of professional testimonies and reflections offered by members of the Architecture, Engineering and Construction (AEC) community. The status quo shows that at least 60% of the participants do not count with standards to create Work Breakdown Structures and majority of them perform their schedules based on in-house conventions. Moreover, the diagnosis indicates that 53% update their construction master schedule on a monthly basis and up to 85% use multiple approaches to track project progress. Similarly, the study reveals that 87% of the recipients are familiar with 4D BIM to some extent and 94% leverage multiple uses from it. Construction visualization and project monitoring account as the main 4D BIM uses within the industry.

Finally, this study includes a descriptive analysis and interpretation of construction scheduling data retrieved from real estate projects. This data has been related to object-driven standards such as Uniformat. The results show that 77% of construction activities are BIM-based and only 19% present a high level of detail regarding the type of object. Categories such as services present the largest amount of BIM-based data, and elements such as HVAC, walls and framing account for the highest level of detail incorporated within construction schedules. Discussion regarding the status quo of construction scheduling data analysis results, professional practices, and methods towards 4D BIM automation has been discussed and suggested.

ACKNOWLEDGEMENTS

Special thanks to my adviser Dr. Mani Golparvar-Fard for inspiring this research journey and guiding me through the steps of completing the master's program at the Civil and Environmental Engineering Department in the University of Illinois at Urbana-Champaign. Working on transforming the construction industry with cutting-edge methods to reinvent traditional workflows in project monitoring and controls account as the most exciting academic work I have done. Thank you for considering me a part of the lead team aimed to achieve such reinvention. In addition, my gratefulness to the RAAMAC team for providing the data to conduct this study.

Similarly, all my gratitude to the CEE-UIUC faculty and staff for this 2-year of outstanding learning experience in Construction Engineering and Management. So grateful to be part of the best Graduate Department in Civil Engineering in the U.S. Distinctive recognition to the CEE Office of Alumni & Corporate Relationships and the UIUC Technology Services for their support with distributing the survey contained in this Thesis, and to all the participants who devoted part of their time to collaborate with this research work. Many thanks to all.

Additionally, remarkable mention to the Fulbright Program Scholarship for facilitating my academic journey. It has been an incomparable life experience. I am truly convinced this contribution will help with shaping the world in a better way, as the Senator J. W. Fulbright envisioned one day.

Finally, all my appreciation to my family, colleagues and friends in Moquegua, Peru. Your motivation and encouragement were fundamental to start and conclude this academic chapter successfully.

DEDICATION

With much Love to

Abelino & Deysi,

my Parents,

and,

Deysi & Joaquin,

my Sister and Brother.

Your example is the best source of Inspiration I have in life. Thanks for showing me that nothing is impossible when you truly want to achieve it.

And Chris,

it would not be possible without your support.

Love you all.

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CHAPTER 1: INTRODUCTION

1.1 State of Practice in Construction Planning and Scheduling & BIM

In the U.S, the total value of productivity in construction has declined half way since 1960 (Sveikauskas L. , Rowe, Mildenberger, Price, & Young, 2016). Indeed, there is an annual $1 trillion shortfall across the world in infrastructure due to the delays and over budgets of current infrastructure projects (The Economist, 2017). Remarkable issues in construction productivity are associated with the complexity of its process in comparison with other sectors like retail and manufacturing. The advance digitalization and automation of these markets have transformed them enormously creating a huge gap in productivity in comparison with construction. This difference is observed by comparing labor-productivity rates over the past two decades. Construction productivity has grown only 1 percent in average, whereas the global economy and manufacturing have reached 2.8 percent and 3.6 percent respectively (McKinsey Global Institute, 2017). Despite the pessimism of this trend towards the future, new studies have demonstrated that at least three industries in the sector show positive and strong productivity rates. These sectors are: single-family residential construction, multifamily residential construction, and industrial construction. (Sveikauskas L. , Rowe, Mildenberger, Price, & Young, 2018). According to experts, higher labor productivity values in construction are associated with less complex and more reliable schedules (McKinsey Global Institute, 2017). Therefore, efforts to enhance schedule quality control workflows during preconstruction and construction monitoring during construction are necessary.

The concept of Building Information Modeling (BIM) was implemented in the Architecture Engineering and Construction (AEC) industry in the early 2000's (Volk, Stengel, & F., 2013). Although initially introduced as an object-oriented product for Computer Aided Design (CAD), BIM has been visualized as a productivity booster, cost reducer and management aid integrated system during all the stages of the construction process (Succar, 2009). In fact, there is a wide range of benefits obtained from the use of BIM such as technical, knowledge management, standardization, diversity management benefits, integration, economics, planning/scheduling, building lifecycle assessment (LCA), and decision support benefits (Ghaffarianhoseini, et al., 2017). Due to these proven benefits, BIM has expanded its functionality and applicability across the world (Enshassi, Abuhamra, & Alkilani, 2018). Although some practitioners still hesitate on the idea of fully adopting BIM, studies show that a surge from 28% in 2007 up to 71% in 2012 indicates that BIM workflows have continuously been incorporated. Additionally, 91% of large companies and 49% of small firms have introduced BIM within their organizations (Bernstein, Jones, & Russo, 2012). Exceptional interest has been focused on the interaction between BIM and construction planning & scheduling within the AEC community in recent years (Hartmann, Gao, & Fischer, 2008). This is due to the increased number of opportunities to provide a comprehensive understanding of the construction phase through visualization and project progress monitoring (Koo & Fischer, 2000). Under the integrated BIM platform, automated models to track project performance can save time and cost invested in collecting data and updating construction schedule. In addition, problems like the lack of frequent communication amongst subcontractors and project management teams can be improved. (Navon & Sacks, 2007). All these benefits can be achievable through construction visualization offered by the fourth dimensional (4D) of BIM

(Ding, Zhou, & Akinci, 2014), where the combination of construction planning and scheduling data and BIM workflows play a fundamental role.

1.2 Role of 4D BIM in Construction

Research to demonstrate the cost and return of implementing BIM have shown promising and encouraging upfront benefits (Giel, Raja, & Issa, 2013). One of the underlying uses of BIM relies on its fourth dimensional (4D), which is gaining remarkable interest of practitioners and users across the world (Gledson & Greennwood, 2017). 4D BIM improves communication, approval and continuous improvement of construction schedules amongst different trades in construction projects such as design, construction management, owner, subcontractors and community members (Issa, Flood, & O'Brien, 2005). Even though the benefits of 4D BIM are clear, still many users consider this workflow time-consuming and impractical due to the required work to update the model, specifically the schedule, to bring the model to its as-built conditions (Lopez, Chong, Wang, & Graham, 2016). Achieving this goal requires the execution of two tasks: capturing reality of as-built conditions and updated construction schedule based on such conditions. Extensive research on this field has demonstrated the impact of reality capture throughout imaging and geospatial technologies to compare as-planned versus as-built conditions by detecting schedule variances, track project progress and visualize it (Golparvar-Fard, Peña-Mora, & Savarese, 2011). Efforts to automate this procedure continuously evolve. Leite et al. (2016) have identified the automation of retrieved captured data into 4D BIM systems as one of the main challenges to overcome. Moreover, some authors such as Chen et al. (2015) indicate that there is still a gap to fully automate 4D BIM updating of construction schedules based on 3D object-driven data. Indeed, attempts to bridge this gap have been published. Experiments with real construction projects demonstrated high levels of accuracy in real-time performances strengthening the likelihood to automate schedule updating relying on object-based standards such as the industry foundation classes (IFC) (Hamledari, McCabe, Davari, & Shahi, 2017).

The intent of this research is focused on the analysis of scheduling data towards the full automation of 4D BIM under construction planning and scheduling standards.

1.3 Need for automated integration of Construction Scheduling & 4D BIM interface

Construction planning and scheduling can be a cumbersome process that requires full coordination among Architectural, Engineering Construction (AEC) agents. It entails a comprehensive and detailed understanding of the project and its workflows from start to end of the construction phase. It also requires the standardization of tasks and their conventions amongst trades (Hall D. J., 2008). The construction industry has widely accepted and used Construction Specifications Institute CSI® as standards to classify construction information (Chang & Tsai, 2003). Some of these standards are MasterFormat® and UniFormat™. While MasterFormat® has been utilized as the industry standard to retrieve classified construction information regarding the type of work result in the project, UniFormat® has been used as a the classifier of elements and assemblies within the project such as walls, floors, ceilings, roofs and others (Weygant, 2011). In relationship with BIM, Weygant (2011) indicates that UniFormat™ provides opportunities to organize and cross reference element information. Since this standard provides a comprehensive object-driven approach of construction operations, its applicability towards automated schedule generation in a 4D BIM environment is significant.

The computational possibilities of developing automated schedules based on object-driven conventions have been studied (Hamledari, McCabe, Davari, & Shahi, 2017). Furthermore, its benefits have been stablished. Automating 4D model updates offers opportunities for reducing the cost of modeling and user training, which represents a huge step for BIM adoption (Leite, et al., 2016). These steps bring BIM closer to the AEC community, nonetheless updating schedules in 4D BIM should rely on the most common practices used in the industry. This gap has not been covered yet. The intent of this work is to contribute to the automation of 4D BIM schedule updating by researching the current practices in construction planning and scheduling adopted by the industry and analyzing such practices in relation with object-driven standards.

1.4 Organization of this Thesis

This thesis is structured by chapters. Its organization is indicated below:

- *Chapter 2* presents literature review describing the state-of-the-art regarding the evolution of construction planning and scheduling towards automation of 4D BIM schedule updating for tracking progress and project controls.
- *Chapter 3* describes the current tendencies in construction planning, scheduling and 4D BIM. This provides a diagnostic of the status quo of construction operations towards the implementation of 4D BIM automation procedures.
- *Chapter 4* explains the methods utilized to analyze collected construction scheduling data from real estate infrastructure projects and parameters adopted to identify BIM-based tasks within construction schedules.

- *Chapter 5* summarizes the results obtained from this study and opens the discussion for future research on this field.
- *Chapter 6* outlines the conclusions established with the analysis of construction scheduling data towards 4D BIM automation.

CHAPTER 2: LITERATURE REVIEW

2.1 Planning & Scheduling in Construction Operations and BIM

The decision of undertaking planning and scheduling workflows during the construction of infrastructure projects has been widely discussed. It is commonly known that the main goal of planning in construction is associated with the on-time delivery of a project. This goal takes into consideration not only the time, but the cost, safety and quality of the tasks and procedures required to complete the project. Extensive research to optimize time, cost and resources in construction schedules has been studied (Faghihi, Reinschmidt, & Kang, 2016). Regardless the amount of research developed within this field, it is necessary to clearly understand the typical workflow for formulating and controlling construction schedules during the execution of construction projects. Baldwin & Bordoli (2014) provide a comprehensive study of planning and scheduling with real case studies regarding the common practices in construction. They describe the hierarchy led by the owner and project manager who mutually agree on the creation of the *Master Schedule*. This document is a contractual binding agreement commonly used to control project progress along the execution phase. Trades such as consultant (owner's representative), design (architects and engineers) and construction (constructor manager, general contractor and subcontractors) are obligated to use this document as a guide, or a tighter replica of it (*Target Construction Programme*) through the entire process. In addition, these trades have the possibility to elaborate packages that suit their specific targets based on *Work Breakdown Structures.* Yet, these packages do not constitute contractual documents. Meaning that, AEC members tend to create their own version of the master schedule by establishing coordinated conventions approved by the project manager, and eventually, by the owner's consultant team.

The introduction of BIM in the construction domain has generated potential to go beyond the manual generation of construction schedules. Particular attention has been payed to the likelihood of creating schedules within a BIM environment to improve construction operations. This is the case of automated schedules in BIM. Dong, Fisher, Haddad, & Levit (2013) introduced the automation of look-ahead schedules for the final stage of complex construction projects. This innovative approach was achieved by the combination of lean principles and algorithms in charge of optimizing and reducing the amount of errors produced during project completion to zero. Zhang et al. (2013) identified a holistic approach to connect jobsite safety issues with BIM. They explored the possibilities of linking construction tasks with their associated fall-related hazards. In addition, they developed systematic outputs in form of reports / schedules to prevent accidents during the execution period. Similarly, Moon, Kim, Kamat, & Kang (2015) conducted research on computational methodologies to enhance project planning performance. Their study establishes a link between the generation of optimal schedules and 4D BIM environments. Furthermore, researchers such as Liu, Al-Hussein & Lu (2015) discussed the possibility of performing BIM-based schedules relying on the integration of BIM platforms and construction schedule packages by developing "activity level construction schedules". This approach was formulated under resource constraints and represents a forward step towards the automation of planning and scheduling in project management. More recently, other efforts to understand the relationship of BIM workflows into scheduling practices were led by Sigalov & König (2017). They suggest the use of BIM-based schedules to decrease planning time and foster productivity in the jobsite. This study relies on the association of construction processes with their correspondent tasks by dividing the schedule into smaller parts. Identifying this pattern provide opportunities to develop schedule templates to be, eventually, widely applied for specific construction packages. In other words, the method emphasizes the probability of automating BIM-based schedules by the identification of relationships amongst construction scheduling data established under specific parameters.

2.2 Schedule Classification Standards & BIM

Construction planning and scheduling requires collaborative work and coordination among trades. In this process, BIM plays an important role since its integrative approach facilitates the standardization and familiarity of the procedure. For this reason, the implementation of BIM requires the standardization of processes (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013). Similarly, it mandates the need for interoperability and exchange of information (Honti & Erdélyi, 2018). Through the incorporation of BIM system in the U.K., EuroBIM (2017) encouraged the adoption of international standards to generate a common basis in the construction supply chain for exchanging information. These standards promote legal and regulatory frameworks and serve as a guidance throughout the life-cycle of the project. They explained cases such as the Estonian AEC industry, where in-house standards where established to set a benchmark for the developing of BIM workflows, and foster productivity in their operations.

In the U.S., the AEC industry also strives to develop standards and collaboration with BIM workflows. The decision of the General Services Administration (GSA) to establish BIM as a minimum requirement for the submission and collaboration of Public Building Information Technology Services has set an inflection point for the acquisition of BIM within construction operations in the country (Antwi-Afari, Li, Pärn, & Edwards, 2018). Within this scope, studies to measure the success of BIM implementation have been released. Antwi-Afari, Li, Pärn, &

Edwards (2018) indicate that there are similar factors that have contributed to the expansion of BIM, and coordination and planning of construction work lies within this list. In order to accomplish an exemplary phasing between construction scheduling and BIM, the General Administration Services (2009) recommends the adoption of two type of activities in construction schedules: *generic activity categories* and *project specific activity types*. This differentiation allows, in one hand, to have a complete idea of the flows involved in construction activities (construction, temporal or demolition). On the other hand, it encourages the creation of more detailed schedules throughout the incorporation of level of development according to activity types, which includes construction and non-construction tasks. Also, it indicates that similarities between activity names and BIM-driven objects facilitates the linking process amongst 3D and schedule. For this reason, the creation of object-oriented schedules counts as a possibility to enable intelligent models to automate the interface between construction planning and scheduling and BIM (Wang, Weng, Wang, & Chen, 2014).

The implementation of standards to maximize the benefits of BIM through object-oriented schedules has been widely discussed (Issa & Ol bina, 2015). Attempts to classify construction activities by type of building element have been introduced by the Construction Specification Institute (CSI, 2010) through UniFormat™. This classification provided four levels to categorize construction tasks plus one detailed list of designated elements, usually considered as“Level 5”. For further reference, the first level consigns a total of eight classifiers denominated *major categories*: substructure, shell, interiors, services, equipment and furnishing, special construction and demolition, building sitework, and general. The purpose of this level is aimed to cover a wide range of types of construction. Diverse attempts for leveraging the use CSI® standards into engineering workflows have been released. Researchers like Chang & Tsai (2003) have analyzed the use of CSI® standards for engineering management workflows. More specifically, the bridge between UniFormat™ and BIM has been explained by Weygant (2011). The author indicates that UniFormat™ is one of the common methods to organize construction information. Furthermore, he highlights the advantage of arranging BIM data into tabular UniFormat™ classifiers and recommends the adoption of methods to categorize BIM-based elements to optimize the use of such standards. This practice is denominated BIM analytics, and its adoption has shown incredible endeavors towards automation of BIM workflows (Kensek & Noble, 2014). Therefore, there is a significant need to understand the existing patterns between current practices in construction scheduling and object-driven standards towards automation of 4D BIM.

Accordingly, the scope of this paper lies on the intention to tabulate construction scheduling data into UniFormat™ classifiers.

2.3 Construction Scheduling & 4D BIM

The process of incorporating the variable time into modeling of 3D CAD objects or 4D CAD for visualization purposes has been studied since the early 2000’s (Issa, Flood, & O'Brien, 2005). Lately, this process evolved and new advantages from the fourth dimensional (4D) of BIM were leveraged (Borges, Cavalcanti de Souza, Melo, & Giesta, 2018).

Golparvar-Fard, Peña-Mora, & Savarese (2011) developed the connection between point-cloud prototypes – based on the computational analysis of imaging and geo-spatial condition– and 4D BIM. The objective of this study was retrieving as-built conditions of construction sites and compare them with the original as-planned baseline. As a result, 4D BIM models were able to perform not only construction visualization, but progress monitoring. The outputs of this study opened opportunities for investigation in reality capture for construction safety, quality assurance and project controls. Likewise, Chen & Luo (2014) studied the potential of 4D BIM to perform schedule quality control by leveraging BIM as a product, process and organization. This study introduced color coding to distinguish different stages of quality control of BIM-based elements. This differentiation was visualized during 4D BIM. Stepping forward, Dimitris & Golparvar-Fard (2014) designed an interface for project monitoring and BIM. Their model was capable to retrieve imaging information and automatically recognize BIM material patterns. This method achieved around 97% of accuracy in imaging detection compared with 95% average standards of groundbreaking technologies in computer vision for the construction industry. Lately, Golparvar-Fard, Peña-Mora, & Savarese (2015) created an approach for tracking project progress automatically. This automation was based on a systematic recognition of as-build object-driven elements in comparison with as-planned BIM-based objects. By developing this comparison, the authors evolved capabilities to calculate physical progress relying on probabilistic machine learning techniques though the analysis of imaging data. Industry Foundation Classes (IFC) played an important role in this achievement. The authors enabled the automatic recognition of 3D objects classified according to IFC-based categories. In other words, 4D BIM became an automatic procedure for object-driven data analysis. Further research demonstrated increased benefits of 4D BIM progress tracking throughout the adoption of unmanned aerial vehicles (UVA) to capture as-built information (Hamledari, et al., 2017). The benefits of progress monitoring in construction operations have been measured. Alizadehsalehi & Yitmen (2019) demonstrated the positive impact of leveraging the uses of 4D BIM to track physical progress in combination with reality-capture technologies. They found that the overall project delivery is benefited in terms of duration, cost and quality due to the incorporation of BIM workflows.

Although this accomplishment represented an exemplary step towards fully automation of 4D BIM, the automation of construction schedules is still left for further research development.

Remarkable research has been conducted towards automation of construction schedules in 4D BIM. The first attempts to achieve this goal were presented by Han, Cline, & Golparvar-Fard (2015). They incorporated construction scheduling into as-built data and BIM workflows. The authors depicted three main challenges derived from current AEC industry practices that add complexity to the automation process: 1) lack of enough level of details in the designed model (as-planned); 2) lack of level of detail in WBS of construction schedules; and 3) presence of static/dynamic visual obstructions when collecting as-built data. More recently, Hamledari, McCabe, Davari, & Shahi (2017) defined a systematic approach to update construction tasks duration and finish dates in 4D BIM. This prototype was capable to update progress ratios and assign color codes to BIM-based objects based on their actual progress status. To retrofit the process more accurately, the authors differentiated the incorporation of level of detail (construction schedule information) from level of development. (3D objects) The foundation of this technique was based in three modules: model preparation, model updating and schedule updating. While model preparation and model updated represented the modification and apprising of BIM-based objects, schedule updating represented a groundbreaking innovation to turn the updated BIMs into updated schedule information. The validation of the prototype showed 73% of accuracy during performance. For research purposes, this number lies into a high level of accuracy achieved.

A comprehensive investigation regarding the status quo of 4D BIM in the AEC industry has been conducted (Abath, De Sourza, Sampario, & Pinto, 2018). Additionally, applications such as constructability analysis in virtual reality (VR) environments are still in evolution. Even though the limitations found, studies have shown the creation of frameworks to increase team coordination in remote mediums of a single construction project (Boton, 2018).

Accordingly, the automation of 4D BIM updating with construction schedule inputs has been achieved, nonetheless the fully generation of construction schedules based on BIM-based information has not been accomplished yet.

2.4 Big Data for BIM Automation

Distinctive attention has characterized the analysis of BIM data among researchers. Predictive analysis to design intelligent models to optimize BIM workflows has been tendency in the last few years. Indeed, the introduction of algorithms in natural language processing (NLP) have endeavored opportunities for the development of automated models within BIM applications. These methodologies has been utilized to predict injuries during construction phase (Tixier, Hallowell, Rajagopalan, & Bowman, 2016), and tested results have reach high levels of accuracy: up to 95% (Tixier, Hallowell, Rajagopalan, & & Bowman, 2016)or to support decision-making in risk management with the use of machine learning algorithms (Zou, Jones, & & Kiviniemi, 2017). Either way, the utilization of these approaches takes into consideration the use of empirical data to predict results based on retrofit processes.

Multiple applications have been developed thanks to the use of reasoning-based approaches. Goh & Ubeynarayana (2017) have compared the response of multiple machine learning algorithms to predict narrative accident classification reports. They found that methods such as Support Vector Machine (SVM) provide more accurate results (up to 62% accuracy) for experimental data analyzed with text mining. Similarly, Poh, Ubeynarayana, & Goh (2018) have analyzed safety records and number of accidents of a total of twenty-seven construction projects.

Their study concluded that Random Forest (RF) method provided most accurate results for the prediction of accidents and fatalities in the jobsite. They achieved a total of 72% of accuracy in their calculations. More recently, research focused on the analysis of text analytics for contractual documents in construction has been conducted (Marzouk & Enaba, 2019). The study provides an output of the frequent terms found in contractual language for the execution of construction projects and contributes with a framework to develop analysis of unstructured data in a BIM platform.

Specifically, the use of NLP has also played an important role in its interface with BIM. Studies under Latent Semantic Analysis (LSA) to consolidate and analyze relevant BIM literature dataset have been performed (Yalcinkaya & Singh, 2015), This technique facilitated the classification and organization of data into different structures. Results show a remarkable interest of 4D BIM to retrieve as-built conditions of construction projects. Other studies have defined a framework for cloud-based data retrieval of BIM under NLP methods (Lin, Hu, Zhang, & Yu, 2016). The authors suggest the utility of such a framework to develop systematic procedures for data retrieval and, eventually, elaborate automatic reports based on the information acquired. Under the information retrieval perspective, Zhang & El-Gohary (2016) leveraged the retrieval of documentation by extracting design and contractual information from BIM-based models. The intent of this study was the generation of fully-automated code compliance systems under reliable conditions given the nature of information to be checked. This study accomplished 87.6% of precision in anticipated non-compliance results.

Given the cases described, the use of emerged big data in the AEC operations is becoming a more frequent practice that undertakes promising opportunities (Maaz, Bandi, & Amirudin, 2018). Fundamental literature review to set a background of the needs in constructability in the AEC industry has been developed (Kifokeris & Xenidis, 2017). Similarly, the importance of critical factors – reliability, relevance and speed – associated with the success in construction analytics and BIM practices have been described (Han & Golparvar-Fard, 2017). In this scenario, Bilal et al. (2016) reflect on the way of how big data analytics is transforming the construction industry. In fact, the author explains that researchers are using big data analytics for several techniques such as regression, classification, clustering, NLP, and information retrieval. Classification of data into CSI® like UniFormat™ appears as one the utilities of big data in the AEC industry. Opportunities for developing value added services such as *generative design, clash detection and resolution, performance prediction, visual analytics,* among other are some of the tendencies where research has been invested. Special emphasis has been applied to the prediction of different domains in the industry through computational intelligence techniques like *Artificial Neural Network* (ANN) which utility can contribute to the future prediction of automatic schedules in real-time activities such as 4D BIM and progress monitoring. In parallel, other uses of data analytics to study the autonomy of building performance based on big city data has been released (Scaysbrook, 2016).

Finally, the introduction of big data has shown the evolution of automated BIM models along the time. Models for enhancing monitoring systems to track project performance have been analyzed (Navon & Sacks, 2007). Furthermore, stochastic prototypes to foster productivity relying on schedule animations in 4D BIM has been released (Gelisen & Griffis, 2014). To leverage 4D BIM visualization, intelligent models designed under systematic approach to track earned value analysis (EVA) project performance have been studied (Turkan, Bosché, Haas, & Haas, 2013). More recently, outlines to generate automatic schedules during operation and maintenance phase of infrastructure projects have been set and released (Chen, Chen, Cheng, Gan, & Wang, 2018). These evolutions are transforming the perspective of productivity in the construction industry, and most importantly, are creating the foundation for future development in data analytics and BIM.

Regardless the approach where research has focused on, the use of data analytics techniques is evolving operations in the construction industry by enabling opportunities to automate typical workflows that affect quality, safety and productivity. In addition, the study of BIM-based data has brought the technical basis to explore the possibilities to create automated linkage 4D BIM between construction schedule and 3D-objects. For this reason, the study of scheduling data represents a potential opportunity to develop future prototypes based on the prediction of standardized tasks under object-oriented standards.

CHAPTER 3: CONSTRUCTION SCHEDULING AND 4D BIM PRACTICES

A survey study has been conducted in order to have a better understanding of current practices in construction planning & scheduling and 4D BIM in the AEC industry. This study has been conducted in coordination with the Real-Time and Automated Monitoring and Control Lab of the department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign under the supervision of Dr. Mani Golparvar-Fard. The intent of this work was to identify challenges and key factors that would contribute to the adoption of automated 4D BIM scheduling practices under BIM-based environments. The responses provided constituted professional testimony as a result of involvement in construction activities. Therefore, the results do not follow policies of any design/construction firms, but to represent genuine opinions of dealing with planning, scheduling, progress monitoring and project controls in 4D BIM on a daily basis.

The survey was divided into four different sections: participant background, construction planning and scheduling, 4D BIM, and areas of improvement. The results and analysis of each of the aforementioned sections has been developed in this chapter.

3.1 AEC Participant Background

A total of 40 experts in construction operations workflows were surveyed through Google^{TM} Forms. With the purpose of validate the responses within an AEC background, the experts were asked to identify the type of business where they focus their operations in. Majority of them responded to pertain to general contractors' backgrounds (see Fig. 1). In addition, 78% identified building as the type of industry where they mainly develop AEC operations. Other responses identified heavy civil infrastructure, commercial facilities and renovation/restauration as other relevant industry backgrounds (see Fig. 2).

