CHALMERS
UNIVERSITY OF TECHNOLOGY

BIM collaboration with data collection tools

BIM in automated monitoring and management with corrective privilege

Master Thesis in MSc. Design and Construction Project Management

KHALID ALSHAWWA

Department of Architecture and Civil Engineering
Division of Construction Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Master's Thesis ACEX30-19-108
Gothenburg, Sweden 2019

MASTER'S THESIS ACEX30-19-108

BIM collaboration with data collection tools

BIM in automated monitoring and management with corrective privilege

Master's Thesis in the Master's Programme Design and Construction Project Management

KHALID ALSHAWWA

Department of Architecture and Civil Engineering

Division of Construction Management

CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2019

BIM collaboration with data collection tools
BIM in automated monitoring and management with corrective privilege

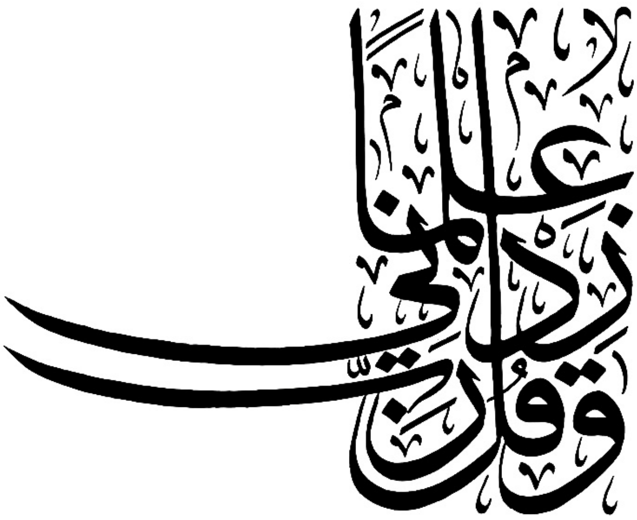
Master's Thesis in the Master's Programme Design and Construction Project Management

KHALID ALSHAWWA

Examensarbete ACEX30-19-108
Institutionen för arkitektur och samhällsbyggnadsteknik
Chalmers tekniska högskola, 2019

Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Department of Architecture and Civil Engineering
Göteborg, Sweden, 2019



And say, "My Lord, increase me in knowledge" (Quran 20:114)

BIM collaboration with data collection tools
BIM in automated monitoring and management with corrective privilege

Master's thesis in the Master's Programme Design and Construction Project Management

KHALID ALSHAWWA

Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology

ABSTRACT

This thesis aims to drawing a conceptual framework that is believed to hold high potential towards the construction industry in terms of progress, development, saving human efforts, avoiding time lags, increasing the quality and efficiency in delivering construction projects. Another objective of this thesis is to analyze the status the construction industry has nowadays and investigating the main reasons and factors acting as a hindrance for coinciding with the recently developed approaches/technologies in the current era. The drawn conceptual framework is mainly about automating management and monitoring daily activities on construction sites. Automation is labeled in different aspects such as site data collection, automatic modeling of 3D point clouds, automatic compliance checking with pre-assigned parameters, and automatic corrective scheduling. Throughout the analysis of possible hindrances three factors were recognized: human interaction factor, technical shortage factor, and business cycle factor. In conclusion, suggestions are made according to analysis in order to mitigate the significance of these factors. In addition, recommendations for future research are made implicitly within conclusion.

Key words: BIM and automation, BIM monitoring, Auto-management with BIM, Compliance checking, Automatic corrective scheduling, Slow development

Contents

Preface

Obedience to Lord, the source of inner peace, for his blessings throughout the various stages of this thesis.

This piece of work is not a result of personal effort but rather an outcome of accumulative support by those who I belong to. I deliver a special greeting to my grandfather, may he rest in peace, for his abundant support throughout the years. I thank my aunt for her dedication in educating my brother and I throughout the decades. I thank the rest of family and friends who have been a solid stable support.

I would like to thank my supervisors Dimosthenis Kifokeris and Mikael Viklund Tallgren and my examiner Christian Koch for their guidance and assistance during the project. They have been a great support during my research, their feedback, insights, analysis and encouragement have been paramount to complete this study.
I would also like to thank the respondents within the construction industry who significantly contributed to this piece of work by their valuable practical knowledge and experience on the subject.

I thank the Swedish institute for funding my master studies in Sweden. Those two years were beneficial and eye opening.

Praises to Lord, the deserving of our gratitude, when we start as well as when we finish.

Warm regards,
Khalid Alshawwa
Gothenburg, Sweden

1 Introduction

Construction projects are massive pool of information. Managing this information in a good manner entails delivering the construction project with adequate time, cost, and quality. The quality of these information is pivotal for decision makers. It is essential for cooperated different parties to have access to this pool of information when needed and at the place of interest within the construction project.

A vital point in construction projects is to deliver all elements within a project in accordance to its pre-determined parameters. Mistaking information from site by inspectors and personnel has been frequently identified as a shortcoming (Matthews et al., 2015). This leads to many deficiencies until the submission of the project such as poor productivity, dismantling and rework which means schedule and budget overruns.

Managing construction projects throughout traditional documents has shown many shortcomings such as defaults in updating documents according to construction site changes, coordination issues among different project's disciplines, holding apart non-geometric data from geometric drawings, inaccurate understanding of construction complexities, overlapping of tasks from different disciplines, duplicating tasks within a single discipline, inadequate estimation of errors consequences (Odeh & Battaineh, 2002).

The gradual introduction of some technologies has helped in managing the traditional documents in a digitalized manner. The development of different software for different purposes has witnessed gradual shifting and dependence on digitalizing data especially in documentation. However, the majority of construction practitioners still prefer implementing construction projects in a traditional manner. This is seen as a result of many factors including fear of change, unnecessary seen need for changing processes, increased expenses due to development, etc. (Babič & Rebolj, 2016).

The introduction of Building information modelling (BIM) has made a jump within the construction industry. The use of Building information modelling BIM had certain fields of focus. The main focus of BIM was in the design stage and its potential was initially seen in technical aspects. Afterwards, its potential was seen vital and more significant within managing construction databases and coordination (Babič & Rebolj, 2016). Meanwhile, reliance on BIM databases entitled a momentous reduction in the reliance on tangible documents. Abandoning tangible documents confronted resistance previously by construction practitioners but this is slowly changing (Babič & Rebolj, 2016).

Project management is a broad concept that holds many aspects within it. Many studies covered some aspects of it such as using BIM in planning for design phase, BIM in construction scheduling, BIM in construction monitoring, the value of BIM in element compliance between as built and as planned models etc. (Pătrăucean et al., 2015). Some of the previous notions, such as construction monitoring, were based on the collaboration between BIM and some data collection tools in order to create "as built" BIM models. Data collection tools are used on sites to capture as much details as possible by scanning the site. Afterwards, some BIM tools are usually used in order to convert these captured data into useful information that can be exploited by constructors (Pătrăucean et al., 2015). Producing "as built" BIM models is widely researched since those models represent a reflection of the construction state at certain points through its construction progress. Those models help in a variety of tasks ranging from quality control to quantity take-offs, project planning, and project maintenance (Pătrăucean et al., 2015).

The combination and comparison among data, which are both construction status reflective and data from the planning phase, opened new opportunities in this field such as monitoring and managing construction sites, constant construction progress checking, applying automatic earned value analysis (EVA), etc. (Pătrăucean et al., 2015).

The purpose of this thesis is to propose a conceptual framework that incorporates both data collection tools with BIM databases to help in assessing construction elements' compliance in accordance to both their parameters and spatial position, tracking construction earned value with time, assessing construction site' status in accordance to it time schedule, and assessing any possible hazards throughout the implementation phase. In detail, the placement of elements should match a definite placement in previous plans in order for schedules activities to be correct. This is dependent on the ongoing circumstances on construction sites. In cases where these two parts don't match, error warnings can show up. This thesis highlights the potential of the collaboration between BIM databases with 3D data collection tools in order to tackle common construction errors.

The proposed conceptual framework main focus is in the construction stage. Then this thesis proceeds to examine this conceptual framework's applicability in cooperation with actual practitioners and focusing on understanding the barriers holding the construction industry from implementing it. Eventually, the areas of needed focus are advised in order to mitigate this shortage within the construction industry.

1.1 Research questions

This thesis aims to investigate if there is some hidden capabilities and potential in the collaboration between BIM databases and recent data collection tools on construction sites. It seeks to fetch some left research gaps and consider bridging different ideas in order to minimize them. This thesis starts by drawing a conceptual framework that links 3D data collection tools on construction sites with BIM databases in a trial to automate different managerial processes within the construction industry. Thereby, it is dedicated to answer the following research questions:

1. What are the major potentials of combining 3D data collection tools on construction sites with Building Information Modeling databases?
2. What are the barriers holding the construction industry apart from implementing the drawn conceptual framework?
3. What are the prospects that should be focused on in order to get the construction industry closer to implementing this conceptual framework within its regular processes?