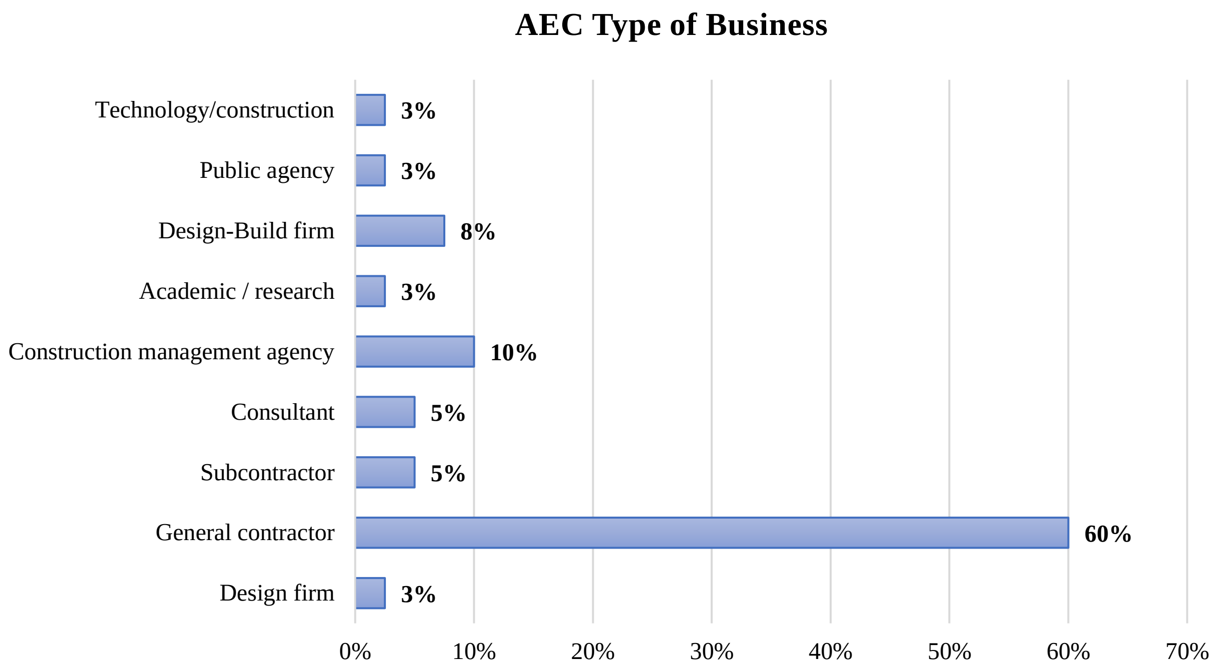


Fig. 1. Business type of the AEC industry.

The main professional background of the participants is Civil Engineering (88%), followed by a 7% of Architects and 5% of other engineering backgrounds (see Fig. 3). That being said, the total of participants have professional background related to design and construction of infrastructure projects. In addition, their responses are reliable since their perspective is familiar to the existing workflows in construction practices.

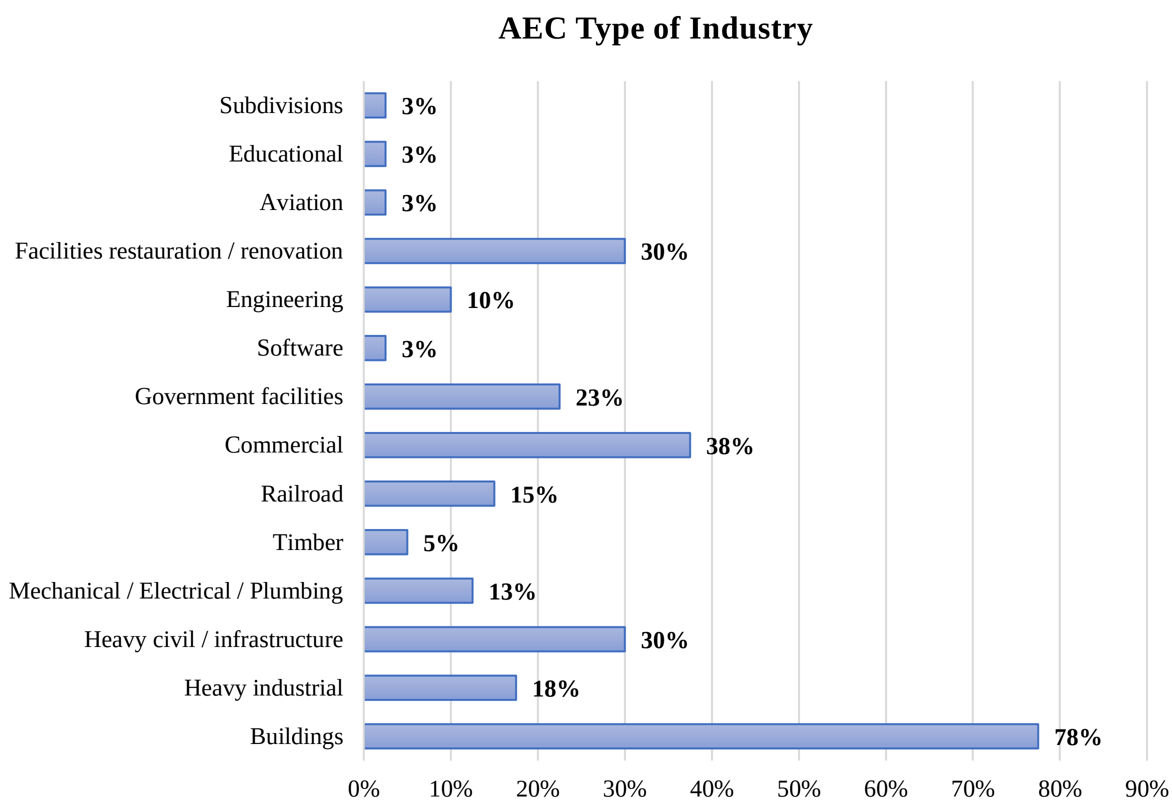


Fig. 2. AEC industry type.

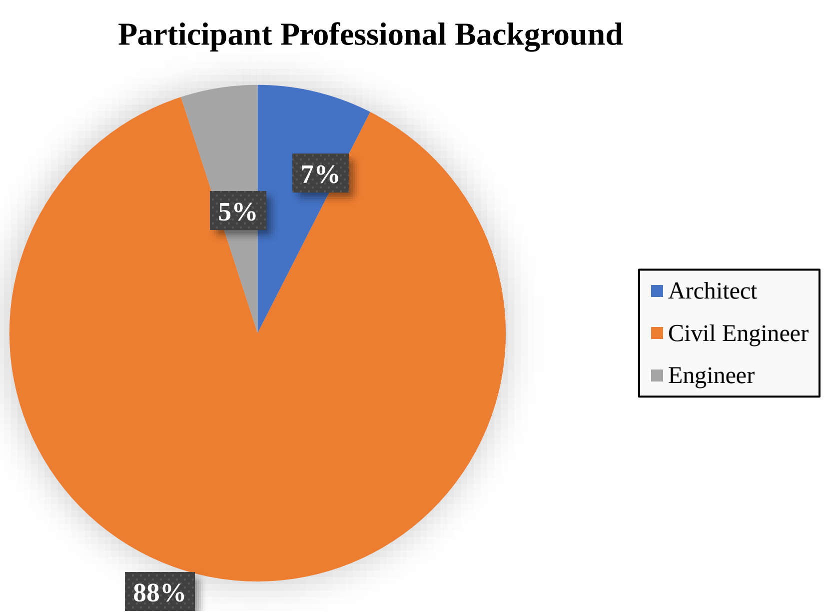


Fig. 3. Main professional backgrounds of the AEC industry.

For more specificity in construction workflow participation, the recipients were asked to indicate the role they developed in their daily basis in construction projects. Their responses define Project and Construction Management as the main role of the participant's profile in construction workflows (see Fig. 4). This category is followed by more specific roles within project management positions (project engineer, scheduler, project controls) and include most of the members of the supply chain in construction.

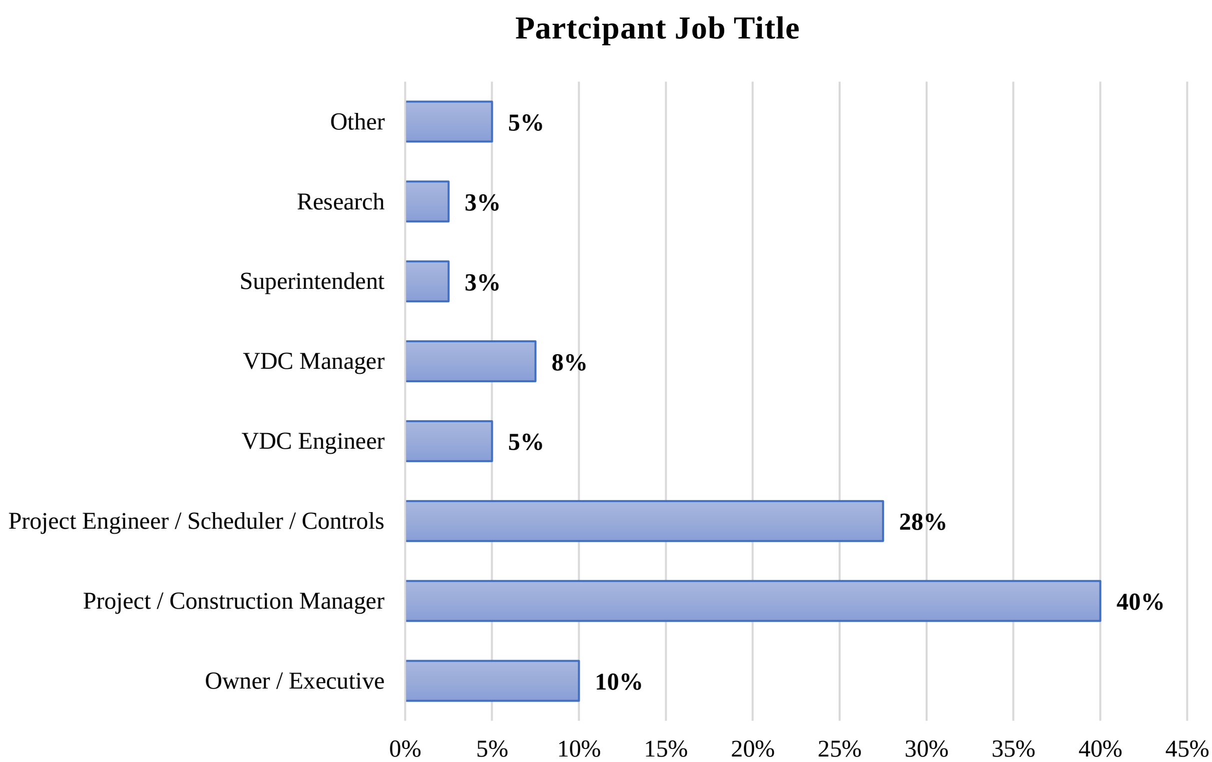


Fig. 4. Job Titles distribution of the AEC industry.

The gross number of surveyed participant's years of experience is between 1 to 5 years of in the industry (around 75% of them). The remaining candidates indicated more than 5-years of experience in the field I(see Fig. 5) .

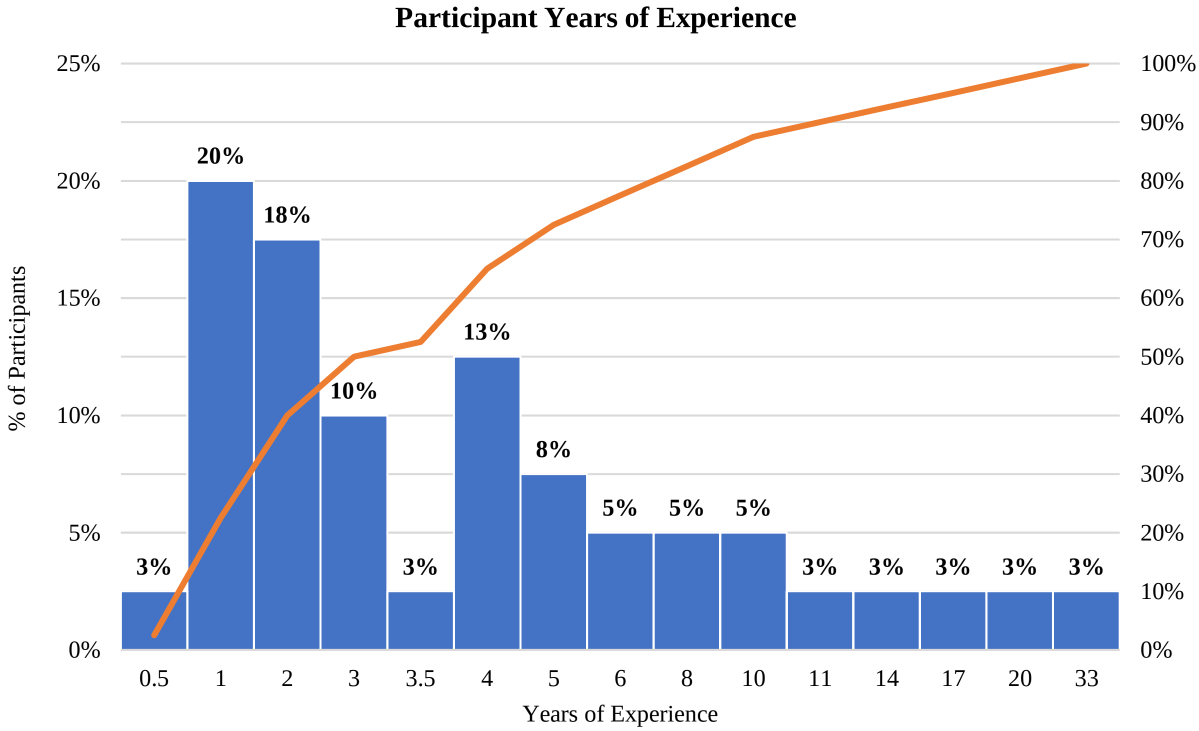


Fig. 5. Accounted Years of Professional experience within the AEC industry.

In order to understand the level of involvement with BIM workflows and groundbreaking technologies based on the size of business, the participants were asked to indicate the annual revenue (AR) range of their organizations. Results evidence that majority of participants develop roles within large companies, whose AR accounts for more than $1 billion / year (see Fig. 6). The rest of the participants barely show an equal distribution between small and medium business sizes.

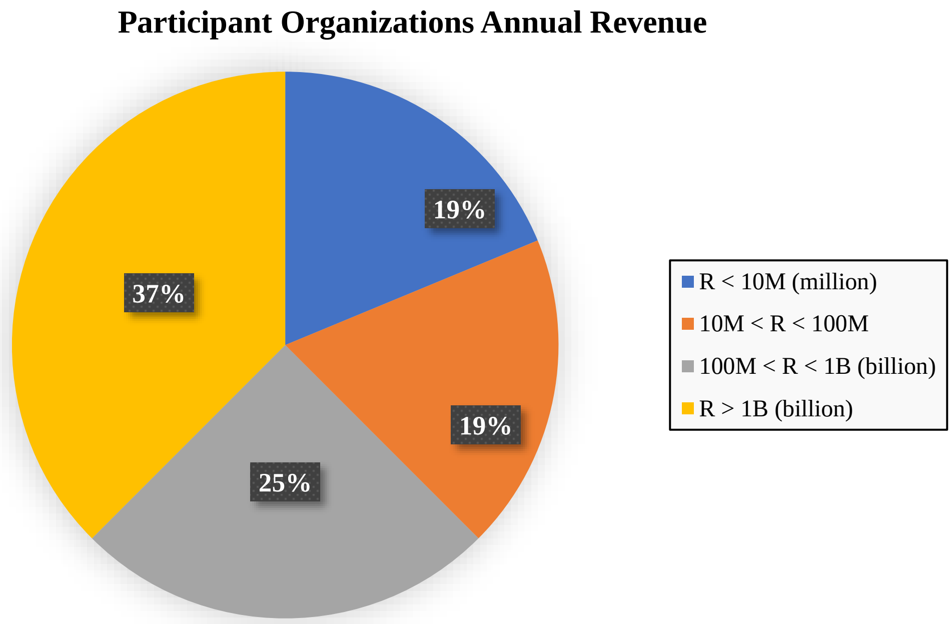


Fig. 6. Annual revenue representation of businesses of the AEC industry.

3.2 AEC Construction Planning & Scheduling Practices

The survey recipients were asked to indicate the type of convention and standards utilized to perform construction planning and scheduling. The responses specify that 63% of the participants count with in-house standards to perform scheduling activities. Other standards such as MasterFormat® and UniFormat™ has relevant connotation in the elaboration of construction schedules according to the participants (see Fig. 7).

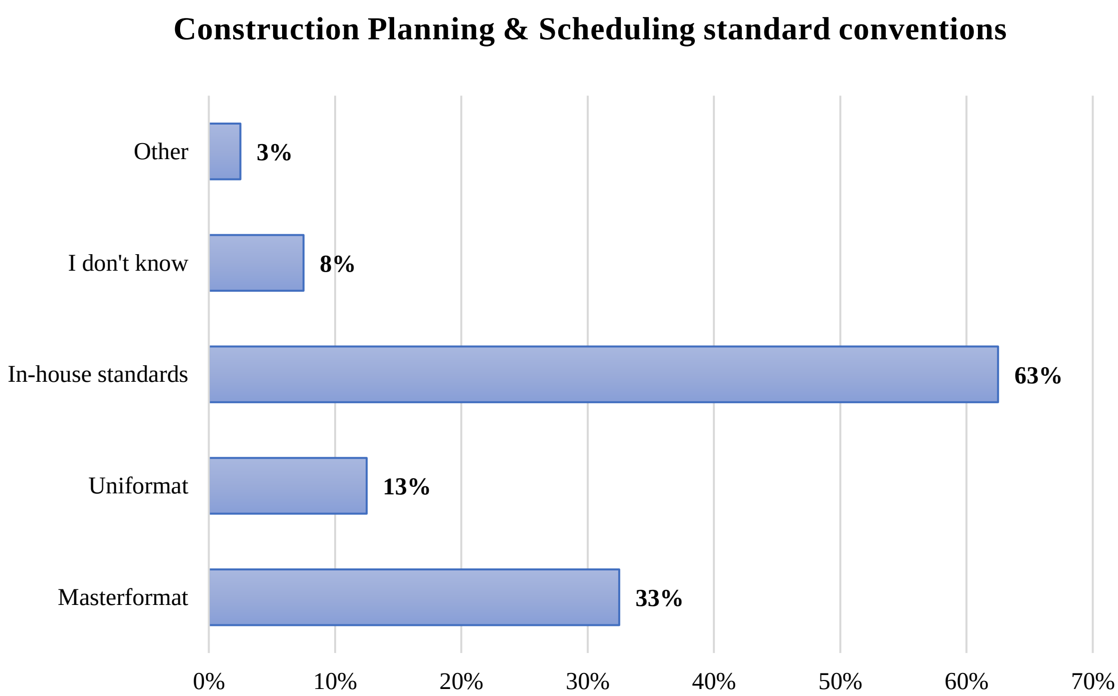


Fig. 7. Type standard conventions in construction scheduling practices in the AEC Industry

One of the significant procedures in construction scheduling is the creation of WBS. Majority of participants (~60%) indicated that they do not count with guides to create WBS (see Fig. 8). That being said, most practitioners in scheduling-related workflows adapt their own standards to the creation of construction documents such as the Master Schedule.

Some practitioners with in-house standards for construction scheduling indicated that the creation of a WBS depends on managerial decisions. Furthermore, they specified that most of in-house standards is broken down into several attributes such as: tittle, description, position code, account code, quantity and unit of measure.

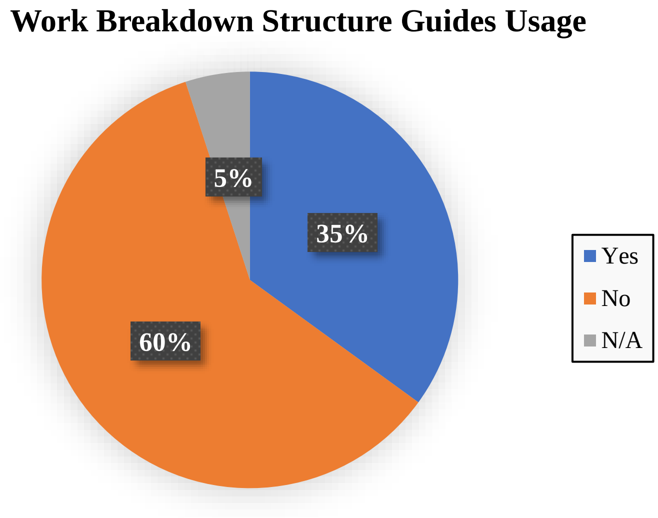


Fig. 8. Use of Work Breakdown Structure guide in the AEC Industry.

In addition to the creation of WBS, the experts were asked to mention the common software interface they use to perform their daily construction scheduling activities. They pointed out Primavera® P6 (~45%) as the main platform to create and control construction activities (see Fig. 9).

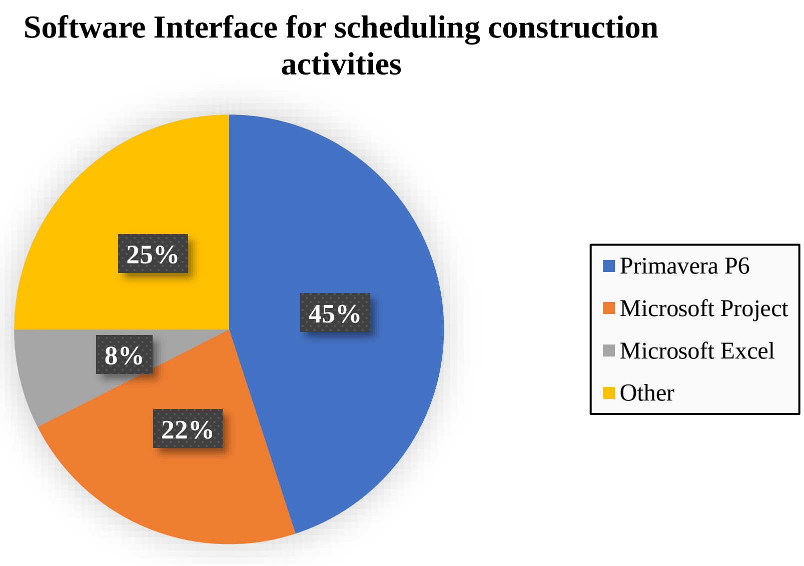


Fig. 9. Software interface in Construction Planning and Scheduling in the AEC Industry.

Other responses included: MS Project, MS Excel, P6 / MS Project / MS Excel combined, Phoenix & MS Excel, BuildPro & MS Excel, Smartsheet, IHMS, ASTA Powerproject, and Touchplan.

In addition, the participants were requested to indicate the techniques they utilize to perform schedule quality control. 73% indicated face-to-face meetings amongst different trades as the most conventional way to achieve quality control of construction schedules (see Fig. 10). Early involvement in design, site visits and direct design/construction coordination count as other relevant common practices in the industry.

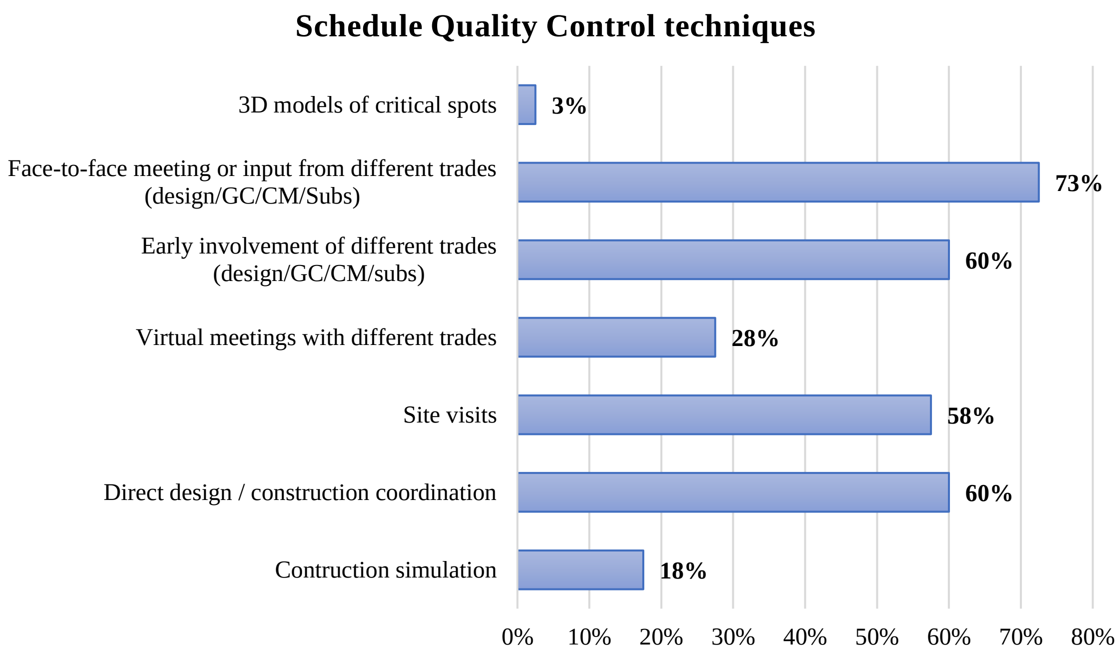
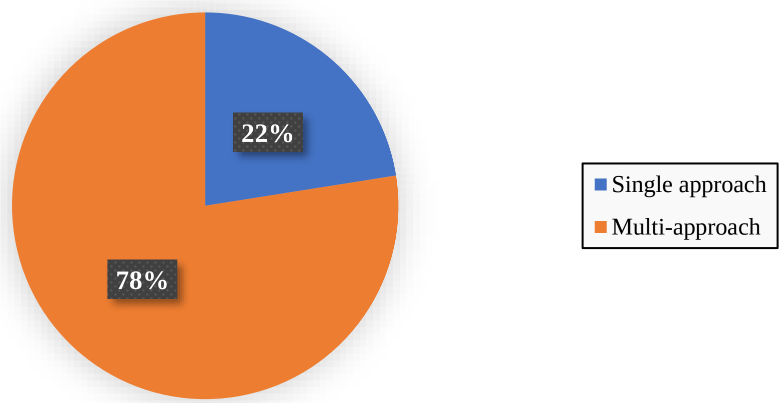


Fig. 10. Schedule Quality Control techniques in the AEC Industry

In terms of multiplicity of approached performed, 78% of recipients indicated to use two or more techniques to perform schedule quality control. Only 22% confirmed the utilization of a single method for this activity (see Fig. 11).

Single vs. Multi-approach Schedule Quality Control techniques



%

Fig. 11. Multiplicity of techniques to perform Schedule Quality Control in the AEC Industry

One of the typical observations found in construction schedules is the inclusion of abbreviation and other conventions to represent modules, location, and sequencing of construction tasks. For instance, some tasks are represented in the next ways: a) Close shower walls L1B3W - c1, which would mean: close shower walls, level 1, area B, west, cell1; or b) FRP shaft D - CFE L1A2, which means Form/Rebar/Pour shaft D, system CFE, level 1, zone A2 The recipients were asked to indicate whether or not they use specific standards to include such abbreviations in different construction activities or packages. Majority of participants (75%) confirmed and they apply or sometimes apply such conventions. Only 25% indicated to avoid the use of such conventions (see Fig. 12)

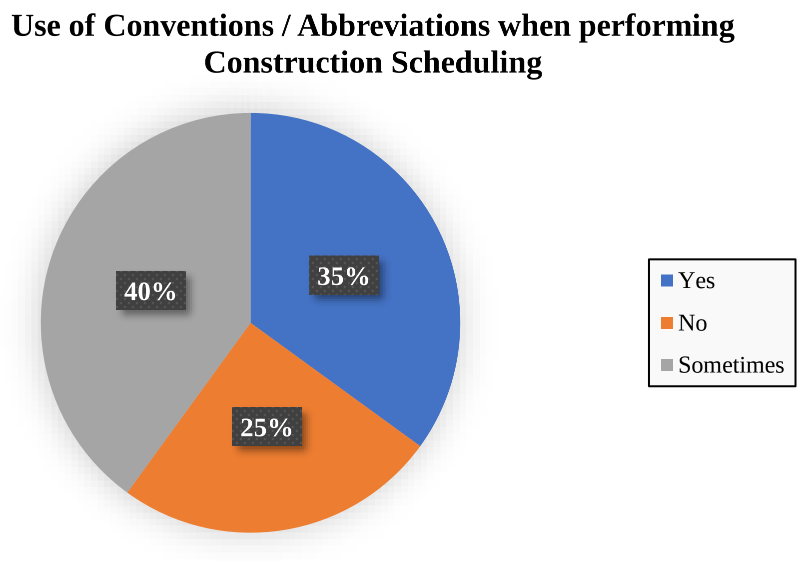


Fig. 12. Implementation of Conventions / Abbreviations in Construction Planning & Scheduling

Among the participants who confirmed the use of abbreviations, a representative 23% indicated such conventions are established by the Superintendent and Project Manager, then are incorporated. Other significant fraction of participants (17%) indicated other ways how these standards are included in construction schedules such as owner requirements and batches of the project (Fig. 13). These responses explain the complexity of the variables involved construction planning and scheduling workflows. Therefore, the complexity of the standardization for information retrieval, and the relevance of the classification of scheduling data.