This thesis is going to highlight future possibilities of using BIM in following up and re-scheduling. This entitles an investigation on the ability of data collection tools to update the "as built" BIM model that reflects construction sites' status. Afterwards, processing this model in accordance with the "as planned" model, i.e. from planning phase, from compliance perspective.

2 Method description

This thesis is a qualitative research since it seeks to deal with different concepts and theories and tries to induce mutual connections among them. This thesis does consider validating its conceptual framework in a qualitative manner. This qualitative thesis comprises a range of different methods within its methodological approach. These included reviewing literature on major topics, observations, employing interviews and transcribing their recordings into texts, interpreting these texts throughout different stages including coding and analysing. The conducted approach in reasoning was inductive since initial observations were transferred into patterns and hypotheses which eventually were used to create a conceptual framework (Fereday & Muir-Cochrane, 2006). However, the presented conceptual framework needs further reasoning and testing which entails a recommendation to change to deductive research in order to completely validate and confirm the highlighted hypotheses in the framework.

2.1 Collected data analysis

This thesis depends heavily on reviewing literature on different topics and concepts in order to cover the major objectives highlighted within research questions. The topics gathered varied diversely including 3D data capturing, 3D BIM modelling, BIM in scheduling, BIM usage in compliance checking, human interaction with organizations, human behaviour, managing organizations, development in construction industry, financing innovation. The choice of those highlighted topics was based on meeting a limitation. This is to provide a comprehensive idea of latest research connected to the drawn conceptual framework and to provide a closer connection between literature review and empirical findings. The main idea was to dismantle the main conceptual framework into its simplistic conceptual origin and seeking the most related latest literature covering its fragmented modest concepts. In other words, the main conceptual framework idea was dismantled into smaller segments. Thereafter literature coverage was mainly put to investigate those concepts. Literature coverage also targeted with less dominance connecting the conceptual framework to empirical findings.

The reviewed literature had two major confronted limitations that need to be elaborated. In accordance to latest technological innovations in field of 3D data capturing, there was noticed a gap between academic and practical knowledge. In order to mitigate this, reviewing practical developing websites was performed to assist the gathered literature data. Another limitation was the scarcity in fetching literature covering specific concepts within the conceptual framework. In such cases, close concepts were reviewed in an attempt to bridge gained data to the desired concepts.

The obtained data were acquired from different elements including annual reports, master theses, e-books, conference papers, scholarly articles, magazine articles, software websites, comparative studies, case study documents, and interview transcripts,. The selection of these elements was based on the needs of the constructed conceptual framework and the gained empirical findings. Coding was mainly utilized in terms of analysing and handling the gathered data. The coding approach was handled throughout two phases; first coding cycle and second coding cycle. This was accomplished for the refinement of gathered data to the needed level of deduction. Each one of these coding cycles had its own methods. The two mainly used coding methods for first cycle coding were Simultaneous Coding (Grammatical methods) and

Descriptive Coding (Elemental methods). While the chosen coding method for second coding cycle was Focused Coding (Hedlund-de, 2013).

Simultaneous coding, choice of at least two distinct codes, was applied since the targeted data content could be interpreted in multiple significant meanings that may not be only grasped in one single code (Hedlund-de, 2013). To handle some other parts of the collected data within the first cycle coding descriptive coding was also used since it offers basic generic labels towards data. Descriptive coding was applied in terms of content description and not topic description; provided topic is what is generally being talked about whilst content is the actual body of a passage (Hedlund-de, 2013). For the second cycle, Focused coding was employed since it seeks to find the most considerable initial codes to evolve the most salient categories that can facilitate upcoming analysis.

In few parts of interview transcripts In Vivo Coding was applied to capture a code directly taken from what the interviewee literally declared (Adler & Adler, 1987). It is worth mentioning, however, that coding process itself apart from the successive analysis can differ from an observant to another depending on which textual filters are considered when perceiving data (Adler & Adler, 1987).

2.2 Interviews & their findings

The empirical foundation within this thesis was based purely on interviews. The course of interviews employed were semi-structured qualitative interviews since questions were presented and were structured with no strict adherence to the interview schedule. This thesis encountered six interviews in order to build the empirical part of it. Five interviews out of these were held in the company’s office and one of them was managed through Skype for Business. And it was only one interviewee and interviewer per interview. The length of interviews varied from 50 to 75 minutes. The interviews were initially recorded and then transcribed literally for later assessment throughout the captured texts. The coding and analysis of these text was accomplished in accordance to the previously highlighted criteria mentioned under section 2.1.

The interviews were done mainly with two different companies. One of these companies is a leading BIM consultant in using laser scanner for multidisciplinary BIM purposes in the Swedish construction industries. The other company is a big consultant office which is engaged to a high extent with designing and planning in accordance to UN sustainability goals and is considered Europe’s leading architecture and engineering consultant. Six interviews were accomplished with employees in both companies. Four interviews with the first company and two other interviews were done in the second one. The positions of the six interviewees were, respectively, BIM strategist, BIM coordinator and team leader, Data coordination BIM/CAD, BIM coordinator, BIM manager, and VDC engineer (see sections 5.1-5.6).

Those positions were chosen since they were considered most relevant and might hold highest potential in terms of expertise, technical knowledge, and experience in handling data in BIM data environments plus laser scanning and managing point cloud data.

These positions were also believed to be able to provide a comprehensive perspective on the topic and to understand their perspective in accordance to the conventional planning and construction compliance methods. Moreover, it is to get an idea on the way practitioners view BIM as a tool that brings all teams together technically, and the way construction implementers see its future potential. Another highlighted aspect was questioning the social factors in cooperation with BIM and how much are practitioners open to implement data collection tools on daily basis on site.

The interview schedule was initially general in terms of scope in order to provide the interviewee some space to gradually reach the main spot of this thesis and also provide the interviewer space to examine some further questions as a response to what the interviewee might say and seem significant to the thesis (Bryman, 2016). The entry part of these interviews came in the sense of having a small open conversation on the topic of BIM in the construction stage which acted as a preparation for the mind set towards topic. They started by a general introduction by the interviewer on the main topic of thesis and then presenting the created conceptual framework to the interviewee. Afterwards, guiding the interview slowly towards the needed topics through the interview schedule (Bryman, 2016). The style of these conversations was to good extent informal and the way of presenting the topic and issues was nearly the same through all interviews.

Furthermore, some specific questions were presented at a later point in interviews to direct the focus to the specific area of interest. These closed questions were used sometimes to mitigate the variation of interviewees' answers and make the answers more convergent than divergent to increase the validity of measures in the interviews (Bryman, 2016). The use of these closed/pre-coded questions had a major privilege in facilitating data processing and the ease of making simple comparisons of interviewees' answers (See Appendix, section 9.2).

The covered questions within the interview schedule focused on understanding the current status of the global construction industry from different points of view. However, some of interviewees' answers were based on their experience within the Swedish construction industry. These questions included investigating current norms within construction activity scheduling, technology interaction, compliance checking procedures, etc. The questions sought to spot the current gap, holding this conceptual framework back from practice, in global construction industry generally and Swedish construction industry specifically. This was done in an attempt to bridge the constructed conceptual framework, which is a pure theoretical substance, with practice. (See Appendix, section 9.2).

The general purpose of interviews was getting different perspectives on the current approaches used in construction industry within the construction phase and understanding the consequential faced challenges for the current approach. Moreover, predicting possible future challenges faced by the presented new approach, and getting suggestion from practitioners that might facilitate its integration in practice.

2.3 Research limitation

The main domain of this thesis is limited, at least for the built conceptual framework, to the construction phase within construction projects. Meanwhile a part of this thesis is also concerned about the possible changes/corrections that might happen in planning and scheduling phase during the construction phase, for instance in case client made change of order in some aspects. In other words, the conceptual framework built is mainly concerned about day to day changes on construction site and is still significantly dependent on the planning phase and its corresponding changes during the construction phase. It is worth mentioning that the presented thesis is mainly based on the Swedish construction context but it still covers general aspect on the global construction approach.

3 Literature review

In the following sections, three main prospects are covered. Individuals, organizations and their interaction with each other. Many psychological and organizational related factors in affecting individuals are covered. Then literature resumes to elaborate some recent financing approaches adopted by the construction industry towards innovation and development bases research. Finally, different aspects that are needed for construction a conceptual framework on using BIM in automatic management and monitor of construction sites, are elaborated fragmentally. Previous researches on construction monitoring and scheduling using different techniques were investigated. In the following sections different models, approaches, technological inventions from relevant researches will be thoroughly shown. These sections will cover both traditional and recent views in data collection and presenting some of the recent tools used for this purpose. Then cloud-based BIM collaboration with these data collection tools will be presented. And finally viewing some of BIM's capabilities in managing construction projects automatically, i.e. in construction scheduling/rescheduling and following up.

3.1 Individuals, organizations, and progress

Construction companies are currently known for following traditional agendas in implementing construction projects. This has been the case for decades since the start of construction business. Through time and through the evolution of different types of organizational structures. The construction industry has taken the shape of hierarchical organizations in a bureaucratic manner (Faridi & El-Sayegh, 2006). Construction firms have been witnessing, since the commencement of construction history, a segregation among its different employee levels. A hierarchical structure that allocates responsibilities of groups of sub-ordinates on collective positions dominates the vast majority of construction companies (Faridi & El-Sayegh, 2006).

Different organizational structures have their influence on their individuals. Flat organizations are known for distributing nearly the same level of responsibility on different recruitment positions (Clegg et al., 2016). This allows for more room of interaction and contribution from the different levels of employees, i.e. managers and sub-ordinates. A major issue in accepting new forms of approaches within the construction industry is the lack of human acceptance to adopt new approaches/frameworks. The organizational structure has a major role in letting different employee levels to have the same access to openness to change (Fleming, 2008). In cases where hierarchical structure dominates an organization, sub-ordinates access to express their willingness to change is limited. Flat organizations, however, are known for developing a more resilient atmosphere for its employees in terms of ability to influence the organizational body in relatively the same degree among its different contributors (Clegg et al., 2016).

Organizational structure has also its influence on its individuals and the way they perceive their contribution to their firm. In other words, individual might built up inherently an uncomplete understanding of their role within an organization in terms of influence and contribution (Clegg et al., 2016). The manner in which construction firms perform organizationally is nearly the same since construction commencement. This has gradually shifted from being a practice towards being a tradition. This has its possible effect on individuals by perceiving change as an industrial-level responsibility rather than being individual-level responsibility (Fleming, 2008). Thereby, change has been timely related to the level of responsiveness of organizations' superiors at the first place.

The manner in which humans perceive and interact with change varies among them. Some industry sectors witness higher levels of acceptance than others (Fleming, 2008). For instance, mobile phones industry has evolved rapidly through its evolution stages where its practitioners were, to a high extent, resilient in terms of understanding the need for adaption as technology progresses (Funk, 2009). This is especially true if comparison is to be made with other industries that are relatively slow in their adaption with technology, such as the construction industry.

Individuals' fear of organizational change is psychologically related to previous experiences related to change in other industries (Fleming, 2008). Generally speaking, change as a pillar for increasing organizational efficiency and seeking improvement has a variety of consequences. These consequences might be both seen and unseen for it predictors (Fleming, 2008). In the majority of cases, practitioners are aware of the seen/anticipated consequences while their fear of adopting new changes comes as a result of their fear for not evaluating and assessing the hidden consequences of adopting new approaches/practices (Fleming, 2008).

One of the major consequences of organizational process change, especially in cases where new technologies enter organizations' frame of work, is the turbulence affecting job vacancies (Schwab, 2017). This is valid and true in cases where automation overwhelms organizational systems that are human dependent. This is also true when considering previous events such as the industrial revolution, currently referred to as the first industrial revolution, and its effects on some fields such as agriculture and reducing factory labours drastically by the invention of some machines of which one of them is the cotton gin (Schwab, 2017).

Changing people's mentality in an attempt to increase their willingness to adapt to new approaches/strategies is a matter of convincing (Fleming, 2008). Although, humans as psychological creatures have different degrees of complexities of which part of them are relatively harder to persuade (Clegg et al., 2016). Persuading humans to change systematically in their daily based work implies eventually dealing with organizational process-based changes. These process-based changes might vary in their degree from simplistic to radical changes (Schwab, 2017). In order to persuade practitioners to change, handling the radical change should be exquisitely clarified, explained, and solved in order to gain higher levels of acceptances by practitioners towards involving new strategies and approaches (Fleming, 2008).

3.2 Financing research & development in the construction industry

Although construction firms are mostly project-based organizations (PBOs). A portion of them try to investigate their capabilities to exploit and explore their financial ability in an educative manner (Eriksson, 2013). This entitles construction bodies to learn to grow financial both internally as well as externally, i.e. funding exterior project that hold rewarding financial potential (Eriksson, 2013).

Investment and innovation are known for boosting industries' capabilities in meeting futuristic standards and requirements. Innovative ideas can increase the efficiency in achieving tasks and thereby are seen vital and worth developing investments. Many studies have covered the general trend in supporting research and innovation from different aspects in the construction industry. It is seen that supporting innovation and development research within the construction industry is different than other industries terms of focus areas and long term vision (Rus, 2016).

Nowadays, it is prominent that financing research on development and innovation is essential regardless of cost. This is more apparent in industries that witness competing markets with many competitors with nearly the same capabilities (Rus, 2016). This is speculated to be valid since competitors seek to find customers attraction in uniqueness of performance throughout their historical innovative reputation that acts as a first attraction for interested clients (Rus, 2016). Rus (2016) has done a comparative study that aimed to understanding the interaction of construction companies with innovation and development research in terms of finance and sustainable support. His comparative study included three construction-related companies from US, France, and China that have different reputations in the global market.

One of the major findings of his work is that the construction-related companies that financed developing research have eventually increased their sales value and this incentivized them to allocate further expenses for innovation and development reasons (Rus, 2016). Another finding in the study is the dominant effect national economic stability has on world class companies in determining the amount of support they can withhold in sever times. This was evident in the French industrial company Lafarge group. It has suffered from dropping turnover, significant reduction in employees' level and consequently lowering research and development finances as a result of the economic crisis that hit Europe during the end of 2008 and through 2009 (Rus, 2016).

Another study was done by Chirkunova et al. (2016) with the aim of investigating the possible financing instruments in the field of innovation and development for construction projects. Their study also included an analysis of the major factors that can guide in the process of selecting the most suitable financing instruments. They covered many ways of financing innovation and investment in projects. Some of these ways were direct such as taking bank loans, e.g. investment lending and project financing, seeking innovation credit and fund raising and some were indirect such as financing the instalment of needed project equipment or renting the equipment needed for performing the required innovation-related research, purchasing a license for the technology that is anticipated to be invented and then paying the cost of the required research-related expenses, e.g. instruments, renting laboratories, etc., used throughout its invention phases in the form of royalties (Chirkunova et al., 2016). Royalties mean cutting a portion of income after selling a product in the market, upon agreement, in order to pay relatively high costs in a fragmented manner without the need of explicit investment capital (Chirkunova et al., 2016).

Chirkunova et al. (2016) have thereby suggested a classification map for choosing the most suitable financing instrument, whether being direct or indirect, depending on many aspects such as the financing duration, organizational membership in financing-related boards, implementation possibilities in the form private-public partnership (PPP). One of their outcomes is that there is no such notion of 'ideal financing instrument' for innovation based research programs but rather each financing instrument has its suitability and thereby will have its advantages and disadvantages on case to case basis (Chirkunova et al., 2016).

An earlier study done by Akhmetshina & Mustafin (2015) highlighted the role of private-public partnership in assisting the financing procedure of projects, within construction industry and other industries, that are innovation oriented. They specifically investigated the dominant factors in restricting the cooperation of this kind, i.e. partnership. They also analysed and recommended the suitable use of such partnerships.

They focused of demonstrating the advantages and disadvantages of promoting private-public partnership. The major advantages included providing higher return on research funds and addressing the issues they confronted cooperatively, attracting the private sector with its expertise and creating competitive environments that eventually mean producing exquisite innovations and competing transparently in tendering projects, and finally it allocates shared responsibility between partners (Akhmetshina & Mustafin, 2015). However, private-public partnership also encounters some negative features when it’s being involved in innovation-based projects. These downsides include the interference the state applies throughout the different stages of the development process, and the indirect trials to resume an active business involvement in innovation from both the private and public parties, which can be considered a downside by the private sector since the financial contribution can be considered mainly external rather than being internal (Akhmetshina & Mustafin, 2015).

3.3 Data collection evolution on construction sites

Conventionally, tracking progress on construction sites is held throughout visual inspections and periodic reporting based on those inspections. Construction element’s specifications are checked throughout site inspectors. Their role ensures that all elements executed on construction sites match those pre-allocated specifications in the project contract. A checklist is usually used to ensure checking all needed construction elements on construction sites, whether they conform their pre-determined parameter or not (Schaufelberger & Holm, 2002). In case of unconformity, corrective discussions are held at the follow-up periodic meetings (Schaufelberger & Holm, 2002).

A vital aspect is questioning the reliability of inspectors in applying inspections. Human interpretations are prone to different types of errors. The most common human error in inspection is ensuring the compliance of an object between its planned position and its built position (Matthews et al., 2015). Other errors might include wrong identification of specific element type, miss checking because of large quantities, requirements misquoting, etc. and this all will lead into incomplete, inaccurate and misleading reports (Matthews et al., 2015).

The introduction of BIM databases implied mainly the creation of digitalized models. The main focus of BIM was in the design stage and its potential was initially seen in technical aspects. Afterwards, its potential was seen vital and more significant within managing construction databases and coordination (Babič & Rebolj, 2016). Two types of models are vital. One being prepared once the planning phase is commenced and known as “as planned” model. The other is referred to as “as built” model and reflects the physical status of construction sites (Pătrăucean et al., 2015).

Generally, the “as built” BIM model is not usually constantly updated once execution commences. This is an issue primarily because contractors and subcontractors prefer to deal with tangible documents and thereby don’t update the “as built” BIM model (Babič & Rebolj, 2016). This creates a difference between the two BIM models, i.e. “as planned” and “as built”. If these two model are updated instantly as construction progresses then accurate real-time monitoring can be achieved (Tserng et al., 2014).