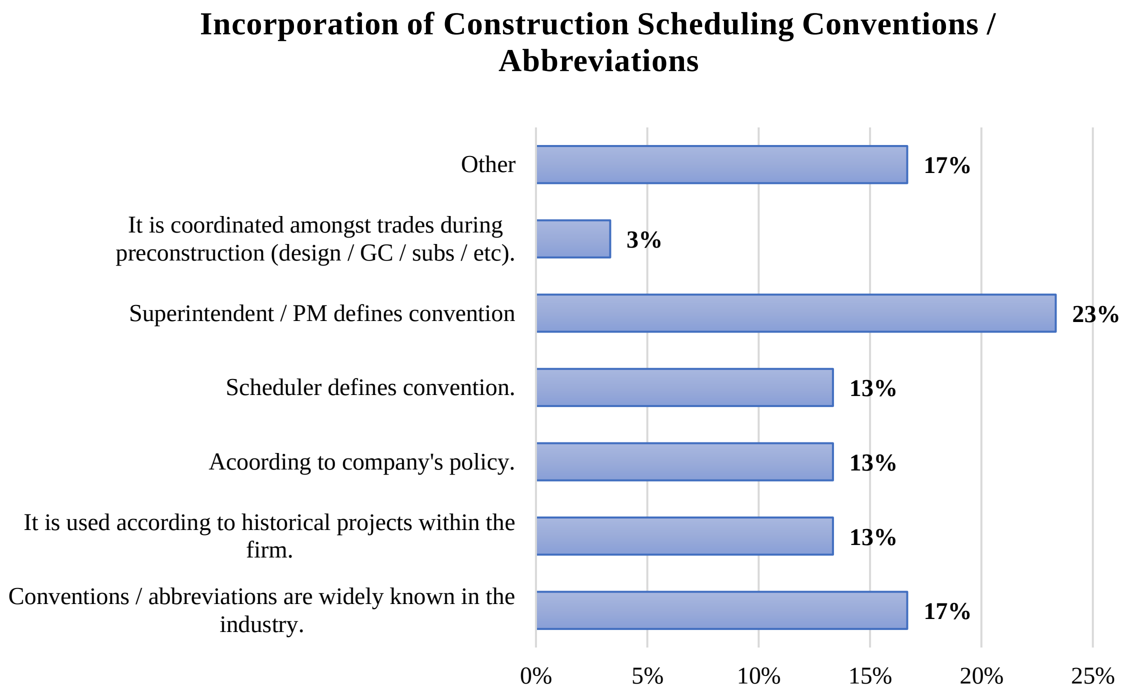


Fig. 13. Implementation workflow for Conventions / Abbreviations in Construction Planning & Scheduling

To establish an average frequency of the inclusion of abbreviation and other convention, participants were asked to select a percentage of the frequency they have observed such convention in construction schedules. Majority of participants indicate they see conventions in a range of 50-80% of construction activities (see Fig. 14). Moreover, they define Mechanical, Electrical, Plumbing and Fire Protection (MEPF) as the construction schedule package where they see those conventions more frequently (see Fig. 15). Along with MEPF, participants observed at least 47% of abbreviation in packages such as architecture, structures, and civil. Other packages were pipping & equipment, specialized residential construction and interior & exterior finishes.

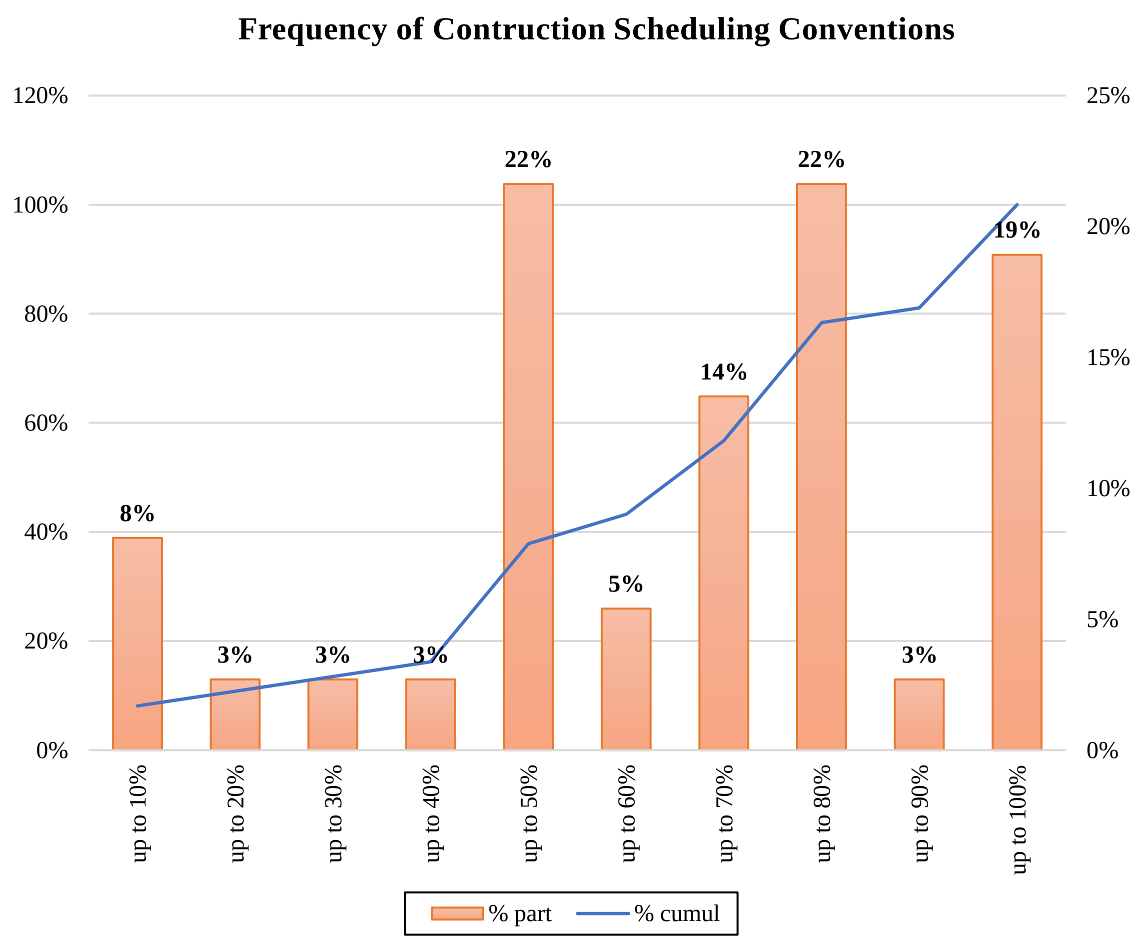


Fig. 14. Frequency distribution of Construction Planning & Scheduling Conventions / Abbreviations in the AEC industry

According to the recipient responses, frequently, multiple construction schedule packages include abbreviations and other conventions. Only 46% of participants manifested they have seen convention in single packages of construction schedules (see Fig. 16). Therefore, the practice of including abbreviations seem to customary in different trades involved in construction planning and scheduling workflows.

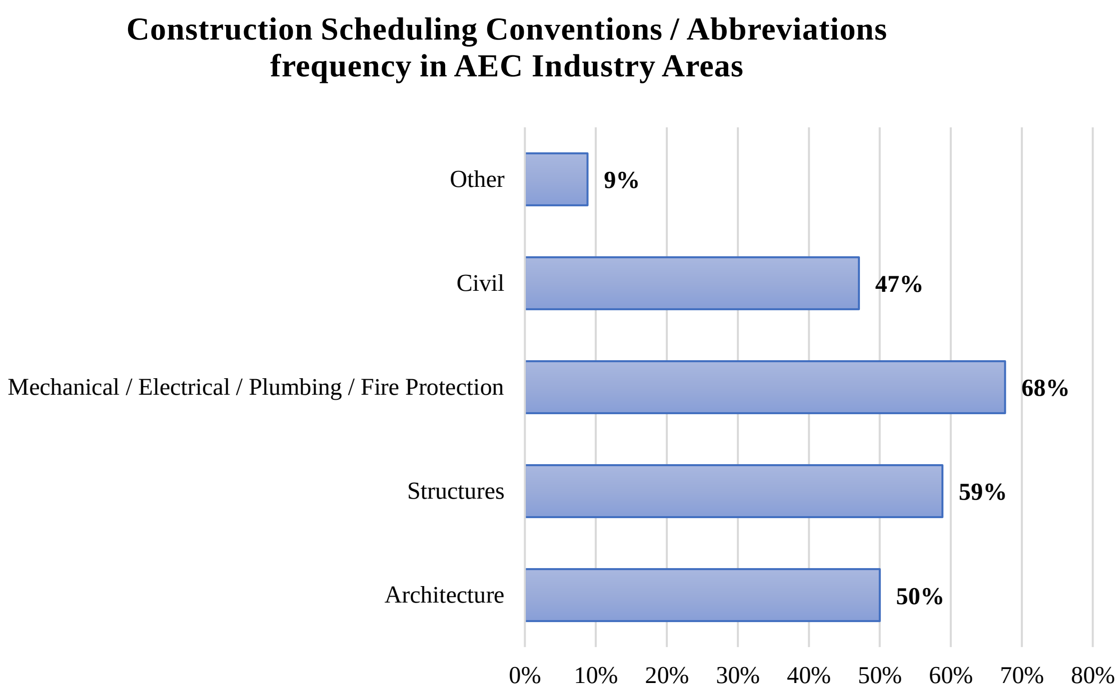


Fig. 15. AEC areas of adoption of Construction Planning & Scheduling Conventions / Abbreviations

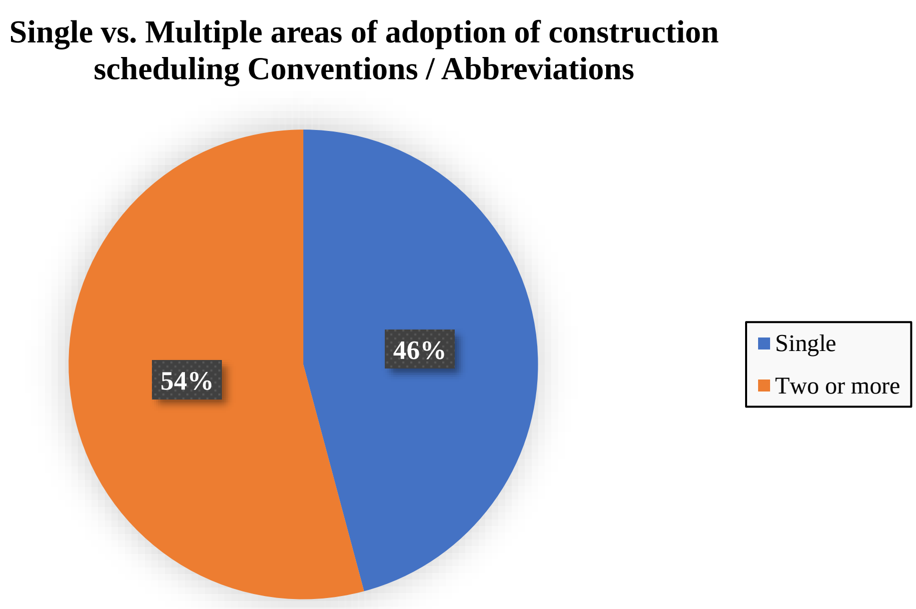


Fig. 16. Multiplicity Construction Planning & Scheduling Conventions / Abbreviations in the AEC Industry

Moving towards the analysis of construction planning and scheduling practices during construction phase, the recipients were interrogated regarding the frequency of using the Master Schedule or construction schedule during preconstruction in comparison with construction phase. In both scenarios, majority of responders indicated they always use the construction schedule (see Fig. 17). Within this category, the intensity of using the construction schedule is higher during execution phase in comparison with preconstruction.

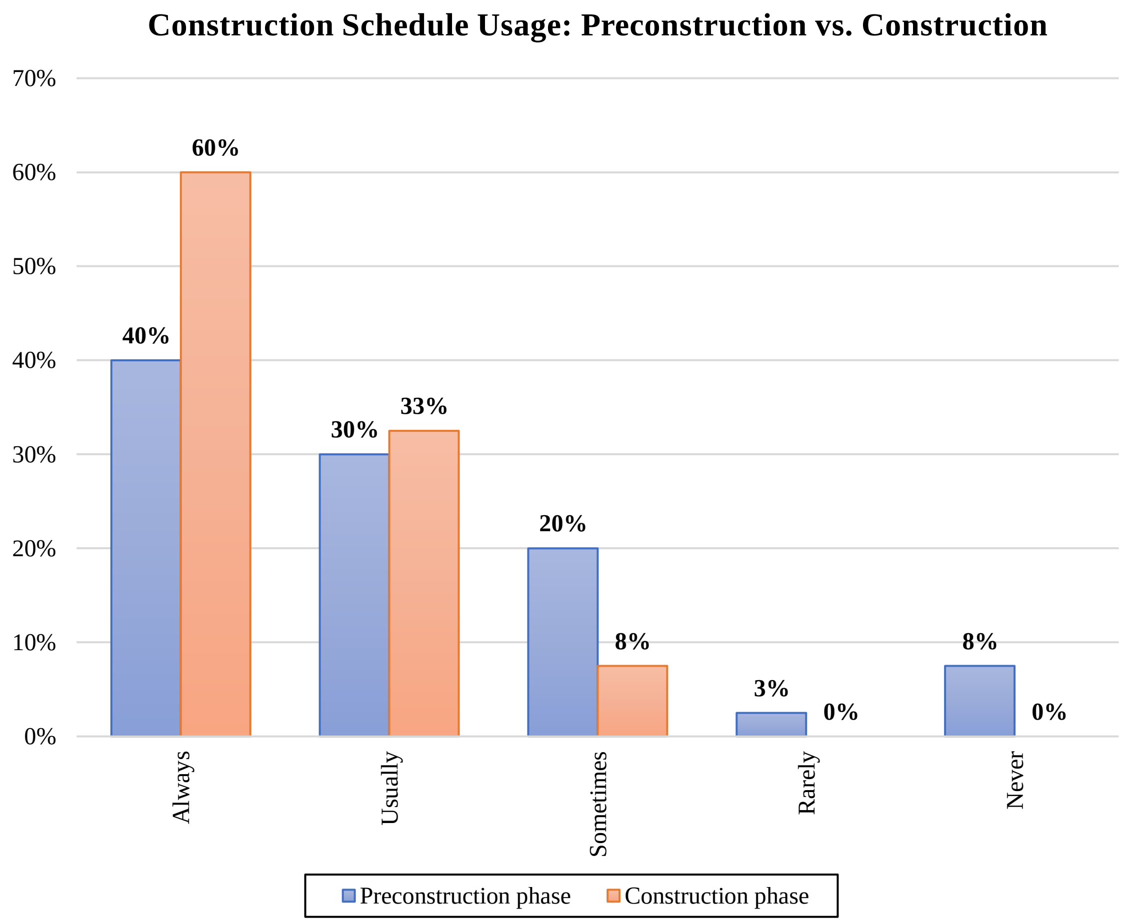


Fig. 17. Master schedule / Construction schedule usage in the AEC Industry

Similarly, the recipients were asked to indicate the frequency for updating the Master Schedule. The common practice in most responders lies on a monthly updating (~53%). Due the complexity of this tasks and contractual agreements, majority of professional involved in construction activities tend to update the master schedule once a month (see Fig. 18). Other responders manifested a bi-weekly or weekly period (~34%). A minimum of participants indicated an updating frequency on a less than a weekly basis (~3%) or more a longer scale than a monthly basis (~10%).

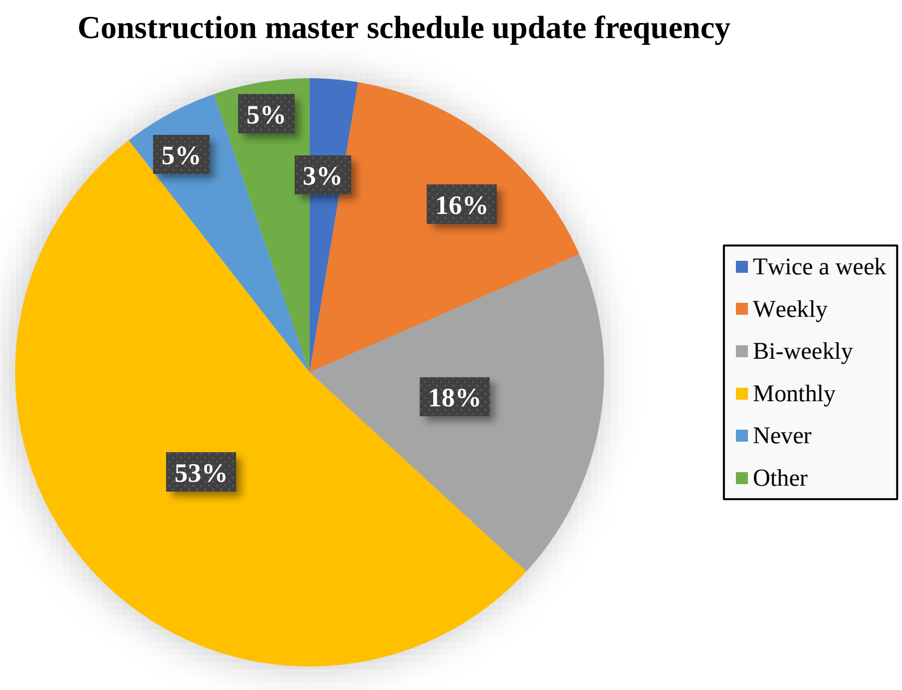


Fig. 18. Master schedule / Construction schedule update practices in the AEC Industry

3.3 AEC & 4D BIM Uses

To understand the needs and practices in 4D BIM, recipients were asked to indicate the methods they utilize to perform progress tracking during the execution of construction projects. Most participants manifested to update construction schedule baseline (68%), use look-ahead schedules (63%), and tracking key milestones only (55%) to perform project progress (see Fig. 19). Regarding the multiplicity of approaches utilized for tracking progress, majority of participants reveled the use of two or more techniques to control physical progress (see Fig. 20).

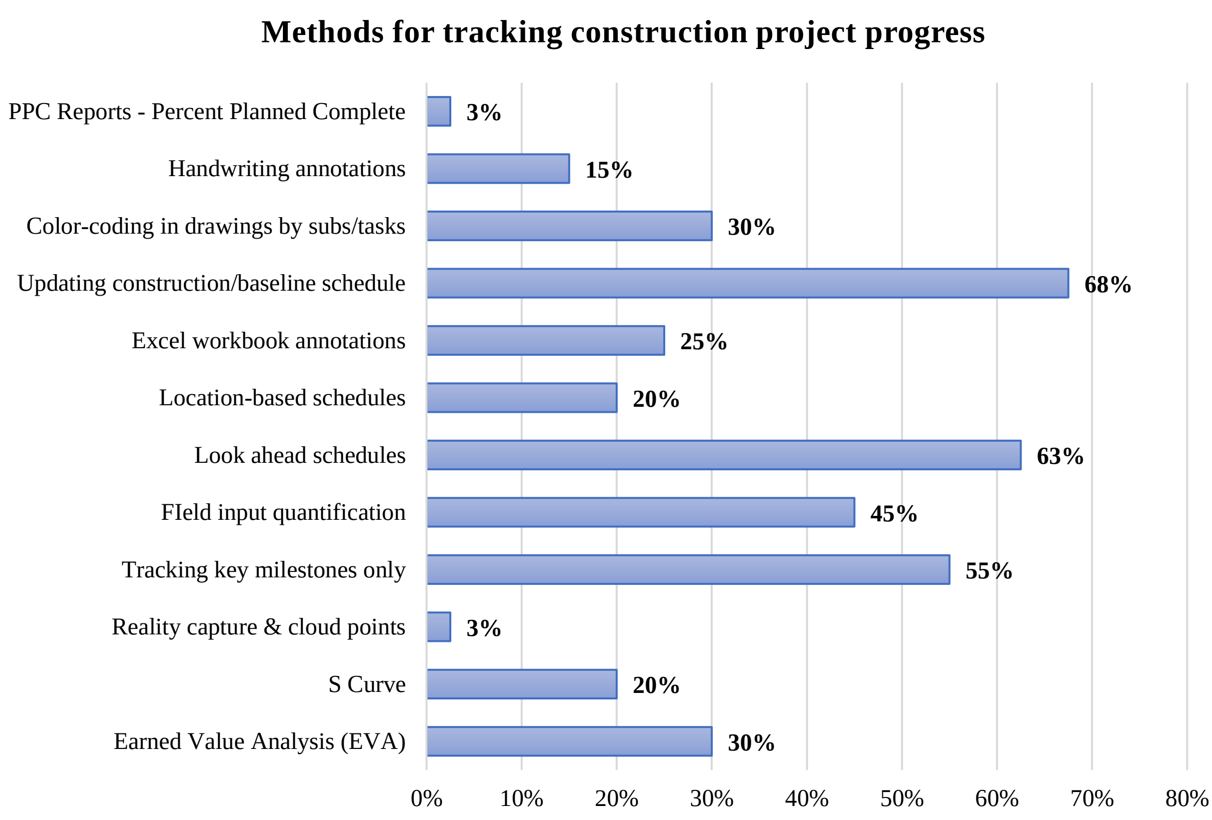


Fig. 19. Construction Project Progress Methods in the AEC Industry

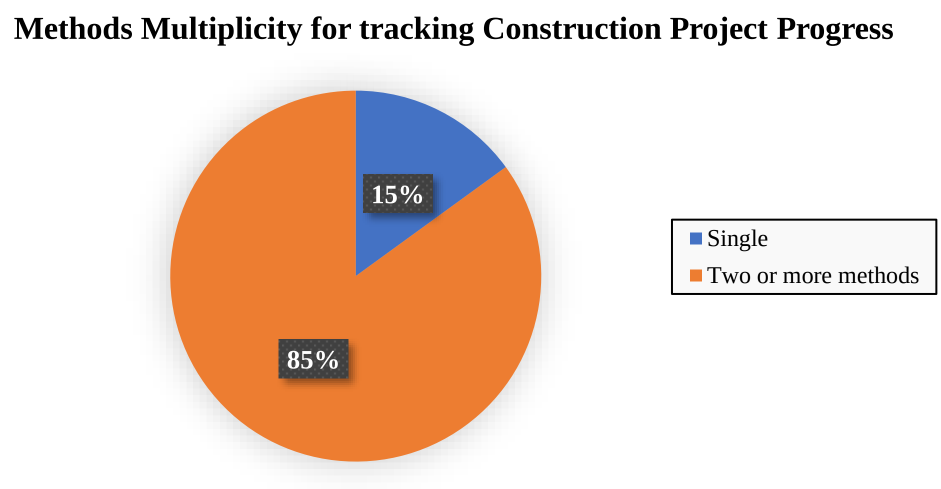


Fig. 20. Construction Project Progress Methods usage in the AEC Industry

Also, surveyed recipients indicated their level of familiarity with 4D BIM (see Fig. 21).

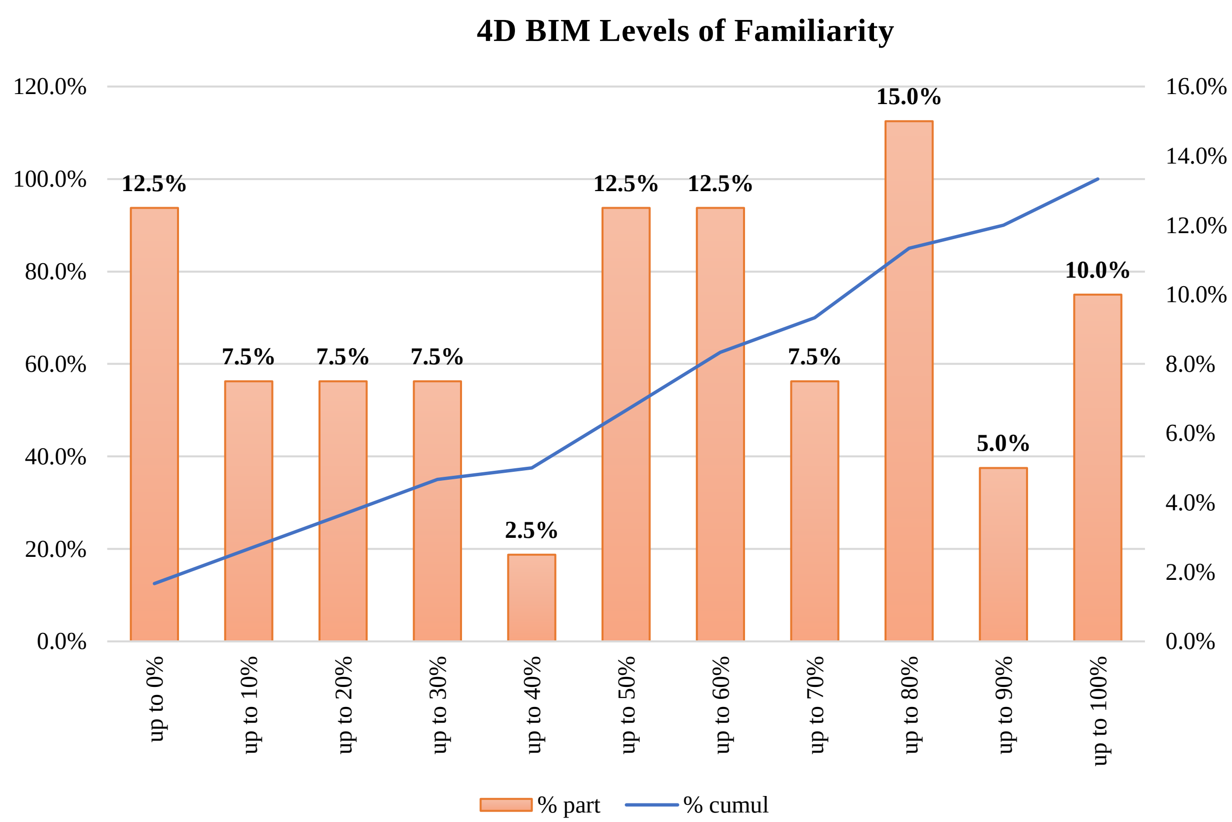


Fig. 21. Levels of Familiarity of 4D BIM in the AEC Industry

Most responders indicated to be familiar with 4D BIM workflows. Indeed, around 85% indicated to be up to 80% with this methodology. Only 12.5% of the recipients indicated not to be familiar at all with 4D BIM (see Fig. 22).

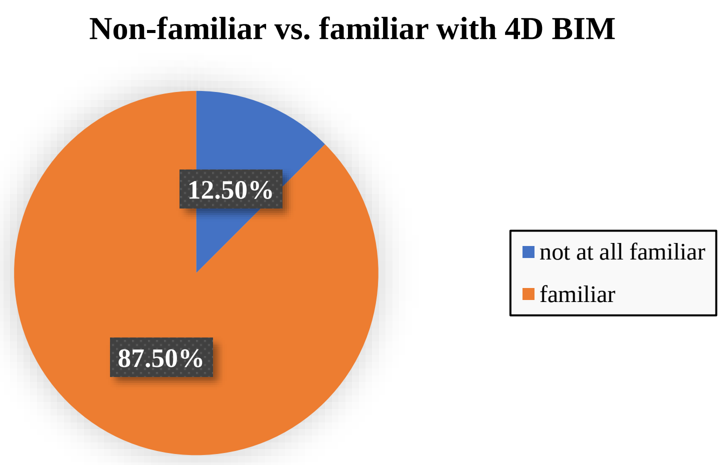


Fig. 22. 4D BIM Familiarity in the AEC Industry

Correspondingly, participants have manifested the utility of 4D BIM for one or multiple purposes (see Fig. 23).

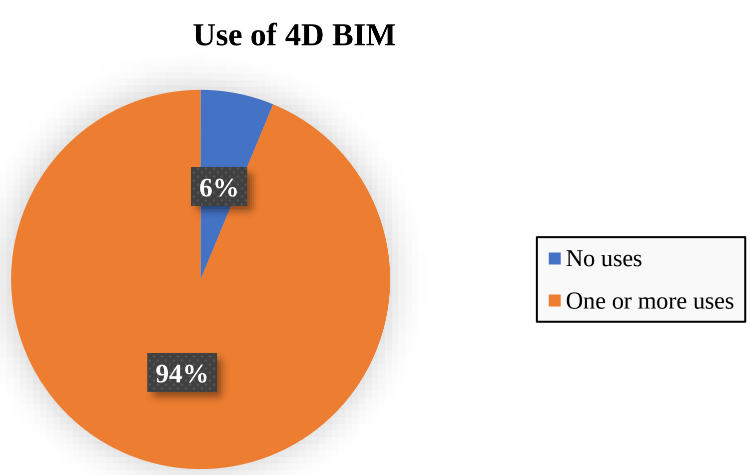


Fig. 23. 4D BIM Usage in the AEC Industry

Among the main 4D BIM uses, recipients responded that construction visualization (63%) is the most useful benefit they retrieve from 4D BIM (see Fig. 24). Other relevant answers highlight the use of this workflow for progress monitoring (45%), trades coordination (40%), constructability analysis (38%) and owner communication (33%).

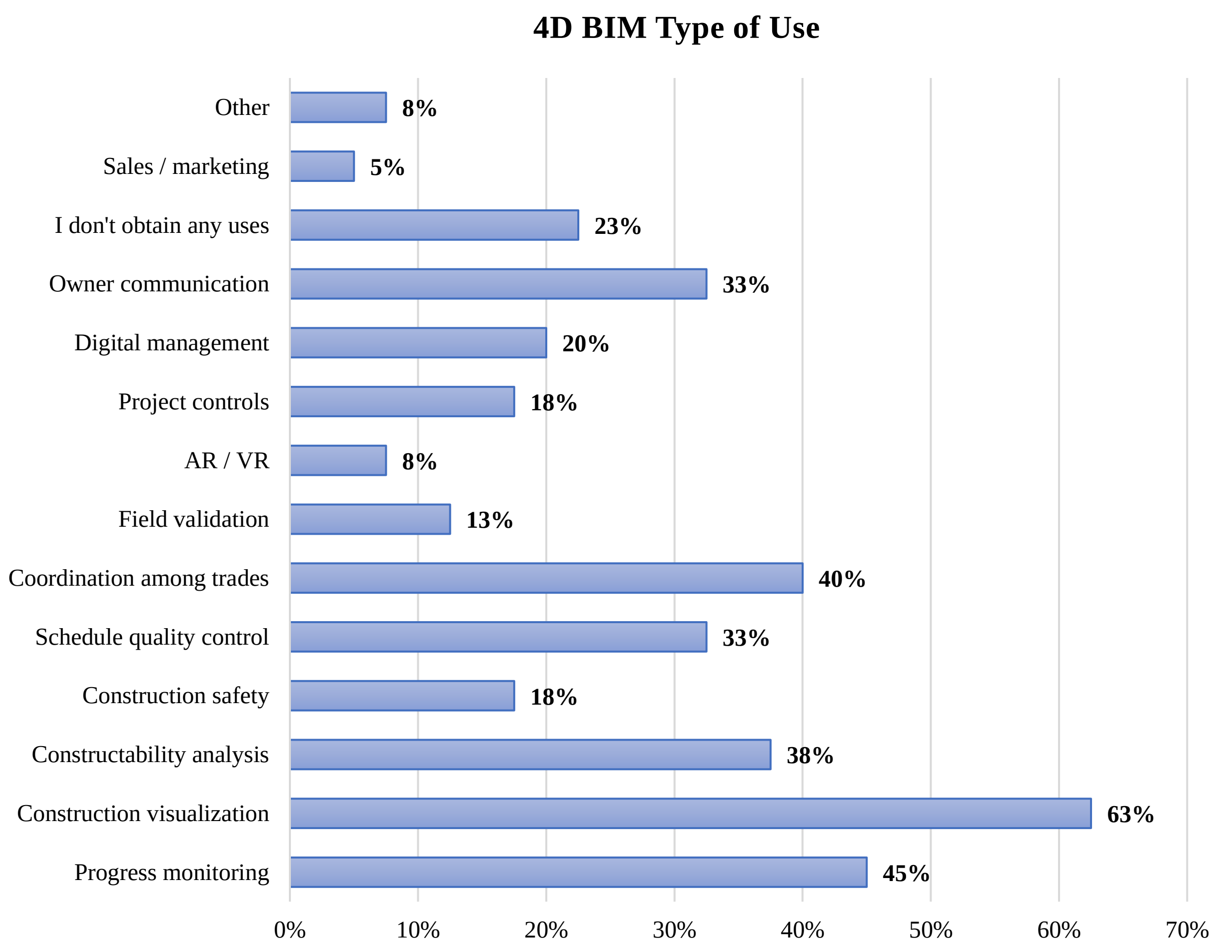


Fig. 24. 4D BIM Type of Use in the AEC Industry

Regarding the utility of 4D BIM during preconstruction and construction phases, most recipients manifested they find 4D BIM somewhat useful in both scenarios. In general, participants consider most useful 4D BIM during preconstruction than construction phase (see Fig. 25)

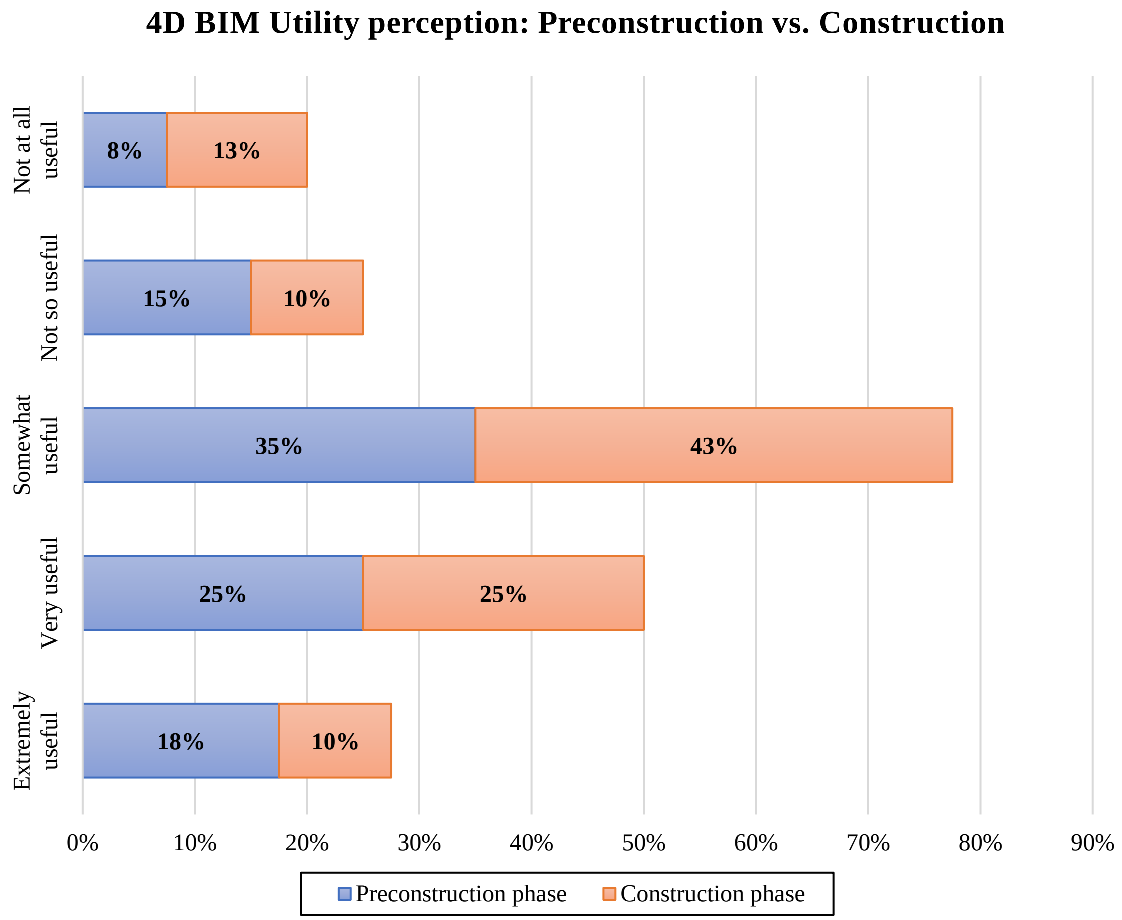


Fig. 25. Perception 4D BIM utility during Pre-construction and Construction phases in the AEC Industry

Regarding the challenges of performing 4D BIM, participants selected the *omission of various task procedures* as the most challenging process to face within 4D BIM. Furthermore, they indicated *linkage between construction activities and 3D-objects* represents highest moderate challenge. Finally, responders highlighted the *inconsistency of task names* as the least challenging part when performing workflows in 4D BIM (see Fig. 26).

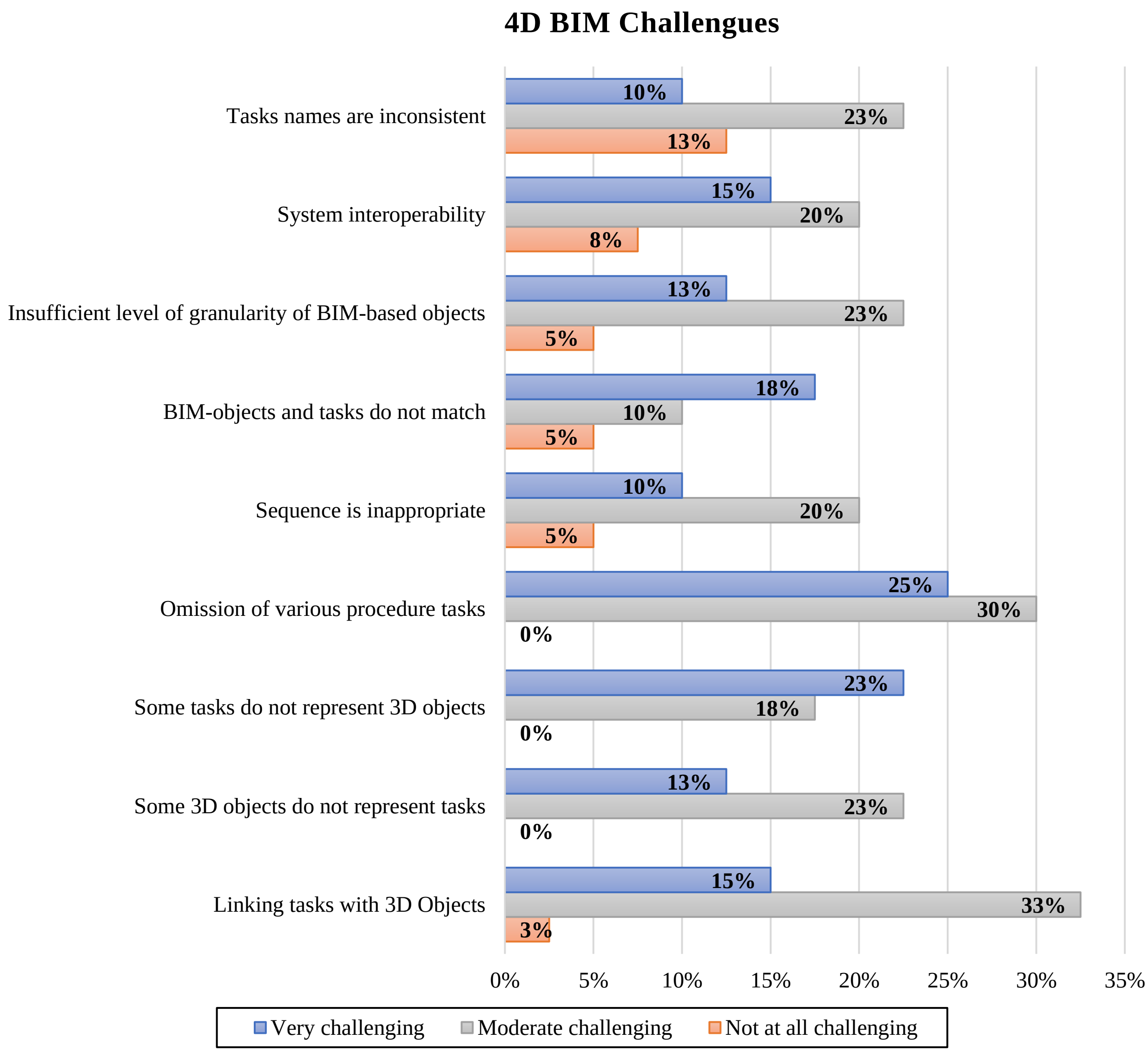


Fig. 26. Type and Level of 4D BIM Challenges in the AEC Industry

In addition, participants had the opportunity to define other challenges not addressed in Fig. 26. As a summary of responses, Table 1. shows other less frequent challenges during 4D BIM performance.

Table 1. Summary of less frequent 4D BIM challenges

Item	Challenge description
1	*Flexibility for project duration*, If it is a very long and large project, it's hard to foresee everything, so it might not be very efficient to put an effort in this project in advance. But 4D BIM would be useless over the project if it doesn't meet any required quality.
2	*Applicability to Bid-Build Public work*, there is substantial effort required to bring the project into 4D BIM. Design-Build and Engineering / Procurement / Construction (EPC) are more integrated at the design phase to reduce this barrier to entry.
3	*Lack of detail and LOD*, it needs an extreme level of precision in both BIM and schedule for optimal utility (maybe that's what is meant by granularity)
4	*Sequence arrangements*, changing conditions in sequencing, manpower and schedule make integrating the model extremely hard. For mega-jobs, in my experience the model is only a visualization or measuring tool. Very hard to have updated models of large scale that have the confidence of the whole staff. Models frequently do not even have materials tied to the BIM due to lack of transfer from design phase. 4D is much more useful to have material information than schedule
5	*Trades training*, educating trades that are not familiar with 4D coordination
6	*Trades applicability*, Does all subcontractors use 4D?
7	*Scheduling-friendly platform*, Flexibility in changing WBS as job progresses to system based

3.4 AEC Construction Scheduling & 4D BIM Improvement

Regarding the areas of improvement, the surveyed AEC experts indicated construction scheduling requires a lot of improvements for *trade coordination*. 58% of the participants selected this area as the most relevant area of improvement for scheduling workflows (Fig. 27). In addition, they voted *software interoperability* as another relevant area of improvement for this procedure.

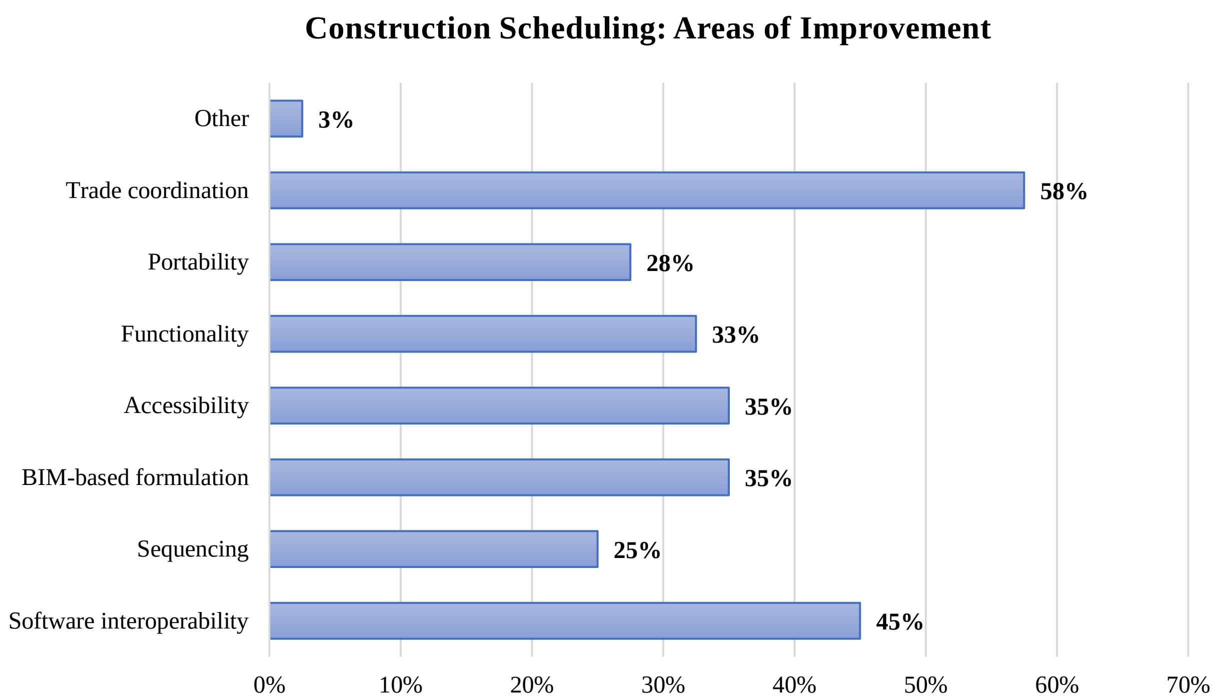


Fig. 27. Areas of Improvement of Construction Scheduling in the AEC Industry

Meanwhile, responders considered *3D / scheduling coordination* as the main area of improvement within 4D BIM workflows. Additionally, special significance was given to areas of improvement such as *task linkage procedure*, *functionality*, and *accessibility* (see Fig. 28). Other responses referred to improvements within the binding relation of 4D BIM Technology Information (TI) sources, and bandwidth accessibility.

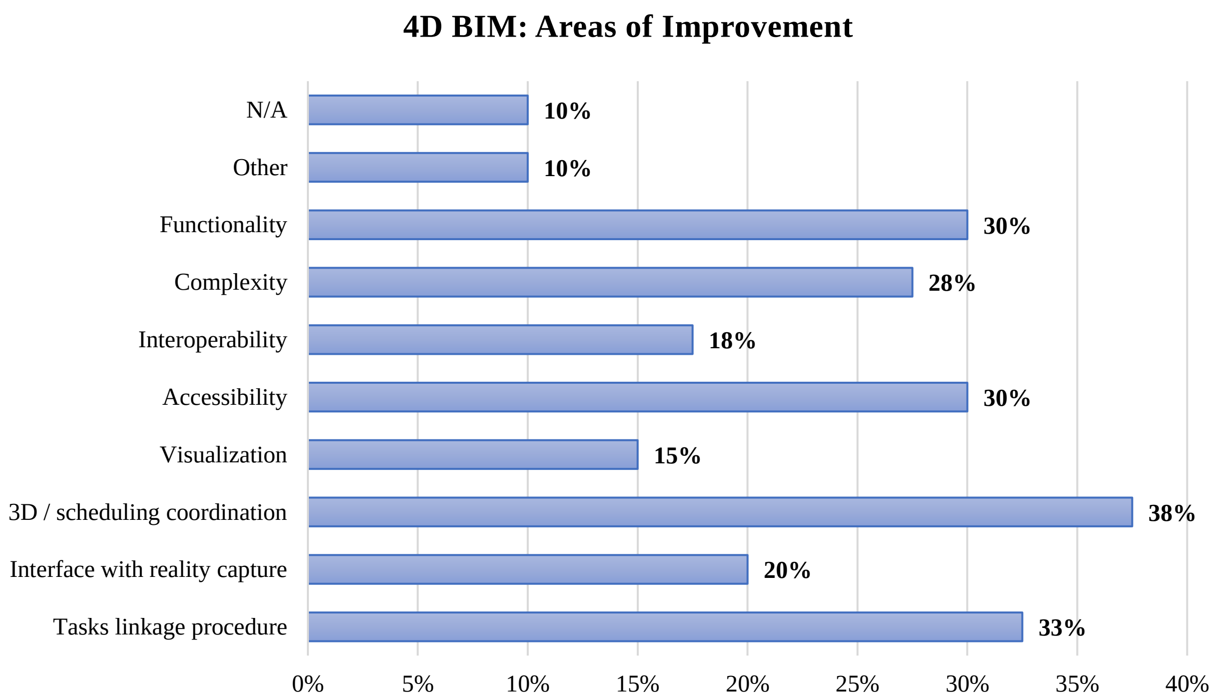


Fig. 28. Areas of Improvement of 4D BIM in the AEC Industry

Consequently, participants were asked to provide their opinions regarding their vision of construction scheduling and 4D BIM for future developments. They manifested positive inputs regarding the current utility of 4D BIM. Most importantly, they shared their perspectives regarding a widespread and more functional platform across construction trades (see Table 2.)

Table 2. Summary of vision of development in construction scheduling and 4D BIM

Item	Challenge description
1	*Functionality,* helpful during preconstruction, hard to update during construction. Useful to a large extent, reaches limits due to the need of extremely accurate input.
2	*Accessibility and shareability,* easy to access, to update and to share. 4D is extremely useful if all trades and subcontractors know how to do it. If it is only used by the BIM Manager, can be a waste of time because the rest of the team doesn't see the true value it adds.
3	*Automated scheduling,* BIM can develop an ideal schedule. In addition, software packages should be able to create a better connection between the schedule and model. Sequencing can be optimized.
4	*Operability,* if software is easy to use, implement, and share with other members of the project team, it would be more feasible to use
5	*Standardized,* industry needs a standard to measure the progress of construction. Otherwise it is a very subjective issue
6	*Reliability,* more reliable and largely compromised in refurbishment of existing buildings. Additionally, the more it is proven the benefits of driving a project through progress tracking and scheduling, the more company internal standardization of schedules will occur across the industry.
7	*Friendly interface,* a 55-year-old superintendent should be able to put together an excel 3-week schedule and pop it into the model. Furthermore, it should be done easily. People in construction is not so detail-oriented
8	*Granularity, g*etting granular with activity metrics and driving work through KPI analysis

CHAPTER 4: CONSTRUCTION SCHEDULING DATA ANALYSIS

The status quo of construction planning & scheduling and 4D BIM has been stated. Lack of master schedule / construction schedule updating is still one of the difficulties to overcome in construction operation workflows. Similarly, the current perspectives of 4D BIM still rely on construction visibility as the main use to leverage from its application. In other words, AEC members still perceive a lack of reliability in the process of fully implementation of 4D BIM. As indicated, this due to the complexity of its process in comparison with the benefits obtained. Understanding this complexity will facilitate the dissemination of further research in the field. Thus, this thesis intends to step out on understanding the complexity of construction scheduling information.

In lieu to provide a comprehensive understanding towards the automation of 4D BIM, this chapter provides a method to classify and standardize construction activities into BIM-based construction scheduling data. Achieving such standardization required the use of object-based classifiers like UniFormat^{TM}. Thousands of annotations to classify construction scheduling data were required. The methodology applied to achieve such standardization is described in the following sections.

4.1 Construction Scheduling Data

In collaboration with the Real-Time and Automated Monitoring and Control (RAAMAC) laboratory of the department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign we retrieve construction schedule information from ten different real estate projects. These projects focused their operations in building, commercial and sport facilities. The information was retrieved in ".csv" format. The source of schedule datasets has been named as listed below (see Table 3.):

Table 3. Source of schedule datasets

Item	Project
1	Clark
2	MSTR
3	Centene
4	DWP Master
5	Hill Farm
6	Mortenson
7	Saratoga
8	SandConcrete
9	WSHU
10	Stadium

The schedule information was structured into seven different column indexes. Each index represented a category of information. The categories and their organization are listed below:

0 - Activity ID, contains the code of activity systematically generated by the scheduling software utilized to formulate the construction schedule.

1 - Activity status, contains three different subcategories: Not started, In progress and Complete.

2 - WBS code, this category varies depending in the conventions utilize to code WBS. As discussed in chapter 3, this could be established according to the existing or in-house standards.

3 - WBS name, again this varies depending on the standards used in the project.

4 - Activity name, as discussed in chapter 3, it is mainly assigned by the project manager or superintendent. Practitioners do not use guides to name the activity tasks.

5 - Start, represents the as-planned o as-built start date of the activity tasks. This depends on whether the construction schedule has been updated or not.

6 – Finish, established according to the as-planned or updated as-built finish date of the construction activity.

The information contained in each of these categories represented by activity task is considered *construction scheduling data* or *scheduling data*. In other words, each construction activity is composed by a total of 7 datapoints of construction scheduling data. The scope of this study is the analysis of the column index *Activity Name*.

The timeline for the analysis of the date has been approximately 6-months (June 2018 to December 2018). Due to the large amount of data, it was necessary the creation of batches of datasets. A total of two batches was created to organize and annotate classified data progressively (see Table 5.) The batch No 1contained information retrieved from a total of 9 construction projects. This batch included a total of 15,066 construction activities (105,462 datapoints). Conversely, the data batch No 2 represented a single construction project containing a total of 10,800 activity tasks (75,600 datapoints).

A sample of the construction scheduling in shown in Table 4.

Table 4. Sample of Typical of Construction Scheduling Data Retrieved

Activity ID	Activity Status	WBS Code	(*) WBS Name	Activity Name	(*) Start	(*) Finish
MS1010	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Design Assist Subcontract Awards	30-Sep-14	05-Mar-15
MS1020	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Schematic Design	03-Nov-14	05-Mar-15
MS2000	Completed	150885-MSTR.1.15.1	Building Design & Permitting	SD Package to Kaiser		05-Mar-15
MS2010	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Design Development to 50% DD	06-Mar-15	15-May-15
MS2020	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Design Development to 100% DD	18-May-15	26-Jun-15
MS2080	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Construction Document 1st Backcheck	10-Aug-15	26-Aug-15
MS2100	Completed	150885-MSTR.1.15.1	Building Design & Permitting	C&S Package + Utilities 2nd Backcheck	18-Nov-15	26-Nov-15
MS2110	Completed	150885-MSTR.1.15.1	Building Design & Permitting	C&S Package + Utilities 2nd Backcheck Corrections/Resubmittal	19-Feb-16	19-Feb-16
MS2130	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Pull Building Permit		21-Apr-16
MS2030	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Design Development City Submittal	29-Jun-15	09-Jul-15
MS2040	Completed	150885-MSTR.1.15.1	Building Design & Permitting	Design Development City Submittal – Revised Conference Center	10-Jul-15	23-Jul-15
(…)						

A total of **25886** construction scheduling data were collected, retrieved and analyzed.

Table 5. Construction Scheduling Data batches

Item	Data Batch	No Construction Projects	No Activity Tasks
1	1	9	15066
2	2	1	10800
		Total activity tasks	25866

Preliminary, the scheduling data was distributed according to the amount of activity tasks contained. The result of this distribution is described in Table 6. As seen, the organization of the data shows ~58% of data distributed in batch No 1, and ~42% in batch No 2. Since all construction projects have different scopes, it is relevant to keep the heterogeneity of the datasets in order to avoid skewed results regarding the source of data. Although the annotations were performed according to data batches, the analysis was conducted to the overall data classified.

Table 6. Distribution of Construction Scheduling by Source

Number	Data Batch	Construction Schedule	No Data Act.	Data %
1	1	Clark	686	2.7%
2	1	MSTR	1963	7.6%
3	1	Centene	1587	6.1%
4	1	DWP Master	3993	15.4%
5	1	Hill Farm	846	3.3%
6	1	Mortenson	782	3.0%
7	1	Saratoga	83	0.3%
8	1	SandConcrete	201	0.8%
9	1	WSHU	4925	19.0%
10	2	Stadium	10800	41.8%
		Total	**25866**	

For more detail, distribution of data by course can be observed in Fig. 29.