In order to tackle this defect, researchers studied several technologies that might facilitate automatic inspection. Reviewing emerged technologies considered to have high potential for inspection and compliance, the most promising ones are Radio Frequency Identification (RFID), Ultra-Wide Band (UWB), Global Navigation Satellite System (GNSS), 2D imaging, Photogrammetry, and three-dimensional (3D) Terrestrial Laser Scanning (TLS). Their main applications includes monitoring supply chain progress, monitoring worker's productivity (spatial and physical movement), and monitoring structural elements progress (Bosché et al., 2015).

A lot of technologies as mentioned earlier were experimented for BIM integration such as RFID, time lapse cameras, and laser tagging with Augmented Reality (AR) shortly. The efficiency and effectiveness of such combinations is still limited (Wang et al., 2013). Hinkka & Tätiläl (2013) elaborated that RFID and laser tagging have been mainly used for tracking delivery of plants for progress and quality tracing. They emphasized the advantages of RFID, laser tagging and barcoding in inventory management while it is still limited in real time monitoring with BIM integration. Those technologies are only limited to identify objects on site with hand-held scanners and then can be used to update the BIM model. Yet the scanned objects need to be furtherly inspected to fulfil the overall specification requirements such as being installed correctly, right size, etc. (Hinkka & Tätiläl, 2013).

Golparvar-Ford et al. (2009) demonstrated how machine learning with the utilization of Bayesian statistics, which is a theory that expresses a degree of belief in event occurrence and changes automatically as new data are gathered, can be used to automatically detect elements with specific characteristics on sites. The outcome can be a four-dimensional Augmented Reality (4D AR) model which can let both the "as built" and "as planned" models interact where deviations are to be automatically coloured within the AR BIM model (Golparvar-Fard et al., 2015).

Kim et al. (2013) promoted 3D TLS to be suitable enough for monitoring reasons and creating as-built 3D models of sites. Yang et al. (2017) argue that among these, previously mentioned, technologies 3D TLS has been considered by many to be the most suitable technology for capturing 3D information on construction sites with relatively high precision and pace. An indisputable fact proving the importance of laser scanning software and hardware is the exponential growth of its market the last decade (Bosché et al., 2015). The main focus for those developers is to increase the interaction between 3D point cloud data, which are data captured by 3D laser scanning tools, and BIM models. Even though the usage of 3D TLS in capturing data on construction sites is advised, it still needs further development in terms of capturing quality and precision (Yang et al., 2017).

In the processing of 3D TLS captured data, Bosché et al. (2015) provided a distinction between different terms has to be introduced prior proceeding in order to prohibit misconception:

- **Detected**: it means something was found in the field of vision of the scanner (i.e. some features were found in data such as circular cross section).
- **Recognized**: it means that an object is distinguished from its surroundings (i.e. a pipe for instance was recognized from its complex surroundings).
- **Identified**: it means a specific object with its parameters was caught by lenses. This object identically matches a pre-defined object on the BIM model (i.e. *B-Gas-Vent* pipe 3" was identified).

The limitation in 3D TLS technology is in processing the data through software since the current software isn't efficient enough to recognize objects in the 3D TLS data and thereby is considered limited (Yang et al., 2017). But with the advent of 3D BIM, many of the researchers anticipated a significant privilege of having complete data in a BIM model to be tracked on construction fields. In other words, the new approaches consider 3D data in "as planned" BIM models a tool to assist software throughout definite algorithms to spot the inspected elements on "as built" BIM models (Pătrăucean et al., 2015). These algorithms use the existing 3D BIM data from the "as planned" model to facilitate the processing of captured 3D point cloud data by the laser scanning instrument (Pătrăucean et al., 2015).

A privilege of updating "as built" BIM models automatically is saving time of regular office work dedicated for updating the "as planned" BIM models manually in order to match the delivered "as built" BIM models (Bosché et al., 2015). Another advantage is to compare "as built" BIM models instantly with "as planned" BIM models. This comparison can effectively help in automatically tracking the earned value of construction projects. This can be visualized through a "percent-built as planned" figure (Bosché et al., 2015).

Bosché et al. (2015) have done a research investigating further possibilities in tracking mechanical electrical plumbing (MEP) components with circular cross sections. This research was developed in order to spot the contradictions between "as build" and "as planned" modelled pipes. This was specifically implemented for pipes that might not be noticed by inspectors as a result of different reasons such as human-errors, unnoticed error in pipes placement.

Bosché et al. (2015) focused on MEP components identification, specifically, pipes in complex construction environments. Their major concern was in occlusions of pipes so that a pipe is not recognized as two different elements instead of one. Also pipes that are connected through T-connections and elbows need to be recognized fragmentally instead of recognizing them as one continuous pipe. Those two points are put to be furtherly investigated and developed.

In the construction industry, 3D point cloud data produced by 3D laser scanners are becoming a standard in practice. 3D point cloud data are a datum point for constructing "as build" BIM models. However, the dependence on 3D point cloud data to produce "as built" BIM models in order to perform compliance checking has been relatively limited (Moon et al., 2019). In case of large construction projects, it is difficult to acquire 3D point cloud data from regular laser scanning techniques. This has let image-processing technology in to tackle this issue by the aid of unmanned aerial vehicles (UAVs) (Moon et al., 2019). However, reliance on UAVs to compensate for construction projects' sizes is still limited due to its low precision.

This brings spot light to the concept "Scan vs BIM" which implies that scanning the construction site is associated and boosted by the pre-existing 3D "as planned" BIM model that works as a guiding tool to anticipate specific elements on construction fields. This can facilitate the construction of "as built" BIM models even for large construction projects (Wang et al., 2018). This technique requires a precise and correct geometric alignment between the BIM models in order for the comparison between the "as built" and "as planned" BIM models to be guiding (Bosché et al., 2015). This concept was proven to boost the process of matching the two models. More specifically in the recognition and identification of MEP components but with one limitation. This limitation is the distance between as-planned position and as-built position. It should not exceed δmax, where δ is the difference in position between the two models measured in terms of length (Bosché et al., 2015).

Accordingly the available as-planned BIM model to be tracked plus the collected data from 3D laser scanners can be leveraged for not just detection and recognition but also complete identification of the elements (Wang et al., 2018). This specific approach was proven through real-life experiments to perform well for structural elements work. However, this approach depends primarily on some features in the objects to be tracked such as surface orientation. The issue here is that it can't track an object if it had relatively high contradiction geometrically between its as-planned and as-built positions. For example, a pipe that was placed more than δmax (50 mm) from its planned position will not be recognized (Bosché et al., 2015).

Since the previously mentioned techniques are computationally intensive and perform their best in simple construction environments with regular geometric shapes, they are still cumbersome/slowly managed due to process-agnostic reasons such as segmentation, registration, and matching large scale 3D point cloud data (Chen & Cho, 2018).

Chen & Cho (2018) proposed an interesting approach that seeks to measure the deviation between "as built" and "as planned" BIM models. Their approach is unique in the sense of achieving compliance checking in an opposite techniques. Better explained, the reference point for comparison is the 3D point cloud data. Thereby the 3D point cloud data captured by 3D laser scanner will not be converted into a BIM model. Instead, the "as planned" BIM model is converted to a point cloud file by uniformly allocating points from each side of a building mesh model (Chen & Cho, 2018). The method used by them to translate and transfer rotational parameters between the BIM model and 3D point cloud data is random sample consensus (RANSAC).

Their approach seeks to put both the 3D point cloud data and the derived point cloud from "as planned" BIM model at the same resolution for comparison. Afterwards, a point to point comparison sequence is accomplished to evaluate the deviation of construction elements. The significant aspect of their approach is a trial to mitigate computer computation in processing large amount of data. Furthermore, proposing a class-agnostic and non-parametric based approach for commencing compliance checking between "as built" and "as planned" status of construction projects (Chen & Cho, 2018).

Another different older technique to cover is what is known by "Hough transform" which is a technique for extracting features in digital image processing and computer vision. This technique can be utilized to detect pre-existed parametric features in noisy data environments. Ahmed et al. (2013) has reviewed the Hough transform technique with regard to objects with cylindrical shape. Its limitation was the lack of recognition for objects with non-collinear symmetry (i.e. curved pipes, elbows, etc.). While the Scan Vs BIM approach by Bosché et al. (2015) enables recognition plus identification of both simple and complex objects. But it can recognize neither objects placed more than δmax of their "as planned" spatial position, nor objects that don't exist in the "as planned" BIM model.

Bosché et al. (2015) reviewed the advantages of both approaches and saw the complementary significant advantage of using both to overcome the issues arising from using each one of them separately. Their new approach had significant encouraging results over the simple version “Scan vs BIM” approach introduced earlier by Bosché et al. (2008). The main areas of improvement in reading as-built MEP pipe data were:

1. Out of plane deviations where the new approach is way less sensitive to distances between “as planned” and “as built” positions.
2. Pipe completeness recognition which means the new approach can match different cross-sections taken at regular intervals along a line to a single pipe, where the previous approaches couldn’t match data gathered at different interval to be belonging to a single object.

However, it is vital to mention that their approach was tested in a simple environment (i.e. pipes placed vertically) and it is encouraged to be tested in more complex scenarios (e.g. pipes interacting in different directions). Moreover, Bosché et al. (2015) approach views to which extent the object is built as planned. The accumulated segmental estimations are used to view the percent of execution “percentage built as planned”.

3.4 Automatic modelling from 3D point clouds

The extraction of useful element based data out of random collected construction site based-data is challenging. This is because of the complexity, overlap, noise, the amount of points collected from structures, and unclear Line-of-Sight (LoS) in case point clouds are gathered through remote sensing tools (Tang et al., 2010).

Trials to issue element-based models out of different types of collected data, e.g. 360-degree images or 3D point cloud data, is constantly under research where many challenges throughout the processing of data must be tackled. Many reconstruction algorithms that reconstruct taken 2D images or voxel octree from point clouds into a useful element based model, were constructed by researchers for the sake of getting a better fit that matches as-built characteristics (Nikoohemat et al., 2017). Many of those algorithms make speculations on image-zones that might be subject to misinterpretation. The main challenge for all researches is to issue objects that are topologically accurate and consistent even in high noisy data environments (Pătrăucean et al., 2015). Most constructed methods and reconstruction algorithms are capable of handling single-floor simple zones such as box-like rooms while very few can function in noisy multi-floor complex areas (Bassier et al., 2018).

The field of automatic 3D modelling of elements based on scanning is an ongoing research. Many studies have highlighted different methodologies on reaching such outcomes. A major dilemma is to convert the gathered data, whether being 360-degree images or 3D point cloud data, as fast and efficient as possible directly after scanning construction sites by scanning tools to an element-based BIM friendly format (Bassier et al., 2018).

The general approach followed by most of studies on this conversion evolution is to pass through lengthy processing procedure for the gathered data. For instance, 2D-based methodologies take the point cloud data from certain perspectives/angels as 2D raster images for further analysis while 3D-based methodologies rearrange the point cloud data to a voxel octree form which makes it allowable to perform different types of searches from different angles/perspective (Nikoohemat et al., 2017). Vosselman et al. (2017) applied a research that targeted studying the captured 3D point cloud in order to classify the existing content within it as it is the first step for extracting geo-information. Their approach used contextual classification for segmented data taken by airborne laser scanners.

Afterwards, heuristic and machine learning mechanism is followed to spot class labels (e.g. floors, pipes, walls) and finally the recognized fragmented segments are used for further detailed searches such as extracting their parameters (Nikoohemat et al., 2017). Nikoohemat et al. (2017) have shown the privilege of using the trajectory of indoor mobile laser scanner (IMLS) to create a sense of it and make the interpretation of 3D point clouds more applicable. Their research has proved its validity in recognizing path openings in cluttered indoor environments which was seen as an extra advantage over using usual TLS instruments.

Another study done by Bassier et al. (2018) targeted automatic element-based model creation for partial walls and rooms by following a newly formed algorithm for construction-elements reconstruction, i.e. partial walls and rooms. Their procedure mainly embedded two steps, see Figure 1. The first step was to cluster walls, same approach for rooms, using heuristic algorithms and techniques. This was mainly done by creating a voxel octree, out of the collected 3D data, that mainly included nodes and edges based on surface appearance. Then some relations are computed based on the distances between these nodes. These relations target parallelism, orthogonality, and the overlap between edges and other surfaces. The result graph will be aggregated further using heuristic technique to cut off the ambiguous zones and the result will be clustered walls segments (Bassier et al., 2018).

The second step is accurate reconstruction of the clustered elements themselves (i.e. walls or rooms). Thereby IFCWallStandardCase objects, in wall case, are constructed based on the previous step that are compatible with IFC4 standard. This IFC subtype is compatible with other types such as IFCMaterialLayerSet which embeds material identification layer in the identified object (Bassier et al., 2018).

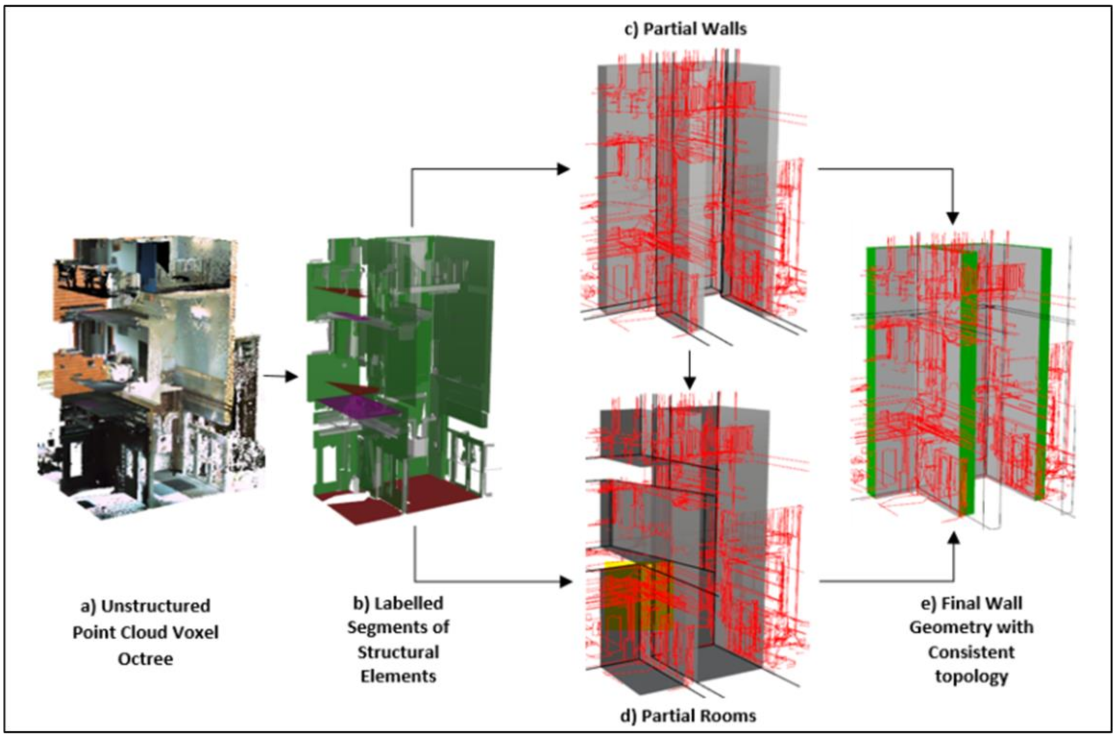


Figure 1: Overview of general workflow for wall reconstruction in IFC file

Their algorithm was tested on a multi-floor structure in Belgium. The majority of wall boundaries were identified accurately but significant deviations were noticed for complicated high detail walls (Bassier et al., 2018). This happened since creating IFCStandardcase objects needed filtration of noisy data. For instance the lower part of walls, which has higher level of detail and complexity, reported increased error. Basically their algorithm needed to cut off some of the data collected in order to create the final objects. It was proven that incorporating as-planned data within the process will significantly mitigate error tolerance (Bassier et al., 2018).

In other words, Bassier et al. (2018) proposed algorithm showed promising results through their experiment where 94% of the rooms were correctly identified and reflect accurately the as-built conditions of the structure. The privilege of their method over others is that it dealt with relatively more complicated construction environments and wasn't limited to a single floor building.

3.5 Cloud-based BIM/collaboration

The intended conceptual framework depends heavily on automating processes without human interaction which spots the light over cloud-based processes. In the following paragraphs, cloud-based BIM/collaboration will be covered to provide a base for the highlighted cloud-based process concept.

Cloud-based data pools provide access from different destinations to the same pool of computing resources such as servers, networks, and applications that can significantly increase efficiency with minimal subordinate personnel interaction (Mell & Grance, 2015). It enables real-time interactive collaboration and taking BIM from a design base to construction (Mell & Grance, 2015). Although many theoretical frameworks discuss implementing cloud-based data in cooperation with BIM, its usage in monitoring projects' progress is still not highlighted enough (Matthews et al., 2015). The previous research had lack of attention towards how to merge this technology in practice, i.e. how cloud-based data tools can allow for bi-directional BIM editing (Wong et al., 2014).

Many studies have highlighted the ability of introduced mobile technology such as smart phones, personal digital assistants (PDAs) and tablet personal computers (PCs) to monitor sites in real time (Kim et al., 2013). Some smart phone applications were invented to spot this. 'Construction progress control' shortly (CPC) is such an application developed to monitor construction projects. However, this program is not technically visual based. It depends on a Microsoft Excel spreadsheet that construction sites personnel will use later on to enter how much percent of work is completed (Garcia, 2013). This is vulnerable to many errors such as basing the amount of completion on human intellect, e.g. plaster actual completion is 37% while construction sites personnel report it as 50%, which will somehow affect the sequence of following activities. Tserng et al. (2014) developed a similar system known as Construction BIM assisted Schedule Management shortly (ConBIM-SM) that gives shared visualization of the updated "as built" feedback on the construction schedule in real time to all different parties in charge.