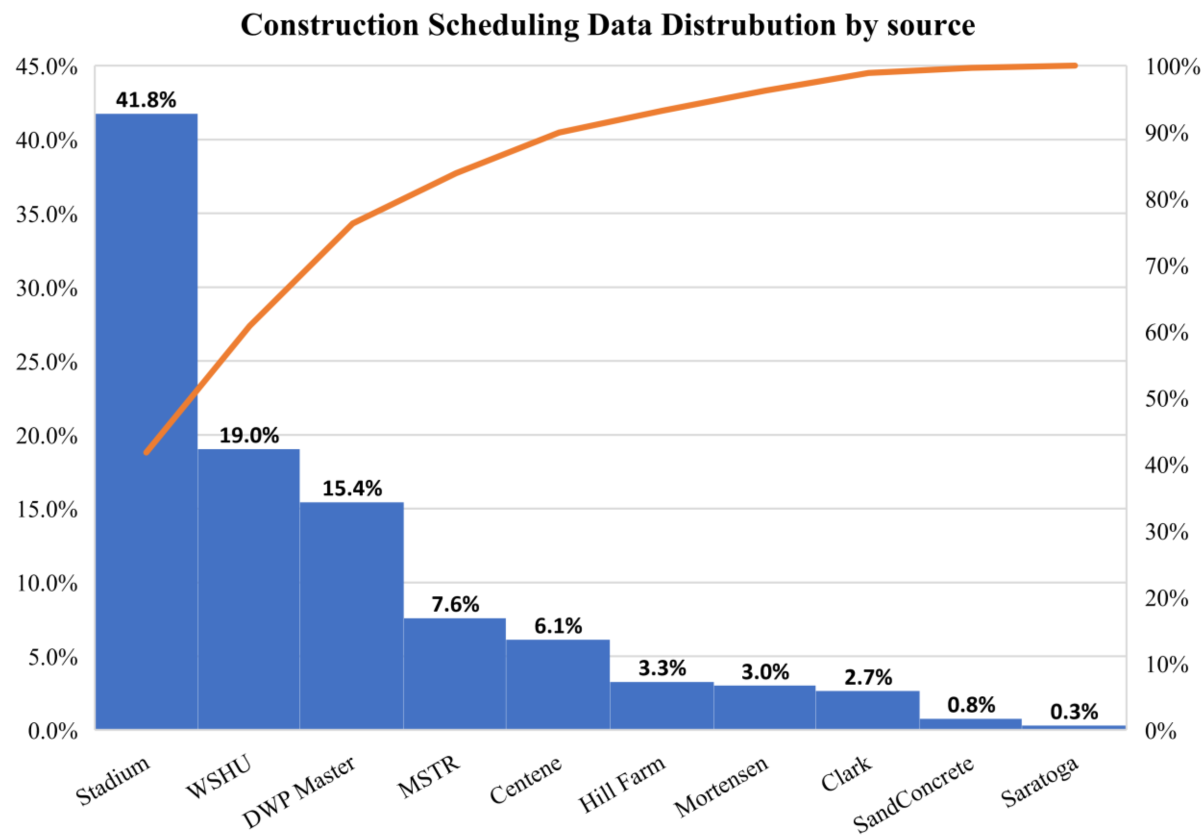


Fig. 29. Construction Scheduling Data distributed by source

4.2 UniFormat™ Data Classification

The standards utilized in this analysis correspond to CSI® UniFormat™. BIM-based elements are represented through Industry Foundation Classes (IFC) and these have relationship with the object-driven elements provided by UniFormat™ standards. For the purpose of this study, construction scheduling data will be classified according to such standards.

The classification process will be broken into five different UniFormat™ levels. Each level increases the level of detail according to the specificity of the construction schedule. A total of seven categories have been established in the first level as follows:

L1, 1 Building sitework, includes all site-related and civil work construction activities,

L1, 2 Equipment & Furnishing, contemplates all tasks for temporal equipment and furnishing to be incorporated in the jobsite,

L1, 3 Interior, includes all construction tasks to perform interior work. Finishes are included within this category,

L1, 4 Services, entails the classification of MEPF-related tasks and installation of permanent equipment,

L1, 5 Shell, includes structural, roofing, cladding and envelop work mainly

L1, 6 Special construction and demolition, entails the classification of specialty construction and all-related demolition work, and

L1, 7 Substructures, contemplates tasks aimed to the construction of foundation elements.

A total of **458** UniFormat™ standards has been annotated. The detail of the classifiers is presented below (see Table 7.):

Table 7. UniFormat^{TM} Element Class List

Item	UniFormat^{TM} Element Class
1	Building Sitework
1.1	Other Site Construction
1.1.1	Service and Pedestrian Tunnels
1.1.1.1	Pedestrian Tunnels
1.2	Site Electrical Utilities
1.2.1	Electrical Distribution
1.2.1.1	Overhead Power Distribution
1.2.1.2	Substations
1.2.1.3	Underground Power Distribution
1.2.2	Other Site Electrical Utilities
1.2.2.1	Site Emergency Power Generation
1.2.3	Site Communication and Security
1.2.4	Site Lighting
1.2.4.1	Site Fixtures & Transformers
1.2.4.2	Site Lighting Poles
1.2.4.3	Wiring Conduits & Ductbanks
1.3	Site Improvement
1.3.1	Landscaping
1.3.1.1	Fine Grading & Soil Preparation
1.3.1.2	Irrigation Systems
1.3.1.3	Other Landscape Features
1.3.1.4	Planters
1.3.1.5	Planting
1.3.1.6	Seeding & Sodding
1.3.2	Parking Lots
1.3.2.1	Curbs Gutters & Drains
1.3.2.2	Guardrails & Barriers
1.3.2.3	Painted Lines & Markings
1.3.2.4	Parking Lot Bases & Sub-Bases
1.3.2.5	Parking Lot Paving & Surfacing
1.3.2.6	Signage
1.3.3	Pedestrian Paving
1.3.3.1	Brick & Tile Plazas
1.3.3.2	Exterior Steps & Ramps
1.3.3.3	Pedestrian Bridges
1.3.3.4	Sidewalks
1.3.4	Roadways
1.3.4.1	Curbs Gutters & Drains
1.3.4.2	Curbs, Gutters & Drains
1.3.4.3	Guardrails & Barriers
1.3.4.4	Painted Lines & Markings

Table 7. (cont.)

Item	UniFormat^{TM} Element Class
1.3.4.5	Roadway Bases & Sub-Bases
1.3.4.6	Roadway Paving & Surfacing
1.3.4.7	Signage
1.3.5	Site Development
1.3.5.1	Fences & Gates
1.3.5.2	Fountains Pools & Watercourses
1.3.5.3	Fountains, Pools & Watercourses
1.3.5.4	Other Site Development
1.3.5.5	Playing Fields
1.3.5.6	Retaining Walls
1.3.5.7	Signage
1.3.5.8	Site Furnishings
1.3.5.9	Terracing & Perimeter Walls
1.3.6	Site Mechanical Utilities
1.3.6.1	Cooling Distribution
1.3.6.1.1	Chilled Water Piping
1.3.6.1.2	Cooling Towers on Site
1.3.6.1.3	Wells for Cooling/Heating
1.3.6.2	Fuel Distribution
1.3.6.2.1	Fuel Piping
1.3.6.2.2	Fuel Storage Tanks
1.3.6.3	Heating Distribution
1.3.6.3.1	Pumping Stations
1.3.6.4	Other Site Mechanical Utilities
1.3.6.5	Sanitary Sewer
1.3.6.5.1	Sewage Piping
1.3.6.6	Storm Sewer
1.3.6.6.1	Ditches & Culverts
1.3.6.6.2	Headwalls & Catch Basins
1.3.6.6.3	Retention Ponds
1.3.6.6.4	Storm Sewer Piping
1.3.6.7	Water Supply
1.3.6.7.1	Fire Protection Distribution & Storage
1.3.7	Site Preparation
1.3.7.1	Hazardous Waste Remediation
1.3.7.1.1	Other Hazardous Waste Remediation
1.3.7.1.2	Removal of Contaminated Soil
1.3.7.1.3	Soil Restoration & Treatment
1.3.7.2	Site Clearing
1.3.7.3	Site Demolition and Relocations
1.3.7.3.1	Building Demolition
1.3.7.3.2	Demolition of Site Components
1.3.7.3.3	Relocation of Buildings
1.3.7.3.4	Utilities Relocation

Table 7. (cont.)

Item	UniFormat™ Element Class
1.3.7.4	Site Earthwork
1.3.7.4.1	Borrow Fill
1.3.7.4.2	Site Grading Excavation & Disposal
1.3.7.4.3	Site Shoring
1.3.7.4.4	Soil Stabilization & Treatment
1.3.7.4.5	Utilities Trenching
2	Equipment & Furnishings
2.1	Equipment
2.1.1	Commercial Equipment
2.1.1.1	Office Equipment
2.1.1.2	Security & Vault Equipment
2.1.1.2.1	Security Equipment
2.1.2	Institutional Equipment
2.1.2.1	Audio-visual Equipment
2.1.2.2	Medical Equipment
2.1.2.2.1	X-ray Equipment
2.1.2.3	Other Institutional Equipment
2.1.2.4	Theater & Stage Equipment
2.1.3	Other Equipment
2.1.3.1	Food Service Equipment
2.1.3.1.1	Food Service - Appliances & Equipment
2.1.3.1.2	Food Service - Cabinets & Countertops
2.1.3.2	Maintenance Equipment
2.1.3.3	Other Equipment
2.1.3.4	Solid Waste Handling Equipment
2.1.3.5	Window Washing Equipment
2.1.4	Vehicular Equipment
2.1.4.1	Loading Dock Equipment
2.1.4.1.1	loading dock equipment
2.1.4.2	Parking Control Equipment
2.1.5	Wall Finishes
2.1.5.1	Wall Finishes
2.1.5.1.1	Wall Finishes - Paint
2.2	Furnishings
2.2.1	Fixed Furnishings
2.2.1.1	Fixed Casework
2.2.1.2	Window Treatments
2.2.1.2.1	Window Treatments - Blinds
2.2.2	Moveable Furnishings
2.2.2.1	Furniture & Accessories
2.2.2.2	Movable Multiple Seating
3	Interiors
3.1	Interior Construction

Table 7. (cont.)

Item	UniFormat™ Element Class
3.1.1	Fittings
3.1.1.1	Bath & Toilet Accessories
3.1.1.1.1	Bath & Toilet Accessories - Commercial
3.1.1.2	Fabricated Cabinets & Counters
3.1.1.2.1	Cabinets
3.1.1.3	Fabricated Compartments & Cubicles
3.1.1.3.1	Toilet Partitions
3.1.1.4	Identifying/Visual Aid Specialties
3.1.1.4.1	Chalkboards & Whiteboards
3.1.1.4.2	Signs
3.1.1.5	Internal Traffic Protection Aids
3.1.1.5.1	Turnstiles
3.1.1.6	Storage Specialties
3.1.1.6.1	Lockers
3.1.2	Interior Doors
3.1.2.1	Interior Door Frames
3.1.2.1.1	Interior Door Frames - Metal
3.1.2.1.2	Interior Door Frames - Wood
3.1.2.2	Interior Door Hardware
3.1.2.2.1	Door Hardware
3.1.2.3	Interior Door Wall Opening Elements
3.1.2.4	Interior Doors
3.1.2.4.1	Interior Doors - Wood
3.1.2.5	Interior Doors with Frames
3.1.3	Partitions
3.1.3.1	Fixed Partitions
3.1.3.1.1	Ext. Wall - CMU
3.1.3.1.2	Partition Components - Drywall
3.1.3.1.3	Partition Components - Metal Framing
3.1.3.1.4	Partition Components - Wood Framing
3.1.3.1.5	Partitions - CMU
3.1.3.1.6	Partitions - Drywall w/ Metal Stud
3.1.3.1.7	Partitions - Drywall w/ Wood Stud
3.1.3.1.8	Partitions - Glass Block
3.1.3.1.9	Partitions - Stone Veneer w/ Stud
3.1.3.1.10	Partitions - Tile
3.1.3.2	Interior Windows & Storefronts
3.1.3.2.1	Interior Glazed Openings
3.1.3.3	Retractable Partitions
3.1.3.3.1	Partitions - Folding
3.2	Interior Finishes
3.2.1	Ceiling Finishes
3.2.1.1	Applied Ceiling Finishes
3.2.1.1.1	Ceiling Finishes - Coatings

Table 7. (cont.)

Item	UniFormat™ Element Class
3.2.1.1.2	Ceiling Finishes - Coverings
3.2.1.1.3	Ceiling Finishes - Paint
3.2.1.1.4	Ceiling Finishes - Paneling
3.2.1.1.5	Ceiling Finishes - Tile
3.2.1.2	Drywall & Plaster Ceiling Components
3.2.1.2.1	Ceiling Components - Drywall
3.2.1.3	Other Ceiling Finishes
3.2.1.4	Suspended Ceilings
3.2.1.4.1	Suspended Ceilings - Acoustical
3.2.1.4.2	Suspended Ceilings - Gypsum Board
3.2.2	Floor Finishes
3.2.2.1	Access Pedestal Flooring
3.2.2.2	Bases Curbs & Trim
3.2.2.2.1	Base - Vinyl & Rubber
3.2.2.3	Bases, Curbs & Trim
3.2.2.4	Floor Toppings & Coatings
3.2.2.5	Flooring
3.2.2.5.1	Flooring - Other
3.2.2.5.2	Flooring - Terrazzo
3.2.2.5.3	Flooring - Tile
3.2.2.5.4	Flooring - Wood
3.2.2.6	Hardeners & Sealers
3.2.2.7	Traffic Membranes
3.2.3	Wall Finishes
3.2.3.1	Column Finishes
3.2.3.2	Wall Finishes
3.2.3.2.1	Wall Finishes - Coverings
3.2.3.2.2	Wall Finishes - Paint
3.2.3.2.3	Wall Finishes - Paneling
3.2.3.2.4	Wall Finishes - Tile
3.3	Stairs
3.3.1	Stair Construction
3.3.1.1	Regular Stairs
3.3.1.1.1	Stairs - CIP
3.3.1.1.2	Stairs - Precast
3.3.1.1.3	Stairs - Steel
3.3.1.1.4	stairs - wood
3.3.1.2	Stair Handrails/Balustrades
3.3.2	Stair Finishes
3.3.2.1	Stair Handrail & Balustrade Finishes
4	Services
4.1	Conveying
4.1.1	Elevators and Lifts
4.1.1.1	Freight Elevators

Table 7. (cont.)

Item	UniFormat™ Element Class
4.1.1.1.1	Elevators - Freight
4.1.1.2	Passenger Elevators
4.1.1.2.1	Elevators - Hydraulic
4.1.2	Escalators and Moving Walks
4.1.2.1	Moving Walks
4.1.2.1.1	Moving Walks
4.1.3	Other Conveying Systems
4.1.3.1	Hoists & Cranes
4.2	Electrical
4.2.1	Communications and Security
4.2.1.1	Data Networking
4.2.1.2	Fire Alarm Systems
4.2.4.3	Intercommunication & Paging Systems
4.2.4.4	Security & Detection Systems
4.2.4.5	Telephone Systems
4.2.2	Electrical Service/Distribution
4.2.2.1	High Tension Service & Distribution
4.2.2.2	Low Tension Service & Distribution
4.2.3	Lighting and Branch Wiring
4.2.3.1	Branch Wiring & Devices
4.2.3.1.1	Receptacles - Floor
4.2.3.1.2	Receptacles - Wall
4.2.3.2	Lighting Equipment
4.2.4	Other Electrical Systems
4.2.4.1	Floor Raceway Systems
4.2.4.2	General Construction Items (Elect.)
4.2.4.3	Grounding Systems
4.2.4.4	Misc. Other Electrical Systems
4.3	Fire Protection
4.3.1	Fire Protection Specialties
4.3.1.1	Fire Extinguisher Cabinets
4.3.1.2	Other Fire Protection Specialties
4.3.2	Other Fire Protection Systems
4.3.2.1	Clean Agent System
4.3.2.2	Hood & Duct Fire Protection
4.3.2.3	Misc. Other Fire Protection Systems
4.3.3	Sprinklers
4.3.3.1	Sprinkler Water Supply
4.3.3.2	Wet Sprinkler Systems
4.3.4	Standpipes
4.3.4.1	Pumping Equipment
4.4	HVAC
4.4.1	Controls & Instrumentation
4.4.1.1	Building Automation Systems

Table 7. (cont.)

Item	UniFormat^{TM} Element Class
4.4.1.2	Energy Monitoring & Control
4.4.1.3	Exhaust & Ventilating Systems
4.4.1.4	Heating Generating Systems
4.4.1.5	Heating/Cooling Air Handling Units
4.4.2	Cooling Generating Systems
4.4.2.1	Direct Expansion Systems
4.4.2.2	Other Cooling System Components
4.4.3	Distribution Systems
4.4.3.1	Exhaust Ventilation Systems
4.4.4	Energy Supply
4.4.4.1	Hot Water Supply System
4.4.5	Heat Generating Systems
4.4.5.1	Boilers
4.4.5.2	Insulation
4.4.6	Other HVAC Systems/Equip
4.4.6.1	General Construction Items (HVAC)
4.4.6.2	Misc. Other HVAC Systems & Equipment
4.4.7	Systems Testing & Balancing
4.4.7.1	Air System Testing & Balancing
4.4.7.2	HVAC Commissioning
4.4.7.3	Other System Testing & Balancing
4.4.7.4	Piping System Testing & Balancing
4.4.8	Terminal & Package Units
4.5	Plumbing
4.5.1	Domestic Water Distribution
4.5.1.1	Cold Water Service
4.5.1.2	Hot Water Service
4.5.2	Other Plumbing Systems
4.5.2.1	Gas Distribution
4.5.2.2	Misc. Other Plumbing Systems
4.5.2.3	Piping & Fittings
4.5.3	Plumbing Fixtures
4.5.3.1	Lavatories
4.5.3.1.1	Lavatories - Single
4.5.3.2	Showers
4.5.3.2.1	Showers
4.5.3.3	Sinks
4.5.3.4	Water Closets
4.5.3.4.1	Water Closets - Single
4.5.4	Rain Water Drainage
4.5.4.1	Pipe Insulation
4.5.4.2	Roof Drains
4.5.5	Sanitary Waste
4.5.5.1	Floor Drains

Table 7. (cont.)

Item	UniFormat™ Element Class
4.5.5.2	Pipe Insulation
4.5.5.3	Waste Piping
5	Shell
5.1	Exterior Enclosure
5.1.1	Exterior Doors
5.1.1.1	Door Wall Opening Elements
5.1.1.2	Glazed Doors & Entrances
5.1.1.2.1	Exterior Glazed Doors - Aluminum
5.1.1.3	Other Exterior Doors
5.1.1.4	Overhead Doors & Roll-up Grilles
5.1.1.4.1	Overhead Doors
5.1.1.5	Revolving Doors
5.1.2	Exterior Walls
5.1.2.1	Balcony Walls & Handrails
5.1.2.2	Exterior Louvers Screens & Fencing
5.1.2.3	Exterior Louvers, Screens & Fencing
5.1.2.4	Exterior Soffits
5.1.2.5	Exterior Wall Construction
5.1.2.5.1	Ext. Wall - CIP
5.1.2.5.2	Ext. Wall - CMU
5.1.2.5.3	Ext. Wall - Metal Siding Panels
5.1.2.5.4	Ext. Wall - Precast
5.1.2.5.5	Ext. Wall - Stone Veneer w/ Stud
5.1.2.5.6	Ext. Wall - Wood Stud w/ Stucco
5.1.2.6	Parapets
5.1.2.7	Standard Slab on Grade
5.1.3	Exterior Windows
5.1.3.1	Curtain Walls
5.1.3.1.1	Curtain Walls - Framing
5.1.3.1.2	Curtain Walls - Panels
5.1.3.2	Exterior Windows
5.1.3.2.1	Curtain Walls
5.1.3.3	Storefronts
5.1.3.4	Windows
5.1.3.4.1	Windows - Aluminum
5.2	Roofing
5.2.1	Roof Coverings
5.2.1.1	Gutters & Downspouts
5.2.1.2	Roof Eaves & Soffits
5.2.1.3	Roof Finishes
5.2.1.3.1	Roofing - Built-up
5.2.1.3.2	roofing - formed metal
5.2.1.3.3	Roofing - Preformed Metal
5.2.1.3.4	Roofing - Shingle & Tile

Table 7. (cont.)

Item	UniFormat™ Element Class
5.2.1.3.5	Roofing - Single Ply Membrane
5.2.1.4	Roof Flashing & Trim
5.2.1.4.1	Base Flashing
5.2.1.4.2	Roof Flashing
5.2.1.5	Roof Insulation & Fill
5.2.1.5.1	Roof Insulation - Rigid
5.2.1.6	Traffic Toppings & Paving Membranes
5.3	Superstructure
5.3.1	Floor Construction
5.3.1.1	Fireproofing - Floor Construction
5.3.1.1.1	Steel Beam Fireproofing
5.3.1.2	Floor Raceway Systems
5.3.1.3	Upper Floor Framing - Horizontal Elements
5.3.1.3.1	Beams - CIP
5.3.1.3.2	Beams - Precast
5.3.1.3.3	Beams - Steel
5.3.1.3.4	Deck - Metal
5.3.1.3.5	Planks - Precast
5.3.1.3.6	upper floor framing - horizontal elements
5.3.1.4	Upper Floor Framing - Systems
5.3.1.4.1	CIP Beam & Slab - Two Way
5.3.1.4.2	CIP Slabs - Flat Plate
5.3.1.4.3	Composite Beam & Slab
5.3.1.4.4	Composite Beam Deck & Slab
5.3.1.4.5	Composite Beam, Deck & Slab
5.3.1.4.6	Steel Beams w/ Steel Joists
5.3.1.4.7	Steel Girders w/ Steel Beams
5.3.1.4.8	W Shape Composite Deck & Slab
5.3.1.5	Upper Floor Framing - Vertical Elements
5.3.1.5.1	Bearing Walls - Block
5.3.1.5.2	Bearing Walls - CIP
5.3.1.5.3	Columns - CIP
5.3.1.5.4	Columns - Precast
5.3.1.5.5	Columns - Steel
5.3.2	Roof Construction
5.3.2.1	Canopies
5.3.2.2	Fireproofing - Roof Construction
5.3.2.2.1	Steel Beam Fireproofing
5.3.2.3	Flat Roof Framing - Horizontal Elements
5.3.2.3.1	Beams - Steel
5.3.2.3.2	Deck - Metal
5.3.2.3.3	Joists - Steel
5.3.2.4	Flat Roof Framing - Systems
5.3.2.4.1	CIP Slabs - Flat Plate

Table 7. (cont.)

Item	UniFormat™ Element Class
5.3.2.4.2	Composite Beam, Deck & Slab
5.3.2.5	Flat Roof Framing - Vertical Elements
5.3.2.5.1	Bearing Walls - Block
6	Special Construction & Demolition
6.1	Selective Building Demolition
6.1.1	Building Elements Demolition
6.1.1.1	Building Exterior Demolition
6.1.1.2	Building Interior Demolition
6.2	Special Construction
6.2.1	Special Construction Systems
6.2.1.1	Special Security Systems
6.2.2	Special Controls & Instrumentation
6.2.2.1	Building Automation Systems
6.2.2.2	Other Special Control& Instrumentation
6.2.3	Special Facilities
6.2.3.1	Aquatic Facilities
6.2.3.2	Liquid & Gas Storage Tanks
6.2.3.3	Other Special Facilities
6.2.4	Special Structures
6.2.4.1	Other Special Structures
7	Substructure
7.1	Basement Construction
7.1.1	basement construction
7.1.1.1	basement construction
7.1.1.1.1	basement construction
7.1.2	Basement Excavation
7.1.2.1	Excavation for Basements
7.1.2.1.1	Basement Excavation & Backfill
7.1.2.2	Shoring
7.1.2.2.1	Shoring
7.1.2.3	Structural Backfill & Compaction
7.1.3	Basement Walls
7.1.3.1	Basement Wall Construction
7.1.3.1.1	Basement Walls - CIP
7.1.3.2	Moisture Protection
7.1.3.2.1	Foundation Dam proofing
7.2	Foundations
7.2.1	Slab on Grade
7.2.1.1	Pits & Bases
7.2.1.2	Standard Slab on Grade
7.2.1.2.1	SOG - Reinforced
7.2.1.2.2	SOG - Unreinforced
7.2.1.3	structural slab on grade

Table 7. (cont.)

Item	UniFormat™ Element Class
7.2.1.3.1	structural slab on grade
7.2.1.4	Under-Slab Drainage
7.2.1.5	Under-Slab Insulation
7.2.1.5.1	Sub drainage Piping
7.2.2	Special Foundations
7.2.2.1	Caissons
7.2.2.2	Dewatering
7.2.2.3	Grade Beams
7.2.2.3.1	Grade Beams - CIP
7.2.2.4	Other Special Foundation Conditions
7.2.2.5	Pile Foundations
7.2.2.5.1	Piles - CIP
7.2.2.6	Pressure Injected Grouting
7.2.2.7	Raft Foundations
7.2.3	Standard Foundations
7.2.3.1	Footings & Pile Caps
7.2.3.1.1	Strip Footings
7.2.3.2	Foundation Walls
7.2.3.2.1	Foundation Walls - CIP
7.2.3.3	Perimeter Drainage
7.2.3.3.1	Footing Drains
7.2.3.3.2	Footings & Pile Caps

4.3 *Data Analysis*

The intent of this methodology is the analysis of *BIM-based construction scheduling data*. For the scope of this study, BIM-based construction scheduling data analyze is the result of two types of information: construction scheduling data and object-driven standards (see Fig. 30). The combination of both variables provides a framework of object-driven tasks that can leveraged through data analytics and IFC ontologies towards the generation of predictive and automated BIM-based schedules. Training this data can provide substantial development in big data analytics and 4D BIM.

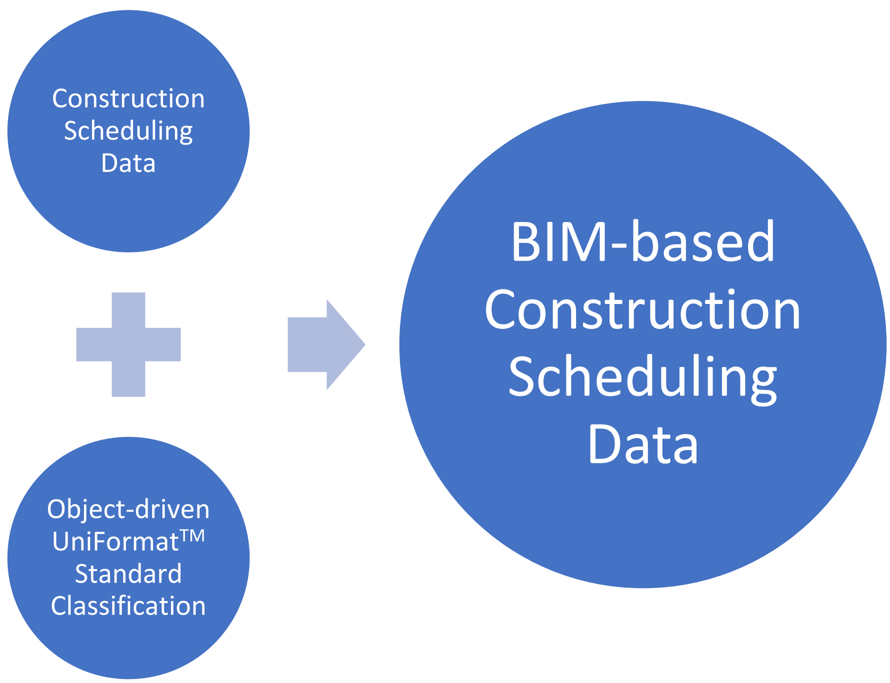


Fig. 30. Definition of BIM-based construction scheduling data

The methodology utilized to analyze the data entails the completion of three different procedures: 1) data collection, 2) data characterization, and 3) BIM-based data (see Fig. 31). Each of these stages requires the compliance of different tasks. *Data collection* contemplates the retrieval of schedule information and data structures processes to organize it; *Data characterization* entails the annotation of classified data according to established standards, in our case, UniFormat^{TM} standard classification; and *BIM-based data* which includes the validation of the classified data through peer review and the analysis of frequencies of BIM-based data. Upon completion of this workflow, BIM-based data is presented to be trained for data analytics purposes.