On the other hand, Matthews et al. (2015) have re-engineered existing research studies done on cloud-based BIM within construction to make it more empirical. Their constructed real time object-based system was tested on a case study. It has allowed for data capture on site with the ability to synchronize these information to a previously united cloud-based BIM.

All of the previous efforts looked at the cloud-based data from one perspective, which is the available technology tools and not from data collection process perspective. In other words, the data collection process can give instant feedback to the existing BIM model through cloud-based database that interacts independently. This can open opportunities to new privileges such as allocating universal codes in assessing progress instead of being vulnerable human assessment and its corresponding errors (Matthews et al., 2015).

3.6 BIM in auto-scheduling

The drawn conceptual framework target automatic scheduling within its processes. Automatic scheduling implies inserting corrective actions in case of arising implementing errors. In following paragraphs, literature review on using BIM in scheduling and auto scheduling will be covered.

Building information modelling being simply defined as a digital presentation of physical and functional characteristics of a unit is seen to have potential capabilities when it comes to Architecture, Engineering, and Construction AEC (National BIM Standard, 2013). Two major capabilities of BIM are (1) its ability to store unlimited data about each element concerning an object and use these data for multiple things such as structural analysis, planning analysis, etc. (Weygant, 2011), and (2) BIM can work as a mutual platform for information exchange between different software during the construction project (Howard & Björk, 2008).

Current practices use BIM models to formulate project-level schedules. Mostly, this means that constructing one building component is to be considered one activity. Or as Liu et al. (2015) illustrate that it might be zone-level schedules where activities are considered for a particular construction zone. Those types of schedules don’t consider the different types of construction operations with their need or resources that will be needed for the intended construction method. In other words, resource constraints were being ignored in BIM-based scheduling and the use of only BIM and process simulation models is meaningless if optimization algorithms aren’t included. Since optimization algorithms are the responsible unit for addressing resource constraints in construction scheduling (Liu et al., 2015).

Conventionally, construction activity scheduling is formulated manually using the concept of critical path method (CPM) and presented in the form of 2D Gantt chart. By experience, this process was found to hold high marginal error that construction practitioners will eventually be obliged to confront. After the technological evolution and the rise of 3D computer aided design (CAD), researchers started focusing on using this computer-based privilege in taking activity scheduling to a new level (Viklund Tallgren, 2018).

One of these efforts that used BIM in scheduling was the 4D CAD, or 4D visualization, that uses BIM 3D capabilities for scheduling purposes. This approach assists project participants in visualizing the sequential order of the CPM activities in 3D to boost mutual understanding among different disciplines and thereby identifying overlaps and conflicts before launching a construction project. This approach was proven to be more efficient than the traditional Gantt chart method in planning (Malsane & Sheth, 2015).

Hamledari et al. (2017) have constructed a model that connects updated progress on construction sites to an automated schedule model using IFC-based 4D BIMs. Their study is based on inserting the updated progress on construction site as completion percent ratios for all inspected elements. Their approach updates automatically IFC based four-dimensional BIM in relation to progress and schedule.

The algorithm provided by Hamledari et al. (2017) includes a model with three connected stages: model preparation, model updating and schedule updating. Their algorithm provides an update on construction schedule based on two major inputs. Those two parameters are the original four-dimensional BIM and a manual entry of the inspected elements' percent completion ratios. One dominant privilege of their approach is the dependence on low level of development (LoD) level within the 3D BIM models. This entails low levels of modelling effort. However, it still needs a certain level of detail for some elements since not all tasks to be tracked all completely modelled in BIM (Hamledari et al., 2017).

The significant outcomes of their study is modifying construction schedules' hierarchy when needed, updating the status of all inspected building elements, updating activities' durations and their ending dates, and finally colour codes all inspected construction elements based on their actual and anticipated progress (Hamledari et al., 2017). Their system's potential was demonstrated through a real case application. It is approved to provide real-time responses in real-life scenarios. Their provided model has its promises toward accurate future usage of automated 4D BIM usage under the construction stage (Hamledari et al., 2017).

Efforts were raised to investigate BIM's ability in planning plus resource management. One of these is the work done by Chau et al. (2005) where they have introduced a 4D graphics system for construction planning. It is an information system that uses 4D technology in resource management and site utilization. It is important to mention that resource management in their approach wasn't done automatically but rather manually. Afterwards, Lu et al. (2009) proposed an extra advantage with their methodology. Its main point was to integrate 4D CAD with 3D animation of a simulation to visualize the operations with their dynamic resource interaction. Another view was to invest technologically in order to link scheduling features to 3D models for the purpose of visualization (Tulke & Hanff, 2014).

Considering algorithms for different purposes, De Vries & Harink (2007) proposed a model that uses algorithm to generate schedules at the component's level which means that it depends on building components geometry/topology, i.e. which component comes first in construction. Afterwards, Kataoka (2008) presented similar work to generate construction schedules from 3D BIM models based on buildings geometry and the used construction method.

Resource optimization use differs by its objective among researcher. For instance Moon et al. (2013) proposed BIM-based construction scheduling with the objective of minimizing activity overlaps through optimization theory. On the other hand, the work of Lu et al. (2008) included a simplified simulation scheduling system, shortly called (S3), to issue critical path analysis with resource constraints by integrating the simulation process model simplified discrete event simulation approach (SDESA) with the optimization approach particle swarm optimization (PSO).

Kim et al. (2013) proposed a prototype for automatic generation of construction schedules based on BIM models. Their work was mainly about automatic extraction of data from a BIM model to use these extracted data as an input for scheduling. Their study was sequence-dependent in order to get the relationships among different activities. The use of BIM construction models in scheduling activities was limited to a certain extent. Previous researchers in most cases used BIM models as a digital representation of objects that holds numerous sets of information on needed elements, e.g. quantity take-offs, for downstream scheduling where nearly all the scheduling is done manually (Liu et al., 2015).

Another perspective in construction activity scheduling was to use construction simulation to issue them. It was seen that simulation usage have a significant advantage at the operational level (Lei et al., 2015). Researchers emphasized the capabilities of discrete-event simulation (DES) to imitate construction logic in the operational stage and investigate resource usage among operational activities (Lei et al., 2015). Incorporating process simulation with BIM can facilitate issuing construction schedules since process simulation needs some information of which quantity take off is one of them. These types of data can be provided automatically by BIM models as elaborated in a study done by Wang et al. (2014). They built a visual basic application that can read quantity take-off data from MS Access and then feed these data into the simulation model to get actual construction schedules. The only downside in this was the manual input of quantity take-off from BIM-based software using the "Schedule" function to MS Access (Wang et al., 2014).

Another work was introduced by Chen et al. (2013) which is BIM based approach to yield the so-called "near-optimum schedule". The downside of their work is that it is nearly done fully manually. First establishing a complete activity network needs to be done and then using the BIM model to provide only quantity take-offs for the activities. Then a process simulation model will run based on these inputs and the "near-optimum schedule" is then obtained by choosing the most suitable solution after multiple runs (Chen et al., 2013). Thoughts were raised on not only using BIM as a quantity take-off provider but also as a rich information pool to feed the simulation model in all aspects. The more the integration between the BIM model and process simulation, the more precise activity-level scheduling is expected to be (Lei et al., 2015).

Lei et al. (2015) highlight in their work the missing gap in previous research which is the lack of integration between process simulation models with BIM to facilitate the automatic generation of schedules. Lei et al. (2015) presented a model that integrates many aspects of which BIM information is one of them for issuing BIM-based scheduling to generate optimized activity-level construction schedules under resource constraints. The inputs to their model were the rich information embedded in BIM model components, simulation approach, and an optimization model.

4 Conceptual framework

The following sections will gradually describe the intended conceptual framework. It starts by clarifying some needed concepts and complementing them. Then the proposed conceptual framework was drawn based on introductory sections. The framework was drawn from different points of view including conceptual connectivity, consequential required activities, and viewing it as a process. The final section takes into account the main possible outcomes of this framework.

4.1 Concept of Data collection on site

The concept of data collection within construction entails absorbing data from the construction site in order to portray these data later on to the interested parties in a beneficial manner (Navon & Goldschmidt, 2003).

A significant amount of data on construction sites under construction stages is considered to be valuable, precious, and holds high potential for different purposes that may be current for ongoing events or subsequent for later usage (Oberlender, 1993). For instance, such different purposes may include tracking construction progress, risk management, safety management, and facility management etc. which some of them are under the construction phase and some others are for later usage (Oberlender, 1993).

The structured conceptual framework, see section 4.4, targets a specific type of data to be captured on construction sites. These data can include 360-degree images and laser point clouds that can be processed to issue 3D construction data models that must reflect precisely the condition of construction sites, at different stages during the construction phase. For beneficial functionality of the drawn framework the collected data must include both Geometric and Non-Geometric data. In other words, the structured framework optimum input is to get a real-time full scanned model of the construction site at different stages, known as “as built” models, and must contain both Geometric and Non-Geometric data. These “as built” models need to reflect the progress on construction sites at different points of time throughout the project period.

Geometric data targets the shape features of elements (such as general pattern, shape, etc.) and usually is in an image format, while Non-Geometric data also known as attributional data aim to describe different aspects of the captured elements (such as type of element, dimensions, texture type, etc.) (Hand, 2008). The structured conceptual framework depends heavily on BIM databases and its tools to give beneficial results. And BIM databases work the best when they are fed with the combination of those two types of data simultaneously (Love et al., 2015).

Construction sites, however, are known for having their complicated data environments especially under the construction stage because of the amount of activities it contains and how they are connected to each other (Oberlender, 1993). Consequently, the extraction of such types of data from specific construction environments might be a challenge because of the noisy/complex surroundings within the field that might act as surveying disturbances.

Trials to capture data on sites were done through the usage of different technologies and techniques. As shown in section 4.3, some of these techniques were RFID, 2D imaging, and Three-dimensional Terrestrial Laser Scanning (3D TLS). Each one the techniques, in section 4.3, has its own advantages and disadvantages depending on the specific purpose it is used for on the field (Bosché et al., 2015).

For this framework, the focus will be on 3D TLS since it is seen to hold high potential for the framework. Many construction industries use it already for site scanning which one of them is the Swedish construction industry. An advantage of 3D TLS is giving 3D processable models which are compatible with the rest of BIM databases structures, fast, able to acquire complete data during work on field, and comprehensive ability in documenting the captured point-clouds (Rudorfer, 2013). Some other 3D capturing technologies might have high potential too such as Photogrammetry and Motion capturing as highlighted previously, see section 4.3.

Concerning 3D TLS, LaserDesign Inc., laser scanning company with international experience, have used different products for 3D laser scanning in different projects internationally. Such products were Faro Focus and Leica where they recommend Faro Focus over others since it can scan higher number of points per second, higher range of view, less photo depth estimation error, and has an installed GPS receiver (LaserDesign Inc., 2019).

Apart from which technology is being used for 3D data capturing on construction sites. The physical technique used for assisting the device in capturing the data will significantly affect the results (Sorbeli et al., 2018). In other words, some 3D scanning devices need human interaction for directing and manoeuvring them on site. For instance, 3D NavVis trolley, see section 5.1, is considered a manned device that needs continuous human interaction to get driven on the construction field (NavVis, 2019). Other devices, such as FARO Focus X130, are multi attachable devices which means they can be mounted on tripods, mobile robots, Drones, etc. (Faro, 2019). Eventually, some physical techniques result in a more turbulent/disturbed 3D images and point clouds than others (e.g. Drones compared to using Tripods) (Sorbeli et al., 2018).

Sorbeli et al. (2018) have made a study focusing on the accuracy of Unmanned Aerial Vehicles (UAVs), specifically drones, in localizing terrestrial objects. Their study investigated the accuracy by measuring the amount of error as a function of altitude, Drone’s hardware precision. The results showed higher errors in image precision in comparison to the fixed hardware supportive instruments.

However, the built conceptual framework depends fully on automated data collection mechanism which implies there should be no human interaction in the process. Some products in the market are dependent on hardware products such as drones where the current status of such drones is that they are fully dependent on human interaction (Faro, 2019). Meanwhile, there are some studies and researches on automating the movement of drone by programming and defining an aerial track before departure (Rakha & Gorodetsky, 2018).

Rakha & Gorodetsky (2018) made a review showing the future potential of Unmanned Aircraft System (UAS) equipment for automated inspection of existing construction buildings where architects, engineers and energy specialists can exploit its privilege. They examined UAS equipment capabilities in building a 3D CAD model on a university campus. One of their major findings was a need to standardize the automatic inspection in building industry at this early stage. On the other hand, other studies showed the existing abilities of unmanned aerial systems in tracking objects remotely and independently with precise systems in decision making for military purposes (Rakha & Gorodetsky, 2018).

These studies and experiments boost the idea of device self-control and thereby independently launching and improvising on the construction site at a certain defined time on periodic basis without human interaction in the process (Rakha & Gorodetsky, 2018).

A pre-identified capturing track is another part within the built conceptual framework. This implies that the 3D data collection tool will have a specific track, whether aerial or terrestrial, within the construction site (Rakha & Gorodetsky, 2018). Selecting the track route will significantly affect the range of view for the 3D data collection tool. Since the built conceptual framework depends heavily on data collection and input the highlighted route must allow the capturing tool to capture as much details as possible will least noise from the surrounding construction environment. This implies that the specific track dedicated for it must but cleared from physical object in order to minimize the level of disturbance that might hinder scanning's progress. However, construction sites all over the world are well known for having their own complexity and being chaotic (Oberlender, 1993).

Thereby, clearing specific zones within the construction site for reasons such as 3D scanning might be difficult for practitioners as a process rather than being an activity. As it was shown by a survey done by Stewart et al. (2004) within the Australian construction industry which showed that some barriers hindering Information Technology (IT) integration within the industrial level include poor inter-operability/cooperation on construction sites and low level of IT awareness.

4.2 Concept of automated Cloud-based process

The concept of online cloud-based platform has become so common nowadays. This concept has evolved with time drastically until this point of time where private users have their own databases such as Google Drive, Outlook Drive, or any other platform. This concept was seen to have intrinsic value for other industries such as the construction industry because of the coordination it entails among different parties (Shi et al., 2010).

The concept of cloud-based BIM was later on introduced since teams' coordination and collaboration within projects that mainly used BIM-based product was relatively poor (Singh et al., 2011). Such reasons for poor collaboration included data loss, inconsistency, ownership matters and intellectual property rights concerns which are human caused/oriented issues (Singh et al., 2011). Consequently, many researches have covered and revealed the potential of using cloud-based BIM as a possible solution to overcome the previously mentioned issues.

Nowadays, the most apparent application of Cloud-based database within the construction industry is within Building Information Modelling (Afsari et al., 2016). Many studies have highlighted the advantages of having a cloud-based BIM including unifying parametric modelling, being a service that enables end users to interact with the BIM model on multiple dimensions nDs (Mathews et al., 2015). This interaction can include three-dimensional modelling interaction 3D, time-programming interaction 4D, cost interaction 5D, and even lifecycle facility management 6D (Redmon et al., 2012). Later on, the concept of cloud-based BIM was furtherly argued to have higher privilege if it is able to host BIM governance since it can contribute further towards teams' collaboration (Beach et al., 2013).

The presented model by (Mell & Grance, 2015), see section 4.5, for cloud-based BIM is very relevant to the constructed conceptual framework that will be described in this thesis. Cloud-based BIM, however, can be seen as a mutual pool of data for multi-party human interaction. The presented conceptual framework looks at this concept from a different perspective. Since the built framework is intended to be fully automated, this creates a need for an automated process. In this case it will be a cloud-based automated process that can be used for coordinating, managing, and directing the available data to its suitable destinations without human interaction. In other words, the drawn conceptual framework, see section 4.4, considers a wider domain for database interaction. It takes it from being a cloud-based BIM, which is mainly about handling and sharing a united BIM model among different end users for united multi-disciplinary interaction, to a cloud-based process. This cloud-based process should have instant access to different BIM models from different destinations and parties.

Precisely, these different BIM models will mainly include the cloud-based “as planned” BIM model, which is being edited and adjusted on frequent basis by structural engineers, architects, MEP engineers and even by some practitioners. The second destination the cloud-based process should access is the 3D point cloud scan issued by the 3D data collection tool. In case the used tool was image based, for example 360o image, then the cloud-based process must have access to it for further image processing. Thereby, the process will be associated with numerous amount of real-time synchronized collected data by the 3D data collection tools which can be challenging since it can be complex data to be handled.

The difference between the well-known cloud-based BIM concept and this described concept, automated cloud-based process, can be understood from the shown figure below, see Figure 2. It is clear from the figure that the cloud-based BIM concept entails that the different parties within a mutual project have access towards the mutual BIM database and not vice versa, i.e. the BIM database doesn’t have access to different parties. While it can be seen from the cloud-based process that the in-between interactive processes have access to different parties/platforms’ data (e.g. “as planned” model from design stage, 3D scanned point clouds from 3D data collection tool, etc.). Thereby, it can interact with the data by directing it towards its appropriate platform/software that is responsible for processing it and issue beneficial and suitable results to the next destination, see Figure 5 under section 4.4.