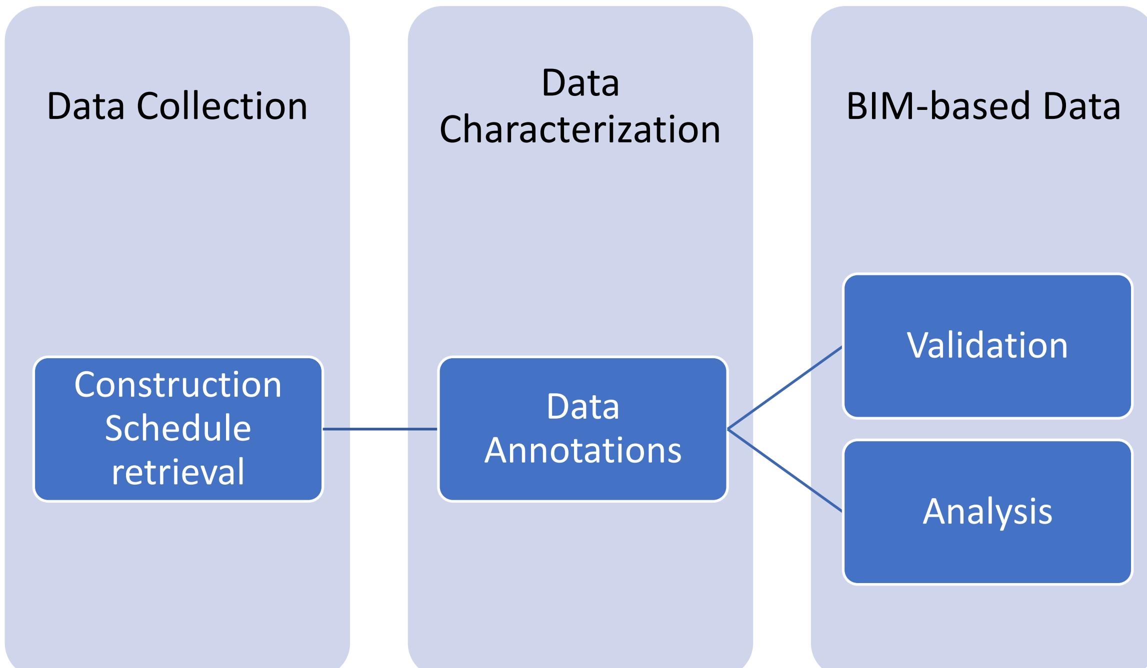


Fig. 31. Construction Scheduling Data Analysis workflow

Special emphasis is required for data characterization procedure. The annotation of classified data required a specific retrofit workflow. This depends on the level of detail or granularity of the retrieved construction schedules. In other words, while non-BIM-based activity tasks were not contemplated in the annotation process, BIM-based activity tasks were fully adapted to the highest level of detail according to their granularity (see. Fig. 32).

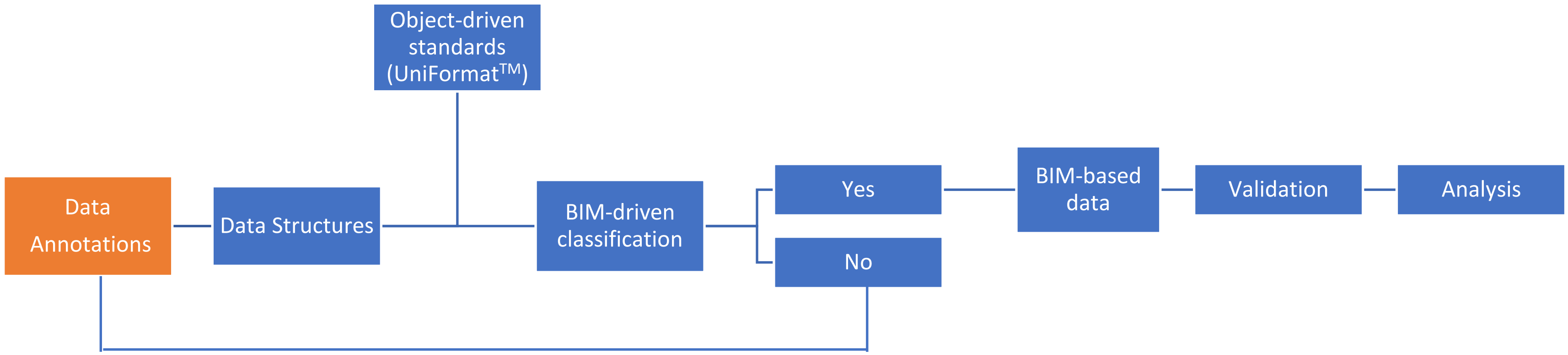


Fig. 32. Construction Scheduling Data Annotations process.

Similarly, the process of data validation required peer review to establish error-prone annotations. This procedure included:

1) filtered annotation review, errors were reduced by applying filters to select the annotated UniFormat™ classes. By executing this action, inconsistencies in annotations where found and solved,

2) *selection of inconsistent data*, inconsistencies within the annotations were found. These were isolated and corrected. Some of these inconsistencies relied in the lack of granularity provided by scheduling data. Scenarios like multiple types of activity tasks for a single classifier, or, multiple classifiers for a single activity tasks were selected and modified,

3) *modification of scheduling data annotations*, all inconsistencies due to errors in annotation, or lack of granularity of the information were modified and updated. Once this step was completed, data was ready to be analyzed.

A typical sample of the annotations performed is shown in Table 8. As observed, in one hand activity tasks with lack of granularity such as "***in wall electric RI 3rd lift-w tower-level 04-utility room***" were classified as object-driven activities for level 2: "***D50 Electrical***". On the other hand, activity tasks like "***layout CMU-w tower-level 04-utility room***" included enough level of detail to be classified as level 5: "***B2010140 Ext. Wall CMU***" in the UniFormat™ category. Difficulties with several types of non-standardized abbreviations count as one the challenges during the performance of data annotation.

Table 8. Sample of Annotation process for UniFormat™ standard classification

Construction Scheduling Data							UniFormat™ Classification for Construction Scheduling Data									
							LEVEL 1		LEVEL 2		LEVEL 3		LEVEL 4		LEVEL 5	
Activ. ID	Activ. Status	WBS Code	(*) WBS Name	Activity Name	(*) Start	(*) Finish	No	Descript.	No	Descript.	No	Descript.	No	Descript.	No	Descript.
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	IN WALL ELECTRIC RI 3RD LIFT-W TOWER-LEVEL 04-UTILITY ROOM	25-Sep-17	27-Sep-17	D	Services	D50	Electrical						
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	SET DOOR FRAMES 3RD LIFT-W TOWER-LEVEL 04-UTILITY ROOM	25-Sep-17	27-Sep-17	B	Shell	B20	Exterior Enclosure	B2030	Exterior Doors	B2030500	Door Wall Opening Elements		
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	IN WALL PLUMBING RI 3RD LIFT-W TOWER-LEVEL 04-UTILITY ROOM	25-Sep-17	27-Sep-17	D	Services	D20	Plumbing						
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	SET EMBEDS 3RD LIFT-W TOWER-LEVEL 04-UTILITY ROOM	25-Sep-17	27-Sep-17	B	Shell	B10	Superstructure	B1010	Floor Construction				
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	INSTALL REBAR 3RD LIFT-W TOWER-LEVEL 04-UTILITY ROOM	25-Sep-17	27-Sep-17	B	Shell	B10	Superstructure	B1010	Floor Construction	B1010200	Upper Floor Framing - Vertical Elements		
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	GROUT 3RD LIFT-W TOWER-LEVEL 04-UTILITY ROOM	28-Sep-17	28-Sep-17	B	Shell	B10	Superstructure	B1010	Floor Construction				
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	LAYOUT CMU-W TOWER-LEVEL 04-UTILITY ROOM	11-Sep-17	12-Sep-17	B	Shell	B20	Exterior Enclosure	B2010	Exterior Walls	B2010100	Exterior Wall Construction	B2010140	Ext. Wall - CMU
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	LAYUP CMU 1ST LIFT-W TOWER-LEVEL 04-UTILITY ROOM	13-Sep-17	15-Sep-17	B	Shell	B20	Exterior Enclosure	B2010	Exterior Walls	B2010100	Exterior Wall Construction	B2010140	Ext. Wall - CMU
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	IN WALL ELECTRIC RI 1ST LIFT-W TOWER-LEVEL 04-UTILITY ROOM	13-Sep-17	15-Sep-17	D	Services	D50	Electrical						
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	SET DOOR FRAMES-W TOWER-LEVEL 04-UTILITY ROOM	13-Sep-17	15-Sep-17	B	Shell	B20	Exterior Enclosure	B2030	Exterior Doors	B2030500	Door Wall Opening Elements		
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	IN WALL PLUMBING RI 1ST LIFT-W TOWER-LEVEL 04-UTILITY ROOM	13-Sep-17	15-Sep-17	D	Services	D20	Plumbing						
	Not Started	113438MSTR.CN.P111.11.3.2.4.5	Utility Room-Level 04	IN WALL ELECTRIC RI 2ND LIFT-W TOWER-LEVEL 04-UTILITY ROOM	19-Sep-17	21-Sep-17	D	Services	D50	Electrical						

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Results

A total of **25,866** construction activities precedent from ten different construction projects have been analyzed. A total of **77% of scheduling data was classified as BIM-based** (see Fig. 33). The non-object-driven activity tasks presented a lack of granularity and object-oriented representation.

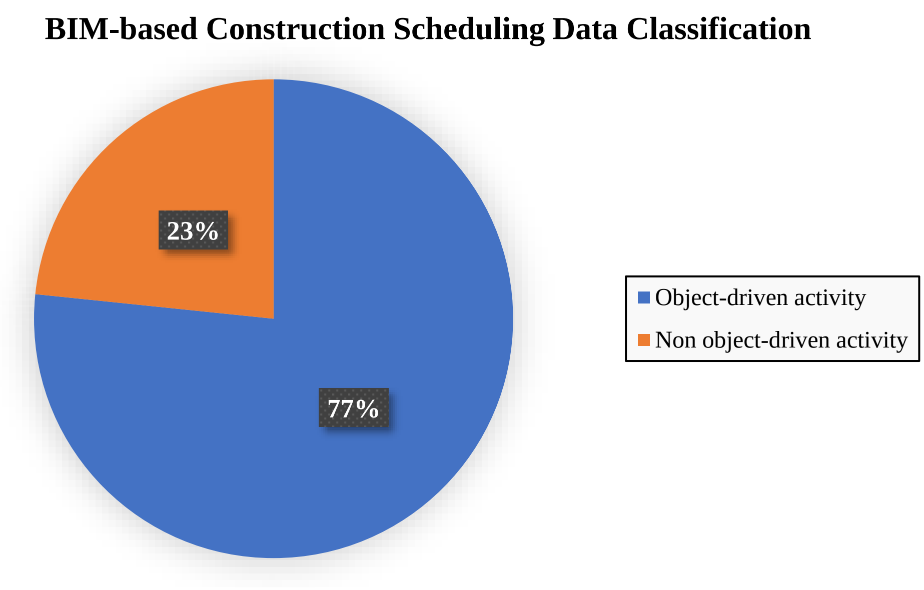


Fig. 33. BIM-based Construction Scheduling Data

In the analysis of BIM-based classification by level and by source (see Fig. 34), results show **consistency in the granularity of scheduling data for level 1 through 4**. In other words, among the BIM-based data, construction activities by different source present consistent level of detail up to level of classification 4. In addition, results indicate **variability of consistency in level 5** by source. Only one data source achieved high level of detail at the highest level of standard classification. In terms of individual analysis by data source, **3 out 10 (30%) datasets presented more than 90% of BIM-based tasks** whereas other sources kept BIM-based elements near to the total average indicated in Fig. 33.

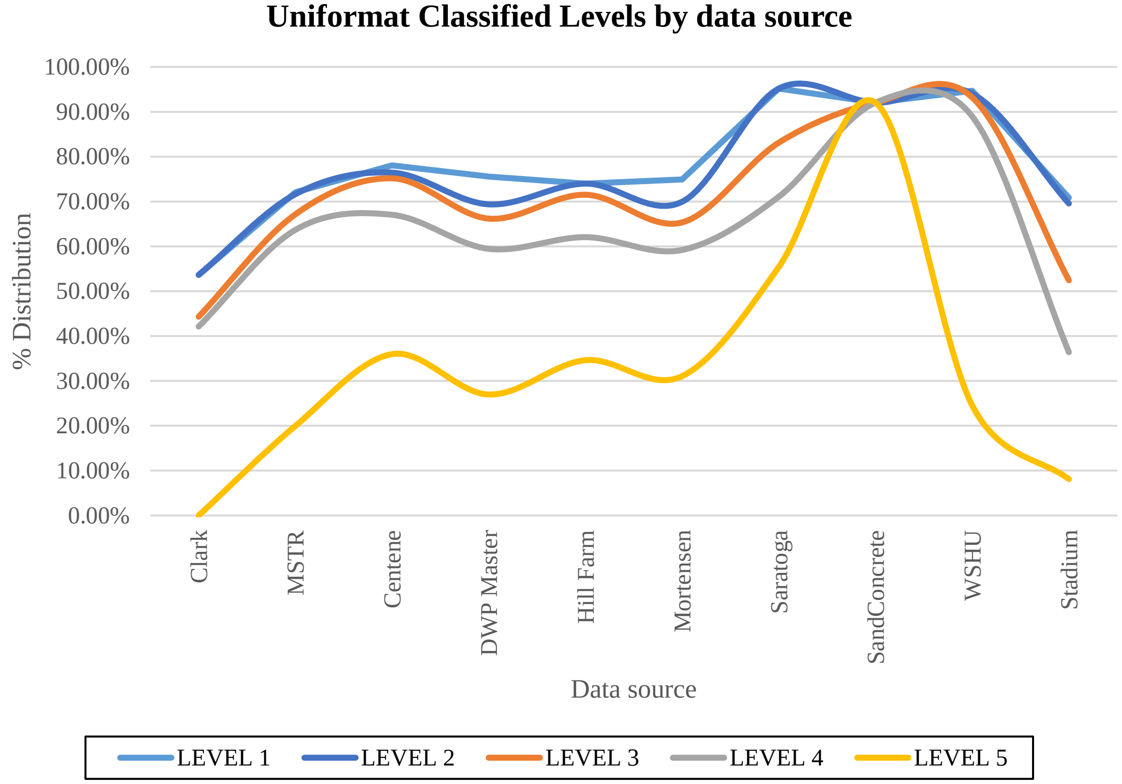


Fig. 34. Uniformat Level Classification for Construction Scheduling Data by source

In general, scheduling data presents different levels of BIM-based tasks for different levels of detail. The higher level of detail, the lower BIM-driven relationship. Among the total of data, **levels of classification 1 and 2 presented the highest rates of BIM-based activity tasks frequency**. Indeed, these levels show consistent granularity for UniFormat^{TM} standard classification (see Fig. 35). Special emphasis requires the frequency achieved in level 5 of classification. **Only 19% of BIM-driven data presents high level of detail** during the classification process.

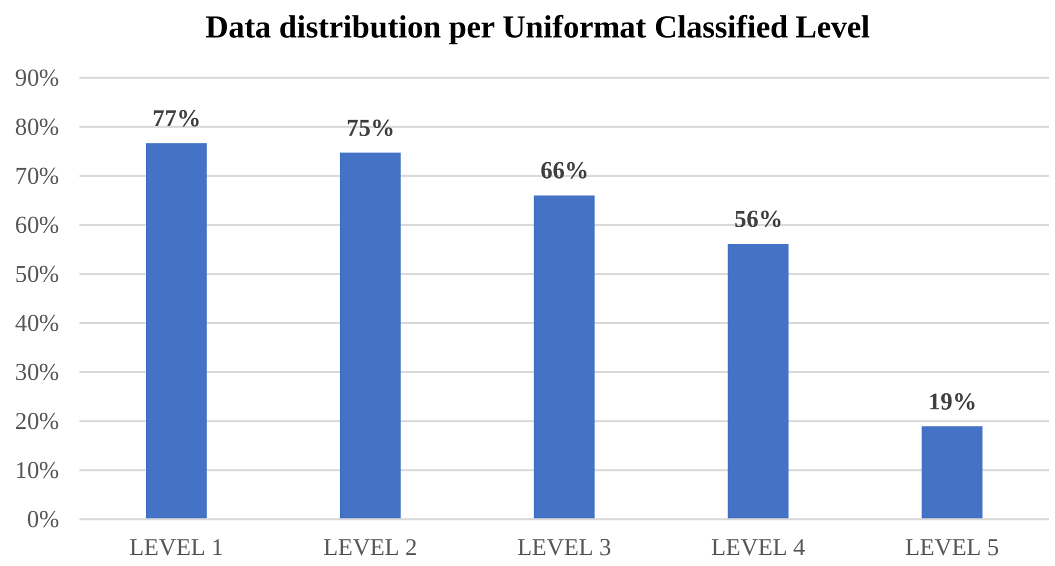


Fig. 35. Distribution of BIM-based Construction Scheduling Data by UniFormat^{TM} Level Classification

By levels of BIM-based standardization, the frequency of activity tasks also showed remarkable results. In Level 1, a total of **19,823** construction activities have been annotated and analyzed. Results show that **most BIM-based construction scheduling data (39.62%) is related to services** (see Fig. 36). This category entails the highest number of BIM-based tasks during construction. In other words, construction activities such as MEPF are more BIM-based oriented in comparison with other activity tasks. Categories like shell and interiors also count with significant quantity of BIM-based tasks. On the other hand, as reasonably expected, categories such as **special construction and demolition count with the least number of BIM-based tasks (0.38%)**.

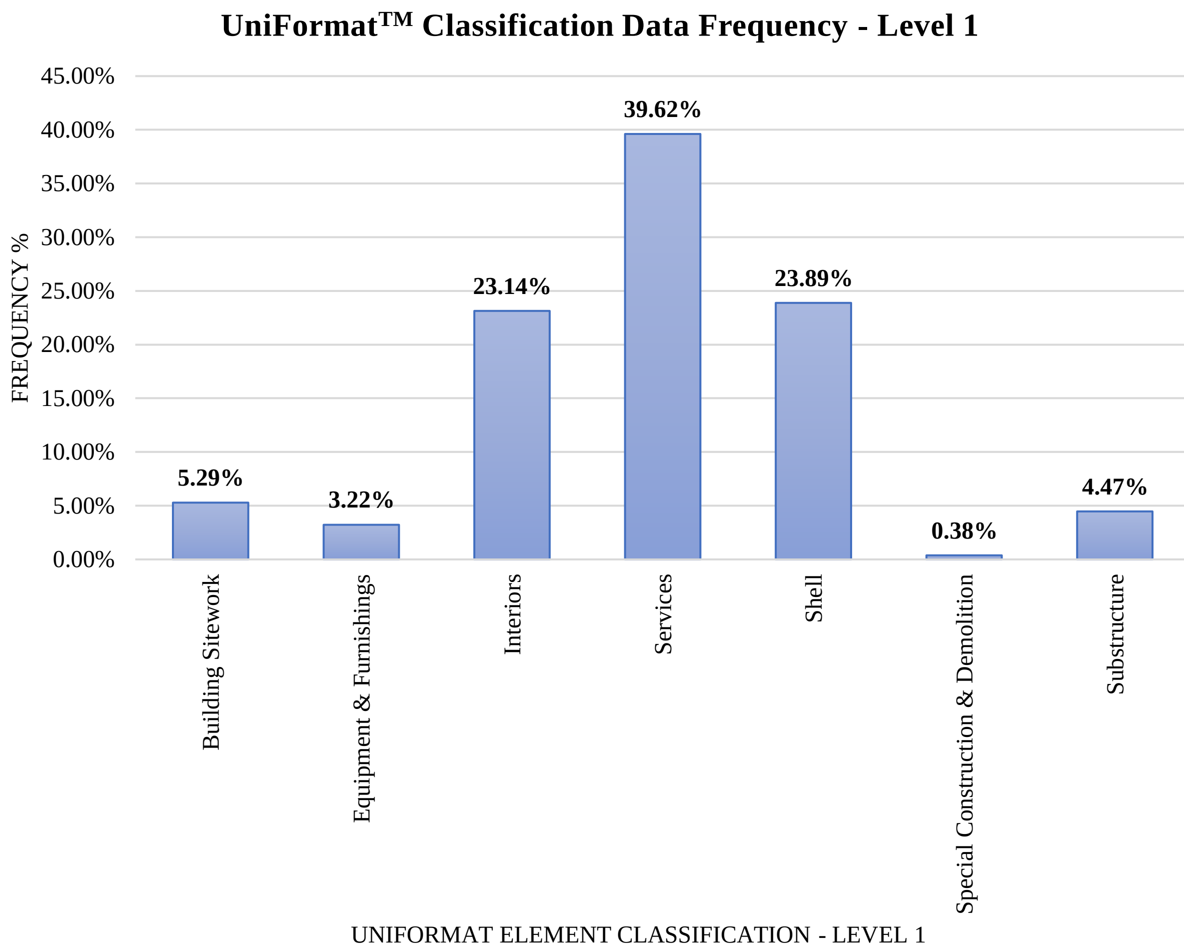


Fig. 36. Distribution of BIM-based Construction Scheduling Data by UniFormat™ Categories - Level 1

Similarly, a total of **19,339** object-driven activities have been annotated and analyzed for Level 2. The activity tasks have been classified into **22** object-driven categories. BIM-based tasks related to **Electrical, Exterior envelop, HVAC, Interior Construction, interior finishes, Plumbing and Superstructures show the highest frequency for object-based classification in Level 2** (see Fig. 37).

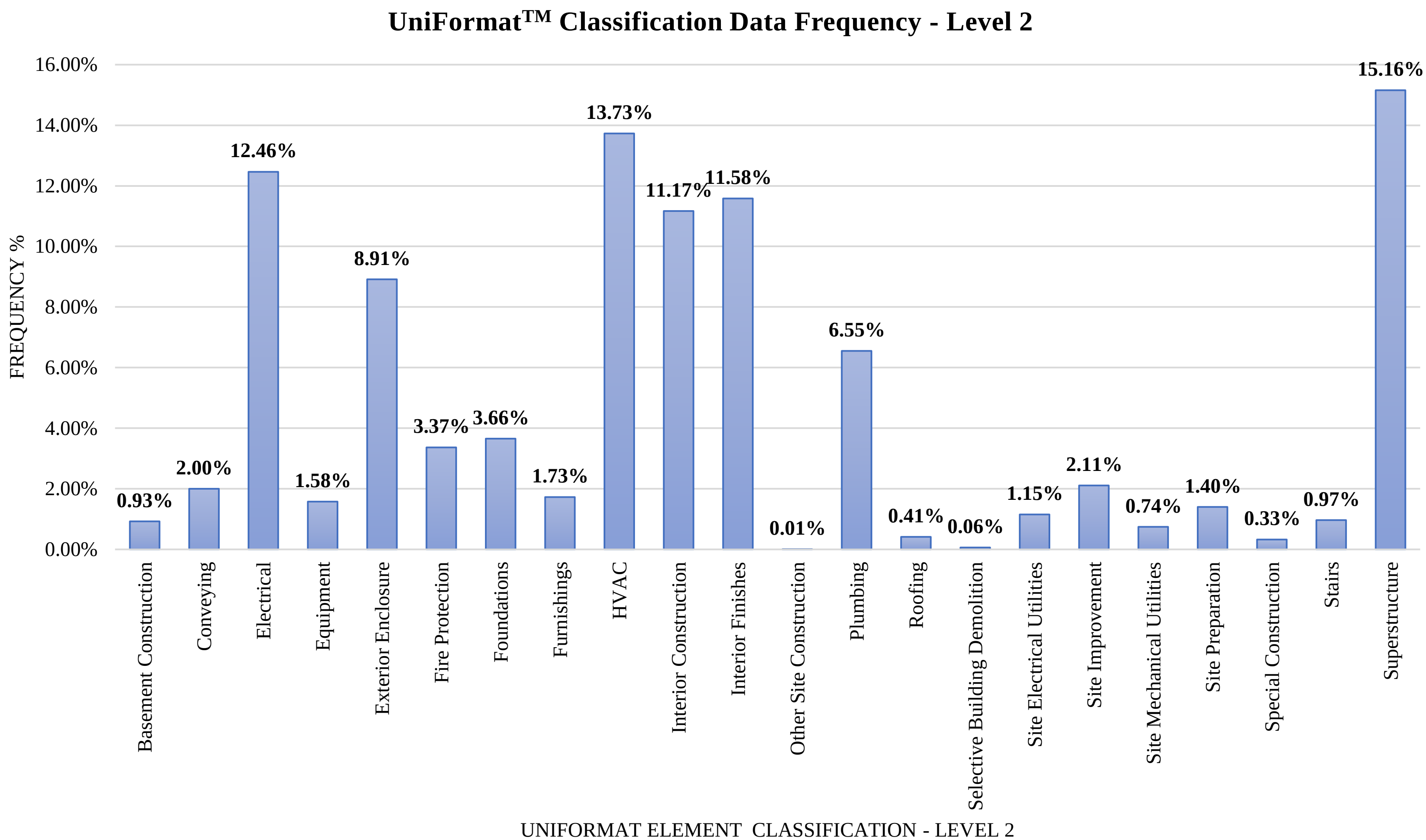


Fig. 37. Distribution of BIM-based Construction Scheduling Data by UniFormat™ Categories - Level 2

Regarding Level 3, a total of **17,081** BIM-based activity tasks were classified. This data was broken down into **76** UniFormat^{TM} categories. The analysis of BIM-based scheduling data at Level 3 shows **Floor Construction (15.88%) and HVAC systems / equipment (11.38%) are the activity tasks with highest object-driven frequency in a medium level of detail** (see Fig. 38). In addition, significant number of frequencies was observed in BIM-based tasks for wall finishes, plumbing fixtures, partitions, other electrical systems, lighting and branch, interior doors, floor finishes, exterior walls, communications and safety, and ceiling finishes.

Conversely than Level 3, classification of BIM-based tasks at **Level 4 show the largest amount of object-driven UniFormat^{TM} categories represented** in the datasets (Fig. 39). A total of **222** categories were utilized to classify **14,523** datapoints. The **activity tasks with the highest BIM-driven frequency were General construction items – HVAC (13.36%); Fixed partitions (7.97%); Upper floor framing – vertical elements (6.14%); Upper floor framing systems (5.78%); Exterior wall construction (5.69%); and Upper floor framing – horizontal elements (2.55%).**

Finally, the analysis of **Level 5 shows a lack of granularity of the detail in BIM-based construction activities (see Fig. 40)**. Only **4,892** reached the highest level of detail of the standards utilized. This data was classified into 113 UniFormat^{TM} categories, which is around 50% of the diversity shown in Level 4. The **BIM-based tasks with the highest level of detail were Wall finishes – paint (9.53%), Partition components – drywall (7.69%), Bearing walls (6.15%), Exterior wall – CMU (5.91%), and Steel girders w/steel beams (4.19%).**

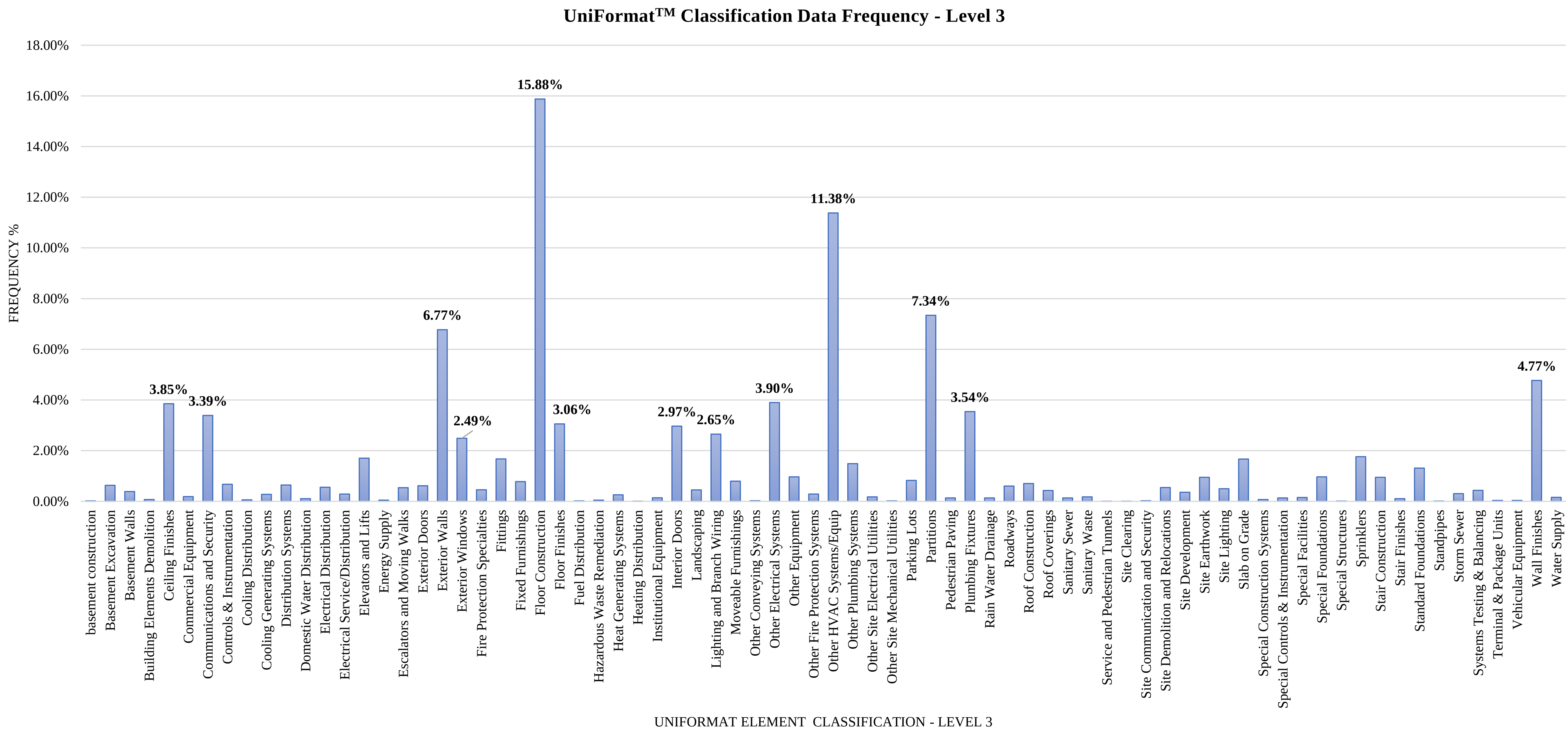


Fig. 38. Distribution of BIM-based Construction Scheduling Data by UniFormat™ Categories - Level 3

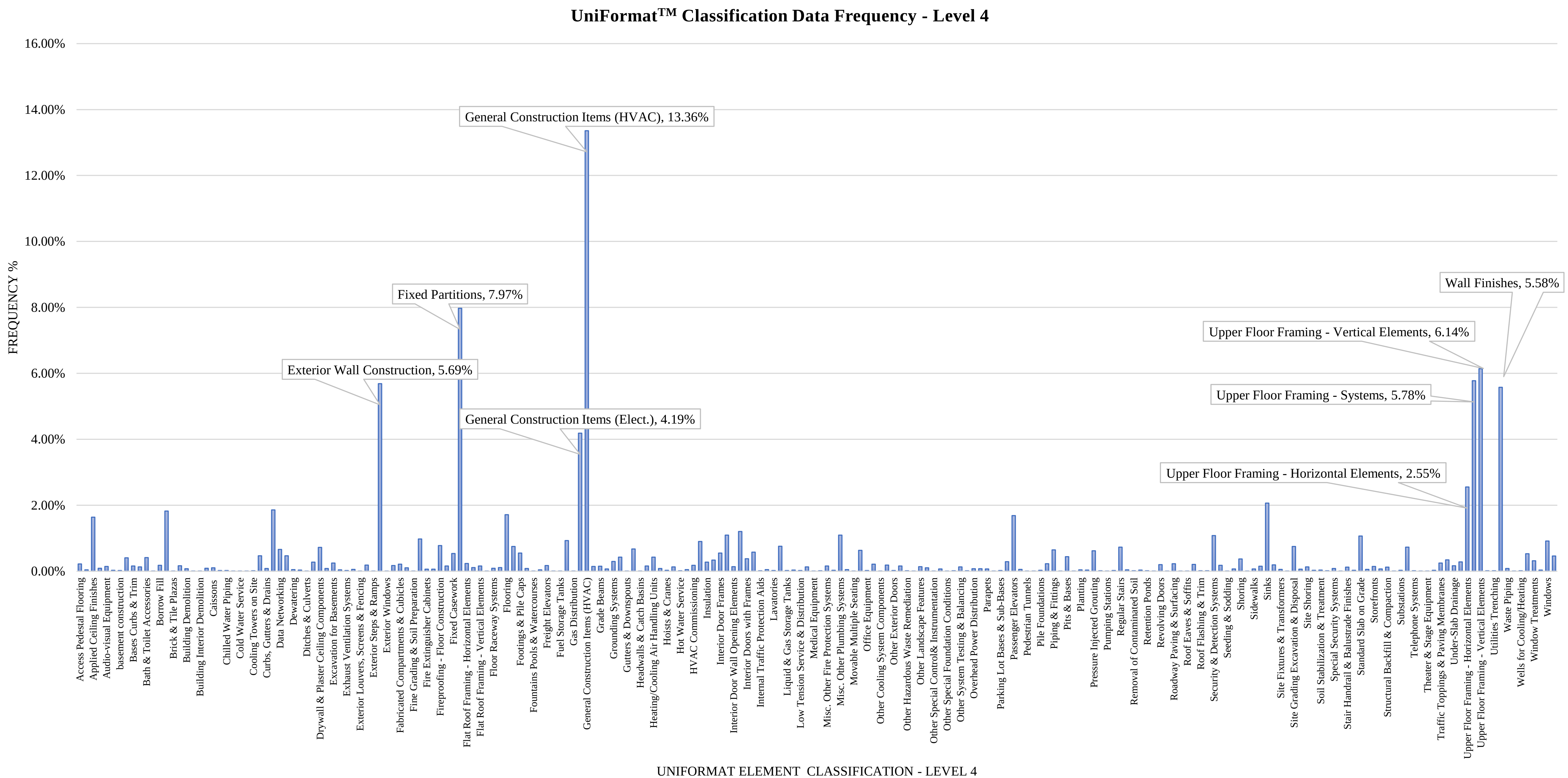


Fig. 39. Distribution of BIM-based Construction Scheduling Data by UniFormat™ Categories - Level 4

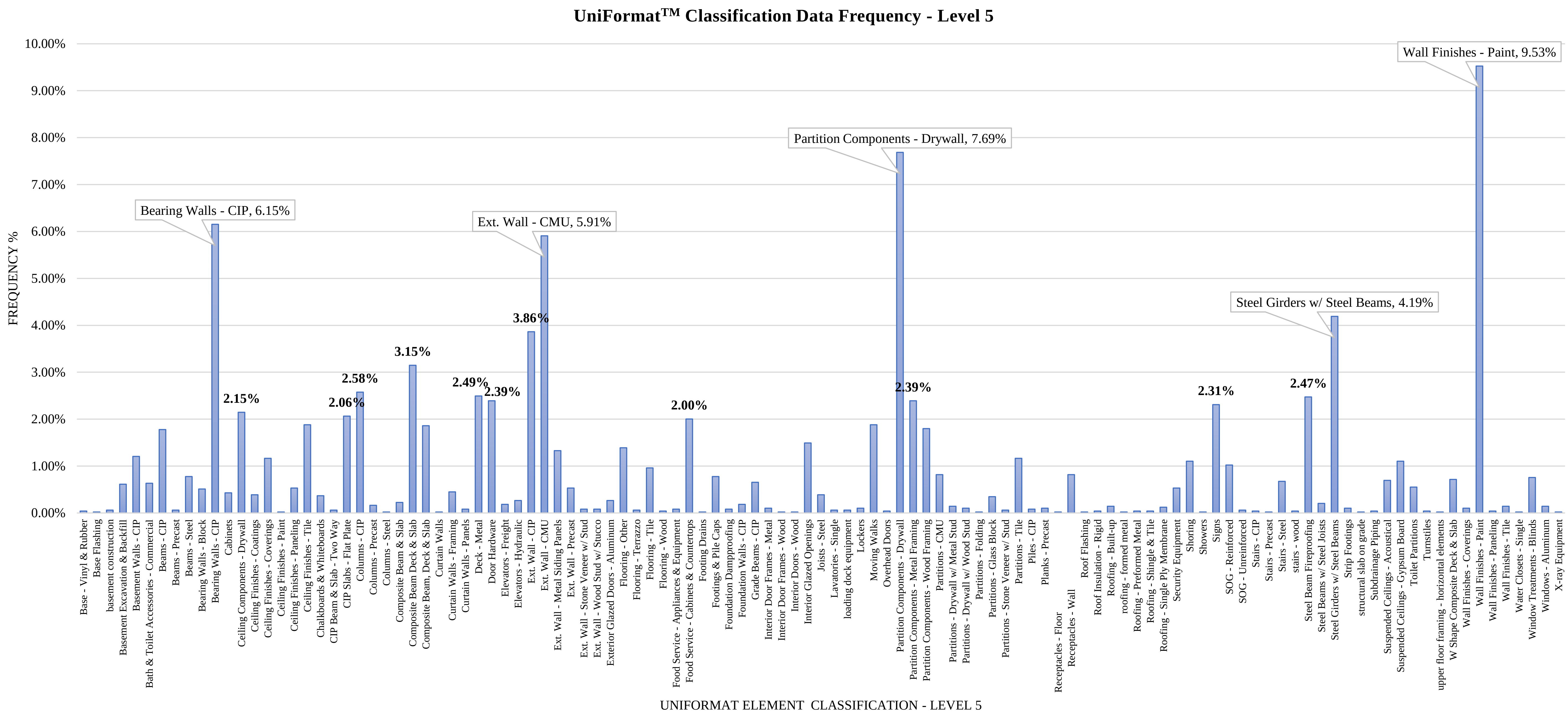


Fig. 40. Distribution of BIM-based Construction Scheduling Data by UniFormat™ Categories - Level 5

5.2 Discussion

The results of this research provide a better understanding of the current practices in construction planning and scheduling and 4D BIM in the AEC industry. The analysis performed indicates that 77% of construction activities are BIM-based. Regardless the level of involvement in 4D BIM, scheduling data shows extraordinary possibilities to standardize this data into object-driven tasks, which creates possibilities to connect such tasks with IFC ontologies in the future. Participants surveyed be

Although results seem to be promising, several challenges were found when analyzing scheduling data. The first challenge was the *variability of the activity name designation*. Through the classification and annotation of scheduling data, different conventions to describe activity tasks were found. Examples such as RI (rough-in), TO (trim-out), FRP (forming / rebar / pouring), CW (curtain wall), etc. are some of the typical abbreviations found. We asked AEC experts how these conventions are introduced in construction schedules and majority indicated it is a decision of the project manager or superintendent. In addition, they manifested more than 50% of activity tasks use such conventions, and these are present in multiple scheduling packages (MEPF, Structures, Architecture, etc.). Furthermore, most responders (60%) indicated the lack of standard guides to create WBS. Apparently, there is a lack of standardization in the process of naming activities that makes construction scheduling data very complex to understand and analyze. Therefore, scheduling data needs to be classified through common object-driven standards in order to provide opportunities for data analytics for the automation of 4D BIM.

The second challenge was the *lack of granularity in construction scheduling data*. Although lot of construction activities were analyzed (around 25,866), few of them contained a high level of BIM-based detail (19%). According to the survey conducted, multiple explanations could be given to understand such shortage like the use of in-house standards, lack of WBS guides, low frequency in the use of the master schedule and its at the jobsite, etc. Regardless the reasons of detail scarcity, the process of classifying certain activity tasks became troublesome. Two typical cases required troubleshooting: “one to many”, and “many to one”. The case of “*One to many*”, where one activity task classified into more than one UniFormat™ categories. For instance, the activity task: “*Prime & paint-w tower – level 03 – entrance corridor*”, due to the lack of detail, classified into two different categories at Level 05: C3010110 Wall Finishes – Paint, and C3030110 Ceiling Finishes – Paint. Because of the uncertainty generated, activities like this were categorized with a lower level of detail (Level 2 - C30 Interior finishes) in order to avoid classification errors. The case “*many to one*” where multiple construction activities required a higher level of specificity than Level 5. For instance, the tasks: “*CMU install Main Entrance (15.5 corridor) (a)*” and “*CMU install – elevator lobby*” can be classified at Level 5 as B2010140 Ext. Wall – CMU. Although both tasks fit in the same category, a higher level of specificity is required to identify specific attributes like type of CMU material.

The last challenge is associated with the *cumbersome validation process*. Due to the large amount of data, continuous validation process was required to acquire a high level of consistency in the data. Typical examples of same activity tasks classified into two different UniFormat™ categories was as trend during the validation process. Introducing NLP algorithms to automate the validation process represents one of the next steps to in the analysis of BIM-based construction analysis data towards 4D BIM automation.

CHAPTER 6: CONCLUSION & FUTURE WORK

The study provided a comprehensive understanding of current practices in construction planning & scheduling and 4D BIM in the AEC industry. Although future work is still required to achieve autonomous workflows for the creation and updating of construction schedules in 4D BIM, the results of the analysis of data utilized for such purpose have been presented and described. Consequently, some of the relevant conclusions and future research opportunities in this field are addressed in this chapter.

6.1 Conclusions

The survey conducted and the analysis of construction scheduling data towards the automation of 4D BIM have set the foundation for future development. Some of the import ant findings of this process are indicated below.

1. Construction planning and scheduling in the AEC industry is still an empirical practice. 63% of industry members utilize in-house standards to create and execute construction schedules. Moreover, this practice has become a process where guides to classify and organize construction activities is no longer a common practice. In fact, 60% of the surveyed participants indicated they do not utilize guides to create WBS. As a result, different conventions have been adopted to organize and name activity tasks. Results show that up to 75% of construction practitioners use their own conventions when performing construction scheduling. They indicate project managers and constructor superintendents are responsible for such incorporation. In addition, they define

MEPF as the most empirical field with incorporated conventions, followed by Structures and Architecture.

2. Mostly, master schedules or construction schedules are updated on a monthly basis. 53% of participants confirmed such trend. Although majority of practitioners indicate a frequent use of construction schedule during construction phase, only 3% of them manifest to update the master schedule in less than a weekly basis. This is a problem in the practice of construction planning and scheduling, especially when AEC professionals: a) do not fully embrace the use of 4D BIM to perform schedule quality control – only 18% of practitioners confirmed their use for this purpose – replacing this opportunity for traditional face-to-face meetings with different trades of the construction project – 73% of participants referred it as the most common technique for schedule quality control; and b) identify updating construction/baseline schedule as the main approach to track construction project progress (68% confirmed the use of this technique as main to for tracking progress).

3. Most of the AEC members are familiar with 4D BIM workflows. The study shows than 87.5% of professionals involved in construction activities are familiar with tasks and challenges to perform 4D BIM. Practitioners define construction visualization, progress monitoring, and coordination among trades as the main usages leveraged from 4D BIM. Furthermore, they indicate that such workflow is primarily *somewhat useful* during preconstruction than construction. Explanation

regarding this perception lies on the challenges inherited within 4D BIM workflows. The study reveals that omission of various tasks procedures is the most challenging difficulty practitioners face in 4D BIM. Also, it identifies linkage of construction activities with BIM-objects and inconsistency of task naming as the most important moderate challenges.

4. Trade coordination has been identified as the primary common area of improvement in construction planning & scheduling and 4D BIM. Software interoperability has been considered as the second biggest challenge to overcome in construction planning and scheduling workflows. Similarly, task linkage procedure has been identified as the main secondary area of improvement in 4D BIM.

5. Standardization of construction activities into 4D BIM-based workflows is feasible. The study reveals that majority of construction activities can be classified as BIM-based scheduling data. Indeed, it shows that 77% of real activity tasks are object-oriented. In a high level, services contain the highest frequency amongst all BIM-based tasks analyzed. This trend is followed by categories such as interiors and shell (structures, cladding, envelope, etc.). For this reason, tasks related to activities like electrical, exterior envelop, HVAC, interior construction, interior finishes, plumbing and superstructures occupy the highest hierarchy of frequency in the analysis of construction scheduling data. like

6. There is a shortage of detail in construction scheduling data. The analysis performed indicates that only 19% of BIM-based scheduling data reaches a high level of detail. In terms of UniFormat^{TM} classification, while a range of 56-76% of BIM-based construction activities can reach the levels of detail 1 through 4, only 19% of tasks can achieve a level of detail 5.

7. There is a possibility to develop further research in the field to investigate more specific relationships between construction scheduling data and 4D BIM workflows. This research can be conducted to provide a more specific analysis of construction activities according to the type of construction industry (commercial, buildings, healthcare, heavy civil, etc.). In addition, BIM-based scheduling data can be leveraged for data analytics purposes. In fact, intelligent models can utilize this standardized data to learn the process of classification of construction activities within BIM environments, and eventually, to automate the procedure of creation and updating of construction schedules in 4D BIM.

6.2 Future Work

The method developed represents an opportunity for future applications and research.

First, the analysis of construction scheduling data could be leveraged through NLP algorithms to increase the efficiency and accuracy of the results. Also, the analysis could be applied to more construction scheduling data and could be broken down into specific type of construction: buildings, commercial, healthcare, education, etc. This analysis will help with more specific understanding of scheduling data diversified by the type of industry.

Second, BIM-based construction scheduling data can be tested in data analytics and machine learning algorithms. Prototypes to predict construction schedules based on the interaction of BIM-based scheduling data and IFC object-driven elements is very feasible with the classified scheduling data. Future research in this field can optimize the process of classifying and annotating information that lately can be retrofit intelligent models and, eventually, can create automated schedules in 4D BIM environments.

Finally, the results show acceptable relationship between construction activities and BIM. This relationship can be optimized by classifying scheduling data with different standards (MasterFormat®, OmniClass®, etc) or in-house parameters. Eventually, the fully automation of 4D BIM in the AEC industry will be possible as long as the workflows in construction planning and scheduling are standardized. This standardization must be studied with more detail.

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APPENDIX A: RESEARCH SURVEY

Scheduling & 4D BIM - Scheduling Information

Thanks in advance for choosing to complete this survey. This study is conducted for research purposes in the Real-Time and Automated Monitoring and Control Lab of the department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign under the supervision of Dr. Mani Golparvar-Fard. The intent of this work is to identify challenges and key factors that would contribute to the adoption of automated scheduling and progress tracking BIM-based techniques for the Architectural / Engineering / Construction (AEC) industry. This goal will be achieved by analyzing and contrasting insights ascribed to construction planning & scheduling and 4D Building Information Modeling implementation provided by different agents involved in construction operations (design, AEC, CM, GC, subs, etc). The responses provided constitute professional testimony as a result of involvement in construction activities. Therefore, the results are not expected to follow any policies / vision of your respective design/construction firms, but to represent genuine opinions of dealing with planning, scheduling, progress monitoring and project controls on a daily basis.

The results will serve as guidance for current research in 4D BIM automation and will be published at the Graduate College of the aforementioned university.

If you have any questions, do not hesitate and email us at abelv2@illinois.edu.

* Required

1. **Email address** *

____

2. **When performing construction planning, do you follow any standard convention to organize/classify planning and estimating construction activities?** *

Check all that apply.

- [ ] Masterformat
- [ ] Uniformat
- [ ] In-house standards
- [ ] I don't know
- [ ] Other: _______________________

3. **Do you have a guide to create a Work Breakdown Structure?** *

Mark only one oval.

- ( ) Yes
- ( ) No

4. **If Yes, can you upload the document (.pdf, .doc, .xls, .jpg). to create the WBS?**

Files submitted:

5. **Which software, or in-house interface, do you use for scheduling construction activities?** *
Mark only one oval.

- ◯ Primavera P6
- ◯ Microsoft Project
- ◯ Microsoft Excel
- ◯ Manually
- ◯ Other: ____________________

6. **When performing preconstruction, how do you conduct schedule quality control?** *
Check all that apply.

- ☐ Contruction simulation
- ☐ Site visits
- ☐ Virtual meetings with different trades
- ☐ Face-to-face meeting or input from different trades (design/GC/CM/Subs)
- ☐ Direct design / construction coordination
- ☐ Early involvement of different trades (design/GC/CM/subs)
- ☐ Other: ____________________

7. **When working with construction schedules, regardless of the WBS structure, do you have any specific convention to abbreviate/identify some activities and their location? For instance, do you work with conventions to abbreviate these tasks: a) Close shower walls L1B3W - c1, which would mean: close shower walls, level 1, area B, west, cell1; or b) FRP shaft D - CFE L1A2, which means Form/Rebar/Pour shaft D, system CFE, level 1, zone A2** *
Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Sometimes

8. **If yes / sometimes, how is this convention incorporated within the construction schedule?**
Mark only one oval.

- ◯ It is coordinated amongst trades during preconstruction (design / GC / subs / etc).
- ◯ Superintendent / PM defines convention
- ◯ Scheduler defines convention.
- ◯ Conventions / abbreviations are widely known in the industry.
- ◯ Acoording to company's policy.
- ◯ It is used according to historical projects within the firm.
- ◯ Option 7
- ◯ Other: ____________________

9. **Similarly, regarding the total number of activities, how often do you find these conventions within a construction schedule?**
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
Never	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Always

10. **What are the primary areas where these conventions are used to name activities?**
Check all that apply.

- [ ] Architecture
- [ ] Structures
- [ ] Mechanical / Electrical / Plumbing / Fire protection
- [ ] Civil
- [ ] Other: ____________________

Scheduling & 4D BIM - 4D BIM uses

11. **During preconstruction, how often do you use the Master Schedule?** *
Mark only one oval.

- ◯ Always
- ◯ Usually
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

12. **During construction, how often do you or the superintendent use look-ahead Schedule?** *
Mark only one oval.

- ◯ Always
- ◯ Usually
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

13. **During construction, how often do you update the Master Schedule?** *
Mark only one oval.

- ◯ Daily
- ◯ Weekly
- ◯ Bi-weekly
- ◯ Monthly
- ◯ Never
- ◯ Other: ____________________

14. **When executing a construction project, what method(s) do you apply to track project progress?** *

Check all that apply.

- [ ] Earned Value Analysis (EVA)
- [ ] "S" Curve
- [ ] Reality capture & cloud points
- [ ] Tracking key milestones only
- [ ] Fleld input quantification
- [ ] Look ahead schedules
- [ ] Location-based schedules
- [ ] Excel workbook annotations
- [ ] Updating construction/baseline schedule
- [ ] Color-coding in drawings by subs/tasks
- [ ] Handwriting annotations
- [ ] Other: ______________________

15. **How familiar are you with 4D BIM?** *

Mark only one oval.

	0	1	2	3	4	5	6	7	8	9	10	
Not at all familiar	○	○	○	○	○	○	○	○	○	○	○	Extremely familiar

16. **What are the uses you leverage from 4D BIM?** *

Check all that apply.

- [ ] Progress monitoring
- [ ] Construction visualization
- [ ] Constructability analysis
- [ ] Construction safety
- [ ] Schedule quality control
- [ ] Coordination among trades
- [ ] Field validation
- [ ] AR / VR
- [ ] Project controls
- [ ] Digital management
- [ ] Owner communication
- [ ] I don't obtain any uses
- [ ] Other: ______________________

17. **During preconstruction, what is the choice that best describes your perception regarding the functionality of 4D BIM?** *

Mark only one oval.

- Extremely useful
- Very useful
- Somewhat useful
- Not so useful
- Not at all useful

18. **During construction phase, what is the choice that best describes your perception regarding the functionality of 4D BIM?** *

Mark only one oval.

- Extremely useful
- Very useful
- Somewhat useful
- Not so useful
- Not at all useful

19. **When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A")** *

Mark only one oval per row.

	1	2	3	4	5	N/A
Linking tasks with 3D Objects						
Some 3D objects do not represent tasks						
Some tasks do not represent 3D objects						
Omission of various procedure tasks						
Sequence is inappropriate						
BIM-objects and tasks do not match						
Insufficient level of granularity of BIM-based objects						
System interoperability						
Tasks names are inconsistent						

20. **Is there any other relevant challenge we did not address in the previous question?**

Scheduling & 4D BIM - Areas of Improvement

21. **What aspects of construction scheduling need improvement?** *

Check all that apply.

- [ ] Software interoperability
- [ ] Sequencing
- [ ] BIM-based formulation
- [ ] Accessibility
- [ ] Functionality
- [ ] Portability
- [ ] Trade coordination
- [ ] Other: ____________________

22. **What aspects of 4D BIM need improvement?** *

Check all that apply.

- [ ] Tasks linkage procedure
- [ ] Interface with reality capture
- [ ] 3D / scheduling coordination
- [ ] Visualization
- [ ] Accessibility
- [ ] Interoperability
- [ ] Complexity
- [ ] Functionality
- [ ] Other: ____________________

23. **What is your vision regarding scheduling and project progress tracking in construction operations?**

____

____

____

____

____

Scheduling & 4D BIM - Background Information

24. **What is the type of business that best describes your company's work?** *

Mark only one oval.

- ◯ Design firm
- ◯ General contractor
- ◯ Subcontractor
- ◯ Consultant
- ◯ Construction Management Agency
- ◯ Construction Management at risk
- ◯ Academic / research
- ◯ Other: ______________________

25. **What type of industry does your company mainly focus operations in?** *

Check all that apply.

- ☐ Buildings
- ☐ Heavy industrial
- ☐ Heavy civil / infrastructure
- ☐ Mechanical / Electrical / Plumbing
- ☐ Timber
- ☐ Railroad
- ☐ Commercial
- ☐ Agriculture
- ☐ Government facilities
- ☐ Software
- ☐ Engineering
- ☐ Facilities restauration / renovation
- ☐ Other: ______________________

26. **What is your primary professional background?** *

Mark only one oval.

- ◯ Architect
- ◯ Civil Engineer
- ◯ Professional degree
- ◯ Trades
- ◯ Other: ______________________

27. **What best describes your job's role in your organization?** *
Mark only one oval.

- Owner
- Project Manager
- Project Engineer
- VDC Manager
- VDC Engineer
- Superintendent
- Foreman
- Architecture / Engineering design
- Other: ____________

28. **How many years of experience do you have working in this position? (use only numbers)** *

____

29. **What is the annual revenue (R) range of your company?**
Mark only one oval.

- R < 10M (million)
- 10M < R < 100M
- 100M < R < 1B (billion)
- R > 1B

Thank you!

You have finished this questionnaire. We appreciate you taking time to complete this survey. The results will help us to identify issues in scheduling and 4D BIM and enhance the aspects that need improvement.

- [ ] Send me a copy of my responses.

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APPENDIX B: SURVEY RESULTS

Question 1			Question 2	Question 3	Question 4
Response No	Timestamp	Email Address	When performing construction planning, do you follow any standard convention to organize/classify planning and estimating construction activities?	Do you have a guide to create a Work Breakdown Structure?	If Yes, can you upload the document (.pdf, .doc, .xls, .jpg). to create the WBS?
1	5/22/2019 11:19:34	[redacted]	Masterformat, Uniformat		[redacted]
2	5/31/2019 17:53:08	[redacted]	In-house standards		[redacted]
3	6/11/2019 12:06:10	[redacted]	In-house standards	No	[redacted]
4	6/26/2019 10:12:52	[redacted]	Masterformat, In-house standards	Yes	[redacted]
5	6/26/2019 10:15:34	[redacted]	In-house standards	No	[redacted]
6	6/26/2019 10:15:54	[redacted]	In-house standards	No	[redacted]
7	6/26/2019 10:20:12	[redacted]	I don't know	Yes	[redacted]
8	6/26/2019 10:25:07	[redacted]	In-house standards	No	[redacted]
9	6/26/2019 10:27:03	[redacted]	In-house standards	Yes	[redacted]
10	6/26/2019 10:30:30	[redacted]	In-house standards	No	[redacted]
11	6/26/2019 10:31:34	[redacted]	In-house standards	No	[redacted]
12	6/26/2019 10:33:08	[redacted]	Masterformat	No	[redacted]
13	6/26/2019 10:38:02	[redacted]	In-house standards	No	[redacted]
14	6/26/2019 10:42:44	[redacted]	In-house standards	Yes	https://drive.google.com/o
15	6/26/2019 10:58:21	[redacted]	In-house standards	No	[redacted]
16	6/26/2019 11:00:45	[redacted]	I don't know	Yes	[redacted]
17	6/26/2019 11:06:51	[redacted]	Masterformat	No	[redacted]
18	6/26/2019 12:50:03	[redacted]	In-house standards	No	[redacted]
19	6/26/2019 14:41:59	[redacted]	Masterformat, Uniformat	Yes	[redacted]
20	6/26/2019 14:48:16	[redacted]	Masterformat, Uniformat	No	[redacted]
21	6/26/2019 15:20:12	[redacted]	Masterformat	No	[redacted]
22	6/26/2019 15:53:05	[redacted]	In-house standards	No	[redacted]
23	6/26/2019 21:31:26	[redacted]	In-house standards	Yes	[redacted]
24	6/27/2019 10:44:20	[redacted]	In-house standards	Yes	[redacted]
25	6/27/2019 13:37:11	[redacted]	Masterformat, In-house standards	No	[redacted]
26	6/27/2019 14:01:34	[redacted]	In-house standards	No	[redacted]
27	6/28/2019 10:32:08	[redacted]	Masterformat	Yes	[redacted]
28	6/29/2019 10:53:42	[redacted]	I don't know	Yes	[redacted]
29	6/29/2019 13:04:31	[redacted]	In-house standards	No	[redacted]
30	6/29/2019 14:48:02	[redacted]	In-house standards	No	[redacted]
31	6/29/2019 19:11:39	[redacted]	We do not have standard in Japan, but I know	No	[redacted]
32	6/29/2019 22:29:04	[redacted]	In-house standards	No	[redacted]
33	6/30/2019 19:47:56	[redacted]	Masterformat, Uniformat	No	[redacted]
34	7/1/2019 11:18:09	[redacted]	In-house standards	Yes	[redacted]
35	7/1/2019 11:59:26	[redacted]	In-house standards	Yes	[redacted]
36	7/1/2019 14:48:22	[redacted]	Masterformat	No	[redacted]
37	7/3/2019 14:51:15	[redacted]	Masterformat	Yes	[redacted]
38	7/5/2019 9:13:23	[redacted]	In-house standards	Yes	[redacted]
39	7/5/2019 17:35:43	[redacted]	Masterformat, Uniformat	No	[redacted]
40	7/7/2019 18:53:37	[redacted]	In-house standards	No	[redacted]

	Question 5	Question 6	Question 7	Question 8
Response No	Which software, or in-house interface, do you use for scheduling construction activities?	When performing preconstruction, how do you conduct schedule quality control?	When working with construction schedules, regardless of the WBS structure, do you have any specific convention to abbreviate/identify some activities and their location? For instance, do you work with conventions to abbreviate these tasks: a) Close shower walls L1B3W - c1, which would mean: close shower walls, level 1, area B, west, cell1; or b) FRP shaft D - CFE L1A2, which means Form/Rebar/Pour shaft D, system CFE, level 1, zone A2	If yes / sometimes, how is this convention incorporated within the construction schedule?
1	Primavera P6	Contruction simulation	Yes	Conventions / abbreviations are widely k
2	Microsoft Project	Direct design / construction coordination	Sometimes	It is used according to historical projects
3	All of above	Contruction simulation, Site visits, Direct	Sometimes	Acoording to company's policy.
4	Primavera P6	Site visits, Virtual meetings with differen	Sometimes	Scheduler defines convention.
5	Primavera P6	Site visits, Virtual meetings with differen	Yes	Superintendent / PM defines convention
6	Primavera P6	Site visits, Face-to-face meeting or input	No	
7	Primavera P6	Site visits, Face-to-face meeting or input	Yes	combination of scheduler defined, superi
8	All of the above for different levels of sch	Site visits, Face-to-face meeting or input	Sometimes	Varies based on Project, Owner requirem
9	Microsoft Excel	Direct design / construction coordination	Sometimes	Conventions / abbreviations are widely k
10	Microsoft Project	Site visits, Face-to-face meeting or input	No	
11	Primavera P6	Early involvement of different trades (des	Sometimes	Superintendent / PM defines convention
12	We use both Primavera P6 and Microsoft	Face-to-face meeting or input from differ	Sometimes	Conventions / abbreviations are widely k
13	Primavera P6	Face-to-face meeting or input from differ	No	
14	Primavera P6	Site visits, Face-to-face meeting or input	Yes	It is used according to historical projects
15	Microsoft Project	Site visits, Virtual meetings with differen	Yes	Superintendent / PM defines convention
16	Primavera P6	Face-to-face meeting or input from differ	No	
17	Primavera P6	Direct design / construction coordination	No	
18	Primavera P6	Site visits, Face-to-face meeting or input	Yes	Scheduler defines convention.
19	Primavera P6	Site visits, Virtual meetings with differen	Sometimes	Conventions / abbreviations are widely k
20	TouchPlan	Site visits, Face-to-face meeting or input	Yes	Broken into digestible phases and "batch
21	Phoenix and Microsoft Project	Site visits, Virtual meetings with differen	Sometimes	Scheduler defines convention.
22	Microsoft Project	Contruction simulation, Site visits, Face-t	Yes	It is used according to historical projects
23	Primavera P6	Direct design / construction coordination	Sometimes	Acoording to company's policy.
24	Excel Spreadsheet combined w/BuildPro	Site visits, Face-to-face meeting or input	Yes	Acoording to company's policy.
25	Primavera P6	Site visits, Early involvement of different	No	
26	Microsoft Project	Face-to-face meeting or input from differ	No	none
27	Primavera P6	Contruction simulation, Virtual meetings	Yes	Its a mix of rules established by Project C
28	Smartsheet	Virtual meetings with different trades, Ea	Sometimes	Superintendent / PM defines convention
29	Primavera P6	Site visits, Virtual meetings with differen	No	
30	IHMS	Direct design / construction coordination	Sometimes	Acoording to company's policy.
31	Microsoft Excel	Contruction simulation, Site visits, Face-t	No	
32	Microsoft Excel	Direct design / construction coordination	Yes	Scheduler defines convention.
33	ASTA Powerproject	Contruction simulation, Face-to-face mee	Yes	It is used according to historical projects
34	Microsoft Project	Face-to-face meeting or input from differ	Yes	It is coordinated amongst trades during p
35	Primavera P6	Site visits, Virtual meetings with differen	Sometimes	Conventions / abbreviations are widely k
36	Touchplan	Site visits, Face-to-face meeting or input	Sometimes	Superintendent / PM defines convention
37	Microsoft Project	Site visits, Face-to-face meeting or input	Sometimes	
38	Microsoft Project	Site visits, Virtual meetings with differen	Sometimes	Superintendent / PM defines convention
39	Primavera P6	Contruction simulation, Virtual meetings	Yes	Superintendent / PM defines convention
40	Microsoft Project	Site visits, Face-to-face meeting or input	No	

Question 9 Question 11 Question 10 Question 12

Response No	Similarly, regarding the total number of activities, how often do you find these conventions within a construction schedule?	What are the primary areas where these conventions are used to name activities?	During preconstruction, how often do you use the Master Schedule?	During construction, how often do you or the superintendent use look-ahead Schedule?
1	8	Architecture, Structures, Mechanical / El	Sometimes	Always
2	7	Architecture	Sometimes	Usually
3	8	Architecture, Structures, Mechanical / El	Always	Always
4	5	Mechanical / Electrical / Plumbing / Fire	Always	Always
5	10	Civil	Sometimes	Always
6			Usually	Usually
7	8	Structures, Mechanical / Electrical / Plum	Usually	Usually
8	10	Architecture, Structures, Mechanical / El	Sometimes	Always
9	7	Civil	Sometimes	Always
10	2	Structures, Mechanical / Electrical / Plum	Sometimes	Sometimes
11	5	Structures, Mechanical / Electrical / Plum	Usually	Always
12	6	Architecture, Structures, Mechanical / El	Always	Always
13		Mechanical / Electrical / Plumbing / Fire	Never	Usually
14	9	Structures, Mechanical / Electrical / Plum	Usually	Usually
15	8	Structures, Mechanical / Electrical / Plum	Always	Always
16			Always	Usually
17	1		Always	Always
18	10	Architecture, Structures, Mechanical / El	Never	Always
19	7	Architecture, Mechanical / Electrical / Pl	Always	Always
20	10	Architecture, Structures	Usually	Always
21	5	Architecture, Structures, Mechanical / El	Always	Always
22	8	Architecture, Structures, Mechanical / El	Usually	Sometimes
23	8	Civil	Always	Usually
24	10	Residential Construction	Always	Always
25	1		Usually	Usually
26	5	Civil	Sometimes	Usually
27	10	Structures, Mechanical / Electrical / Plum	Always	Always
28	5	Architecture, Mechanical / Electrical / Pl	Always	Always
29	6	Architecture, Structures, Mechanical / El	Always	Always
30	5	Mechanical / Electrical / Plumbing / Fire	Rarely	Usually
31	5		Always	Always
32	8	Architecture, Civil	Usually	Usually
33	7	Structures, Mechanical / Electrical / Plum	Always	Always
34	7	Architecture, Structures	Usually	Usually
35	8	Architecture, Structures, Mechanical / El	Usually	Always
36	5	Architecture	Always	Always
37	4	Architecture, Structures	Usually	Always
38	3	Structures, Mechanical / Electrical / Plum	Sometimes	Sometimes
39	10	Mechanical / Electrical / Plumbing / Fire	Usually	Always
40	1		Never	Usually

Response No	Question 13 During construction, how often do you update the Master Schedule?	Question 14 When executing a construction project, what method(s) do you apply to track project progress?	Question 15 How familiar are you with 4D BIM?	Question 16 What are the uses you leverage from 4D BIM?
1		Earned Value Analysis (EVA), Look ahe	6	Construction visualization, Construction
2		Earned Value Analysis (EVA), "S" Curve	5	Construction visualization, Constructabil
3	Tri times an year	Earned Value Analysis (EVA), "S" Curve	3	Progress monitoring, Construction visual
4	Bi-weekly	FIeld input quantification, Look ahead sc	6	Progress monitoring, Construction visual
5	Monthly	Tracking key milestones only, FIeld input	0	I don't obtain any uses
6	Monthly	Tracking key milestones only	8	Progress monitoring, Construction visual
7	Monthly	Tracking key milestones only, FIeld input	1	Progress monitoring, Construction visual
8	Monthly	Earned Value Analysis (EVA), "S" Curve	5	I don't obtain any uses
9	Monthly	Earned Value Analysis (EVA), Look ahe	1	I don't obtain any uses
10	Never	Earned Value Analysis (EVA), Tracking	0	I don't obtain any uses
11	Monthly	Look ahead schedules, Updating constru	0	I don't obtain any uses
12	Bi-weekly	Tracking key milestones only, Look ahea	6	Progress monitoring, Construction visual
13	Bi-weekly	FIeld input quantification, Updating cons	6	Progress monitoring, Construction visual
14	Monthly	Earned Value Analysis (EVA), "S" Curve	7	Progress monitoring, Construction visual
15	Monthly	Tracking key milestones only, FIeld input	2	Construction visualization, Schedule qua
16	Bi-weekly	FIeld input quantification, Location-base	3	I don't obtain any uses
17	Monthly	Earned Value Analysis (EVA)	3	Coordination among trades
18	Weekly	Tracking key milestones only, Updating c	0	I don't obtain any uses
19	Bi-weekly	Earned Value Analysis (EVA), "S" Curve	2	Construction visualization, Constructabil
20	Monthly	Tracking key milestones only, Look ahea	0	Progress monitoring
21	Monthly	Tracking key milestones only, FIeld input	5	Progress monitoring, Construction visual
22	Monthly	"S" Curve, Tracking key milestones only,	10	Progress monitoring, Construction visual
23	Monthly	FIeld input quantification	1	Constructability analysis, Coordination a
24	Weekly	Tracking key milestones only, FIeld input	4	Not sure if our scheduling would be cons
25	Bi-weekly	FIeld input quantification, Look ahead sc	8	Construction visualization, Owner comm
26	Weekly	Look ahead schedules	5	Progress monitoring
27	Weekly	Earned Value Analysis (EVA), FIeld inpu	10	Progress monitoring, Construction visual
28	Monthly	Tracking key milestones only, FIeld input	9	Construction visualization
29	Monthly	Look ahead schedules, Updating constru	7	Coordination among trades
30	Weekly	Tracking key milestones only, Updating c	6	I don't obtain any uses
31	depends. if master schedule is well create	Tracking key milestones only, FIeld input	8	Progress monitoring, Construction visual
32	Never	Earned Value Analysis (EVA), "S" Curve	8	I don't obtain any uses
33	Monthly	"S" Curve, FIeld input quantification, Lo	9	Construction visualization, Constructabil
34	Weekly	Tracking key milestones only	2	Construction visualization, AR / VR, Dig
35	Monthly	Tracking key milestones only, Look ahea	5	Progress monitoring, Construction visual
36	Twice a week	Tracking key milestones only, Look ahea	8	Progress monitoring, Construction visual
37	Monthly	Updating construction/baseline schedule	8	Progress monitoring, Construction visual
38	Monthly	Excel workbook annotations, Updating c	10	Progress monitoring, Construction visual
39	Bi-weekly	Earned Value Analysis (EVA), Reality ca	10	Progress monitoring, Construction visual
40	Monthly	Tracking key milestones only, Look ahea	7	Construction visualization, sales

	Question 17	Question 18	Question 19	Question 19
Response No	During preconstruction, what is the choice that best describes your perception regarding the functionality of 4D BIM?	During construction phase, what is the choice that best describes your perception regarding the functionality of 4D BIM?	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Linking tasks with 3D Objects]	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Some 3D objects do not represent tasks]
1	Somewhat useful	Not at all useful	5	4
2	Extremely useful	Not so useful	3	5
3	Somewhat useful	Very useful	3	4
4	Extremely useful	Somewhat useful	2	4
5	Not at all useful	Not at all useful	3	3
6	Very useful	Very useful	5	5
7	Somewhat useful	Very useful	N/A	N/A
8	Not so useful	Not so useful	N/A	N/A
9	Not at all useful	Not at all useful	N/A	N/A
10	Not at all useful	Not at all useful	N/A	N/A
11	Not so useful	Somewhat useful	N/A	N/A
12	Somewhat useful	Very useful	N/A	N/A
13	Very useful	Very useful	3	2
14	Extremely useful	Very useful	5	2
15	Somewhat useful	Somewhat useful	3	3
16	Somewhat useful	Somewhat useful	N/A	N/A
17	Somewhat useful	Somewhat useful	N/A	N/A
18	Not so useful	Not so useful	N/A	N/A
19	Not so useful	Somewhat useful	3	3
20	Somewhat useful	Somewhat useful	N/A	N/A
21	Somewhat useful	Somewhat useful	N/A	N/A
22	Extremely useful	Very useful	3	2
23	Not so useful	Not at all useful	5	5
24	Somewhat useful	Somewhat useful	N/A	N/A
25	Somewhat useful	Not so useful	5	5
26	Somewhat useful	Very useful	3	3
27	Very useful	Somewhat useful	3	3
28	Very useful	Somewhat useful	3	2
29	Not so useful	Very useful	3	3
30	Very useful	Extremely useful	3	5
31	Very useful	Somewhat useful	5	3
32	Very useful	Somewhat useful	N/A	N/A
33	Extremely useful	Somewhat useful	4	4
34	Very useful	Very useful	N/A	N/A
35	Extremely useful	Somewhat useful	N/A	N/A
36	Very useful	Extremely useful	2	4
37	Very useful	Extremely useful	2	3
38	Somewhat useful	Somewhat useful	1	3
39	Extremely useful	Extremely useful	3	4
40	Somewhat useful	Somewhat useful	N/A	N/A

	Question 19	Question 19	Question 19	Question 19
Response No	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Some tasks do not represent 3D objects]	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Omission of various procedure tasks]	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Sequence is inappropriate]	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [BIM-objects and tasks do not match]
1	3	5	4	5
2	5	5	4	2
3	3	5	5	5
4	4	3	1	2
5	3	3	3	3
6	5	5	4	4
7	N/A	N/A	N/A	N/A
8	N/A	N/A	5	N/A
9	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A
11	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A
13	5	5	3	4
14	5	4	3	4
15	4	5	2	3
16	N/A	N/A	N/A	N/A
17	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A
19	3	3	2	5
20	N/A	N/A	N/A	N/A
21	N/A	N/A	N/A	N/A
22	5	3	3	5
23	5	5	5	5
24	5	5	N/A	N/A
25	5	4	1	5
26	3	3	3	3
27	2	3	3	4
28	2	3	4	1
29	3	3	3	3
30	5	5	3	5
31	3	3	2	4
32	N/A	N/A	N/A	N/A
33	4	3	2	2
34	N/A	N/A	N/A	N/A
35	N/A	N/A	N/A	N/A
36	4	3	N/A	1
37	4	3	2	2
38	4	4	2	2
39	4	5	5	2
40	N/A	N/A	N/A	N/A

	Question 19	Question 19	Question 19	Question 20
Response No	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Insufficient level of granularity of BIM-based objects]	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [System interoperability]	When performing 4D BIM, what are the main challenges you face? (1 is "not at all challenging" and 5 is "very challenging". If you are not familiar with 4D BIM, please select "N/A") [Tasks names are inconsistent]	Is there any other relevant challenge we did not address in the previous question?
1		4	5	
2		4	3	
3	3	5	3	Total duration of project. If it is a very lo
4	2	1	1	
5	3	3	3	No
6	5	4	3	
7	N/A	N/A	N/A	Although I work as a scheduler, I have ne
8	5	5 N/A		In Bid-Build Public work. There is substa
9	N/A	N/A	N/A	
10	N/A	N/A	N/A	
11	N/A	N/A	N/A	
12	N/A	N/A	N/A	
13	5	N/A	1	need an extreme level of precision in bot
14	1	2	1	Changing conditions in sequencing, man
15	4	5	4	
16	N/A	N/A	N/A	
17	N/A	N/A	N/A	
18	N/A	N/A	N/A	
19	3	5	4	
20	N/A	N/A	N/A	
21	N/A	N/A	N/A	
22	3	3	5	educate trades that are not familiar with 4
23	5	5	5	
24	N/A	N/A	N/A	
25	4	3	4	
26	3	3	3	
27	4	2	1	
28	4	2	3	
29	3	3	3	
30	5	5	5	
31	2	3	4	
32	N/A	N/A	N/A	
33	2	2	3	no
34	N/A	N/A	N/A	
35	N/A	N/A	N/A	
36	3	3	1	No
37	3	3	4	
38	3	1	2	Does all subcontractors use 4D? In Colo
39	1	1	3	flexibility in changing WBS as job progre
40	N/A	N/A	N/A	

Response No	Question 21 What aspects of construction scheduling need improvement?	Question 22 What aspects of 4D BIM need improvement?	Question 23 What is your vision regarding scheduling and project progress tracking in construction operations?	Question 24 What is the type of business that best describes your company's work?
1	BIM-based formulation	3D / scheduling coordination		Academic / research
2	Functionality, Portability, Trade coordina	3D / scheduling coordination, Visualizati	Really helpful during preconstruction, ha	General contractor
3	Accessibility, Portability	Accessibility, Interoperability	Easy to access, to update and to share.	General contractor
4	Software interoperability, BIM-based for	3D / scheduling coordination, Functional	BIM can develop an ideal schedule	General contractor
5	Accessibility, Functionality, Trade coordi	3D / scheduling coordination		General contractor
6	Sequencing, BIM-based formulation, Fun	Tasks linkage procedure, Interface with r	Industry needs a standard to measure the	Construction Management Agency
7	Software interoperability, BIM-based for	Introducing the use of 4D BIM in the firs	If software is easy to use, implement, and	Program Management / Project Managem
8	Software interoperability, Sequencing, BI	Tasks linkage procedure, 3D / scheduling coordination, Interoperability, Complexit		General contractor
9	Accessibility, Functionality	Accessibility		Consultant
10	Accessibility, Trade coordination	N/A		Construction Management Agency
11	Sequencing, Portability, Trade coordinati	have never used		General contractor
12	N/A	not a scheduler so I do not know the	N/A not a scheduler so I do not know the issues.	General contractor
13	Functionality	Accessibility, Complexity	useful to a large extent, reaches limits du	Design firm
14	Sequencing, Accessibility, Trade coordin	Tasks linkage procedure, Functionality	Using excel based short term schedules is	General contractor
15	Software interoperability, Accessibility, F	Interface with reality capture, Functionality		General contractor
16	Software interoperability	Complexity		Construction Management Agency
17	Trade coordination	3D / scheduling coordination		General contractor
18	Trade coordination	Functionality		General contractor
19	Software interoperability, Portability, Tra	Complexity		Construction Management Agency
20	Accessibility, Functionality, Portability, T	N/A		General contractor
21	Software interoperability, Accessibility, T	Interface with reality capture, 3D / scheduling coordination, Interoperability, Comp		General contractor
22	BIM-based formulation, Accessibility, Fu	Tasks linkage procedure, 3D /	scheduling software packages should be able to creat	Subcontractor
23	Software interoperability, Functionality	Functionality		Public agency
24	Software interoperability	I would need to better understand how 4DBIM could be utilized in residential cons		Single and Multi-family Homebuilding/D
25	Software interoperability, BIM-based for	Tasks linkage procedure, 3D / scheduling coordination, Visualization, Interoperabi		General contractor
26	Sequencing	Complexity		General contractor
27	Software interoperability, Portability	Tasks linkage procedure, Interface with r	Scheduling and project progress tracking	Technology/Construction
28	BIM-based formulation	Tasks linkage procedure, Interface with reality capture,	Use in TI scope	General contractor
29	Software interoperability, Trade coordina	Tasks linkage procedure, 3D / scheduling coordination, Functionality		General contractor
30	Software interoperability, BIM-based for	3D / scheduling coordination, Visualization, Accessibility, Complexity		DESIGN/BUILD HOMEBUILDER
31	Sequencing, BIM-based formulation, Tra	Tasks linkage procedure, 3D / scheduling coordination, Complexity		General contractor
32	Software interoperability, Portability	Interface with reality capture, 3D / sched	It should be done easily. People in constr	Consultant
33	Accessibility	Tasks linkage procedure, Interface with r	Getting granular with activity metrics and	General contractor
34	Software interoperability, BIM-based for	Accessibility, Functionality		General contractor
35	Software interoperability, Sequencing, BI	Tasks linkage procedure, Interface with reality capture, 3D / scheduling coordinatio		General contractor
36	Software interoperability, Sequencing, BI	Visualization, Accessibility, Complexity	They should all be connected in a more s	General contractor
37	Software interoperability, BIM-based for	Tasks linkage procedure, 3D / scheduling coordination		Integrated Architecture/Design/Construct
38	Sequencing, Trade coordination	Tasks linkage procedure	4D is extremely useful if all trades and su	General contractor
39	Sequencing, Accessibility, Trade coordin	Accessibility, bandwidth relates to access	The more accuracy that can be shown wi	General contractor
40	Accessibility, Trade coordination	Accessibility	updating completed tasks thru 4D BIM w	Subcontractor

Question 25		Question 26	Question 27	Question 28
Response No	What type of industry does your company mainly focus operations in?	What is your primary professional background?	What best describes your job's role in your organization?	How many years of experience do you have working in this position? (use only numbers)
1	Building	Engineer	Research	4
2	Building	Engineer	Construction Manager	4
3	Buildings, Heavy industrial, Heavy civil /	Civil Engineer	Project Engineer	8
4	Buildings	Civil Engineer	Project Engineer	2
5	Heavy civil / infrastructure	Civil Engineer	Project Engineer	3
6	Buildings	Civil Engineer	Project Engineer	1
7	Buildings, Heavy civil / infrastructure, A	Civil Engineer	Scheduler / Project Controls	6
8	Heavy industrial, Heavy civil / infrastruct	Civil Engineer	Project Manager	11
9	Heavy civil / infrastructure	Civil Engineer	Project Manager	5
10	Government facilities, Transportation	Civil Engineer	Project Manager	8
11	Buildings, Heavy industrial, Heavy civil /	Civil Engineer	Project Manager	4
12	Buildings, Commercial	Civil Engineer	Project Manager	3
13	Buildings, Government facilities, Engine	Civil Engineer	Project Manager	2
14	Heavy industrial, Heavy civil / infrastruct	Civil Engineer	Project Engineer	2
15	Buildings, Commercial	Civil Engineer	Owner	4
16	Heavy civil / infrastructure, Railroad	Civil Engineer	Project Engineer	1
17	Buildings, Mechanical / Electrical / Plum	Civil Engineer	Project Scheduler	1
18	Buildings, Heavy industrial, Heavy civil /	Civil Engineer	Superintendent	1
19	Buildings	Civil Engineer	Project Manager	10
20	Buildings, Facilities restauration / renova	Civil Engineer	Project Manager	6
21	Buildings, Commercial, Government faci	Civil Engineer	Project Manager	3
22	Buildings, Commercial, Facilities restaur	Civil Engineer	Project Manager	5
23	Heavy civil / infrastructure, Railroad, Go	Civil Engineer	Project Manager	10
24	Buildings, Subdivisions	Civil Engineer	President/Executive	20
25	Buildings	Civil Engineer	Executive Vice President, Construction	1
26	Commercial	Civil Engineer	Project Engineer	2
27	Buildings, Timber, Commercial, Facilitie	Civil Engineer	New Build R&D and Analyst	1
28	Buildings, Commercial, Government faci	Architect	VDC Engineer	3.5
29	Buildings	Civil Engineer	Project Manager	4
30	Buildings, Facilities restauration / renova	Architect	VDC Manager	2
31	Buildings, Heavy industrial, Heavy civil /	Civil Engineer	Project Manager	5
32	Buildings	Civil Engineer	Owner	1
33	Buildings, Commercial	Civil Engineer	Project Manager	14
34	Buildings	Civil Engineer	Site Engineer	2
35	Commercial	Civil Engineer	Project Manager	1
36	Buildings, Commercial, Facilities restaur	Civil Engineer	Project Engineer	2
37	Buildings, Heavy civil / infrastructure, M	Civil Engineer	VDC Engineer	0.5
38	Buildings, Commercial	Civil Engineer	VDC Manager	3
39	Buildings, Heavy industrial, Mechanical	Architect	VDC Manager	33
40	Buildings	Civil Engineer	General Manager	17

Question 29

Response No	What is the annual revenue (R) range of your company?
1	
2	R < 10M (million)
3	R > 1B
4	R > 1B
5	
6	10M < R < 100M
7	10M < R < 100M
8	R > 1B
9	100M < R < 1B (billion)
10	
11	R > 1B
12	
13	R < 10M (million)
14	R > 1B
15	10M < R < 100M
16	
17	10M < R < 100M
18	R > 1B
19	R > 1B
20	100M < R < 1B (billion)
21	100M < R < 1B (billion)
22	R < 10M (million)
23	100M < R < 1B (billion)
24	
25	100M < R < 1B (billion)
26	
27	R > 1B
28	R > 1B
29	100M < R < 1B (billion)
30	R < 10M (million)
31	R > 1B
32	R < 10M (million)
33	R > 1B
34	R < 10M (million)
35	100M < R < 1B (billion)
36	100M < R < 1B (billion)
37	10M < R < 100M
38	
39	R > 1B
40	10M < R < 100M