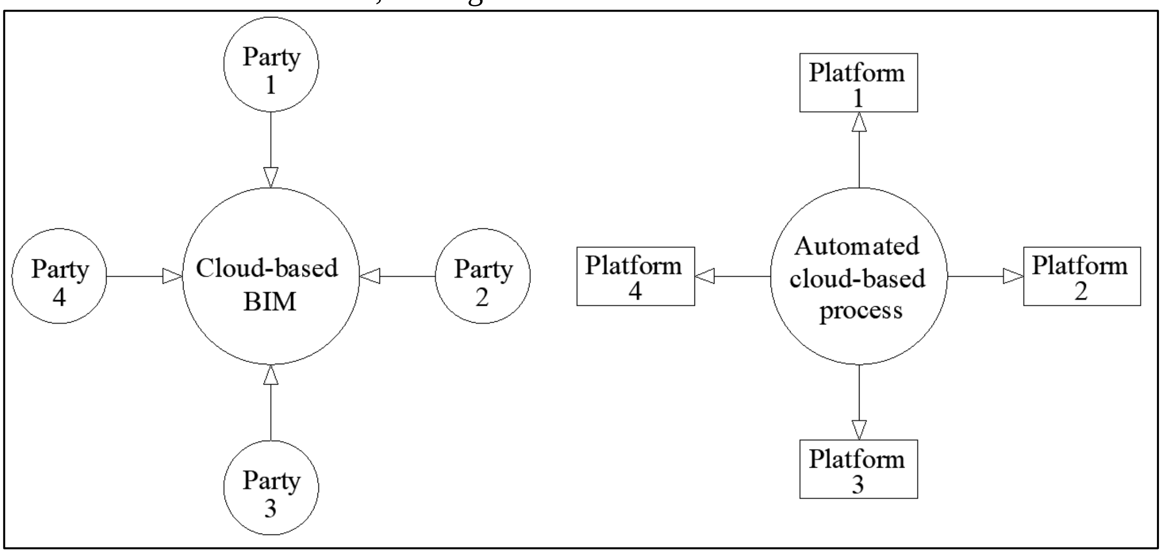


Figure 2: Difference between cloud-based BIM & automated cloud-based

A simplistic example, concerning cloud-based process, is when considering the 3D laser point clouds data acquired from the scanning tool on construction site. In such case the cloud-based process will include importing the data from the data collection tool, 3D laser scanner in this case, and exporting it to the most suitable platform that responsible for refining it to make it a 3D “as built” BIM model. Some developed platforms nowadays that work with such conversion include Trimble RealWorks, AutoDesk Recap, and ClearEdge 3D EdgeWise, see Figure 5 under section 4.4. The same applies when applying comparative compliance checking. The cloud-based process will then be responsible for incorporating the two 3D BIM models, “as planned” BIM model acquired from the cloud-based BIM and “as built” model acquired after refining the data taken from the 3D data collection tool. Then directing the new data package to a suitable platform for checking compliance such as Solibri.

The main information standard exchange format used for BIM databases is Industry Foundation Classes (IFCs). This file format was initiated for storing and carrying all the relevant information concerning a structure from multi-disciplinary departments and processes (Redmond et al., 2012). In cases where the different information exchange users have specific level of standards and detail through their own work and their corresponding files, the collaboration will eventually lead to some error due to these differences (Jeong, 2018). These difficulties in information exchange result in ambiguities in understanding the detailed differences when combining fragmented/separated sets of data taken from different implementers, e.g. in case of transportation projects where implementation is achieved in segments (Jeong, 2018).

Jeong (2018) suggested that more efficient Information Delivery Manuals (IDM) need to be developed that are asset-centric, i.e. facilitate the workflow of targeted data, in order to mitigate data combination flaws, minimize resource wasting by duplicating data in the maintenance stage, ensure smoother data exchange.

For this conceptual framework, the predicted current suitable types of exchange formats for inter-communication among all directions within the cloud-based process are IFCs. This exchanging data format series is common among all the possible interactive platforms presented for this conceptual framework (NBS, 2019). Such possible interactive software may include Revit and Solibri, which deal with this exchanging format. On the other hand, there is an exception for the main source of data on construction site which will be first available as a 3D point cloud. These data are not directly available in IFC format but must be forwarded to a software for extra processing and modelling (Bassier et al., 2018). This software has to deal with Scan-to-BIM concept, which is about using 3D laser scanners with a physical space in order to create an accurate representation of these data (Bassier et al., 2018). Many software are already made for this reason, converting point clouds into models, such as Trimble Realworks or AutoDesk ReCap and they are keep developing.

Concerning compliance checking results within this conceptual framework, see section 4.5, and the manner in which they are handled by automated cloud-based process. The outcome of this comparison will include many changes such as delay warnings, execution changes, falling hazards warnings and advices. These outcomes can be converted into attributional added elements. This means that required changes must change into descriptive information. It should be attributional data since the most possible software for handling these data will be Alice Technologies. This software deals mainly with tabular data that describe how a construction element being built.

These tabular data should also describe the sequential constructive process for their relevant elements whether this was a new element to be implemented, replacement of an old element, repositioning of an old element, or a protective instrument to be implemented.

Consequently, this newly produced results from the compliance checking stage must be exported by the automated cloud-based process to the suitable software (i.e. Alice Technologies) after conversion. Thereby, rescheduling will be processed and the new changes and corrections should be incorporated in the newly produced schedule. Eventually, the automated cloud-based process should be able to update the results on periodic bases and show them on the construction activity schedule in real-time on a digital screen, see Figure 4 under section 4.4.

4.3 Concept of comparative compliance

In the past many problems used to happen within the construction process regarding the implementation of elements that eventually ended with excessive costs and time. These problems included wrong element selection, wrong element implementation, and contrariness with planned documents (Josephson & Larsson, 2001).

These errors within construction implementation were seen as a result of sequence of activities including random causes, human errors, implementation difficulties, etc. which necessitated a need for a controlling concept (Love & Smith, 2018). This is when compliance checking was introduced and paid special attention in order to ensure that everything built comes in confirmatory with the readily set rules, standards, specifications, and policies (Love & Smith, 2018).

Even though compliance checking concept was introduced and developed, i.e. higher inspection level of details, it was still achieved and executed through inspectors (Tan et al., 2010). Thereby, those inspectors apply manual checking, for instance, on building designs in the design phase in accordance to national codes (Tan et al., 2010). Those codes and standards might sometimes be complicated and hard to inspect especially by humans. Humans by their nature are prone to work stress and exhaustion which can ultimately result in assessment errors (Greenwood et al., 2010).

Due to possible consequences of those inspection errors, e.g. significant cost implications, many emphasized the privilege of automated compliance checking as it can overcome many of the previous flaws/shortcomings (Tan et al., 2010). The advantage of automated compliance checking comes in forms of higher ability in handling complex standards, higher consistency in assessment and less overall delays in the construction process (Greenwood et al., 2010).

Further, talking about compliance checking as a concept means to conform to pre-set rule or standard. Thereby compliance checking is mostly used within the planning phase after being done with the design of a construction project (Tan et al., 2010). This happens to conform to the standards set internationally or even locally. While within this proposed conceptual framework, compliance checking has a slightly different approach than the one usually recognized.

Compliance checking within this conceptual framework takes place mainly in the construction phase in an attempt to comply all the work done on site with that previously planned. In other words, all the elements readily executed on site have to be checked on regular basis against those same elements existing in the previously planned and confirmed model, i.e. cloud-based BIM model. Thereby, the “as built” model previously mentioned within this framework has to be checked if it complies with all the characteristics described on the “as planned” model.

If this was to be compared with the usual compliance checking approach then the processed “as built” BIM model will represent the old drawing documents to be inspected, while the “as planned” BIM model taken from the cloud-based BIM will represent the reference to which compliance is checked with.

Compliance checking within this conceptual framework works as a comparison more than being a standard checker. However, other standards’ checking can be applied at another stage such as the planning phase among different designing departments, in case cloud-based BIM was not in use, but this is out of the scope of the presented conceptual framework.

It is worth mentioning that the highlighted comparison/compliance checking between the “as built” and the “as planned” models is time-relevant. Precisely, the built “as built” model is processed and refined with data captured by the 3D data collection tools at a certain point of time, i.e. a snapshot throughout the timeline of the construction project. And for this comparison between the two models to be valid, the “as planned” model has to be taken into account and in accordance to that exact time point. In other words, if the “as build” processed model was taken 3 months after project launch then the “as planned” model which works as a reference point should present the planned element to be installed after 3 months. This is because the comparison cannot be accomplished between a partial model (i.e. “as built” model after 3 month) and a complete model (i.e. “as planned” model for the entire finished construction project).

Current software that encounter many construction BIM models for clash detection include Solibri and Navisworks. Clash detection is taken into consideration since it is similar to comparative compliance checking mentioned previously for this conceptual framework. Clash detection is a process that targets interferences and collisions in 3D project models for the purpose of inspection in an automated and computerized mechanism (Leite et al., 2009). The common aspect between clash detection concept and the presented comparative compliance checking is that they both include more than one model within the software for the sake of comparison.

Different departments’ building models such as structural, architecture, and mechanical, electrical & plumbing systems (MEP) can be hosted in Solibri for clash detection. Within this conceptual framework, the “as planned” model taken from cloud-based BIM can be exported to Solibri after time-factor consideration and the refined/processed “as built” model can be exported to Solibri as well, see Figure 5 under section 4.4. Then comparative mechanism can run within the software that targets incorrect elements placed, miss-positioned elements, yet unexecuted activities, etc.

4.4 The proposed conceptual framework

The proposed conceptual framework drawn in this section is based on the interaction among the three previously mentioned concepts, i.e. Data collection, automated cloud-based process, and comparative compliance checking. Those three separate concepts act as a foundation for this conceptual framework as it cannot be tested if any part is missing. The connection among these concepts and their contribution to the possible outcomes can be seen in Figure 3.

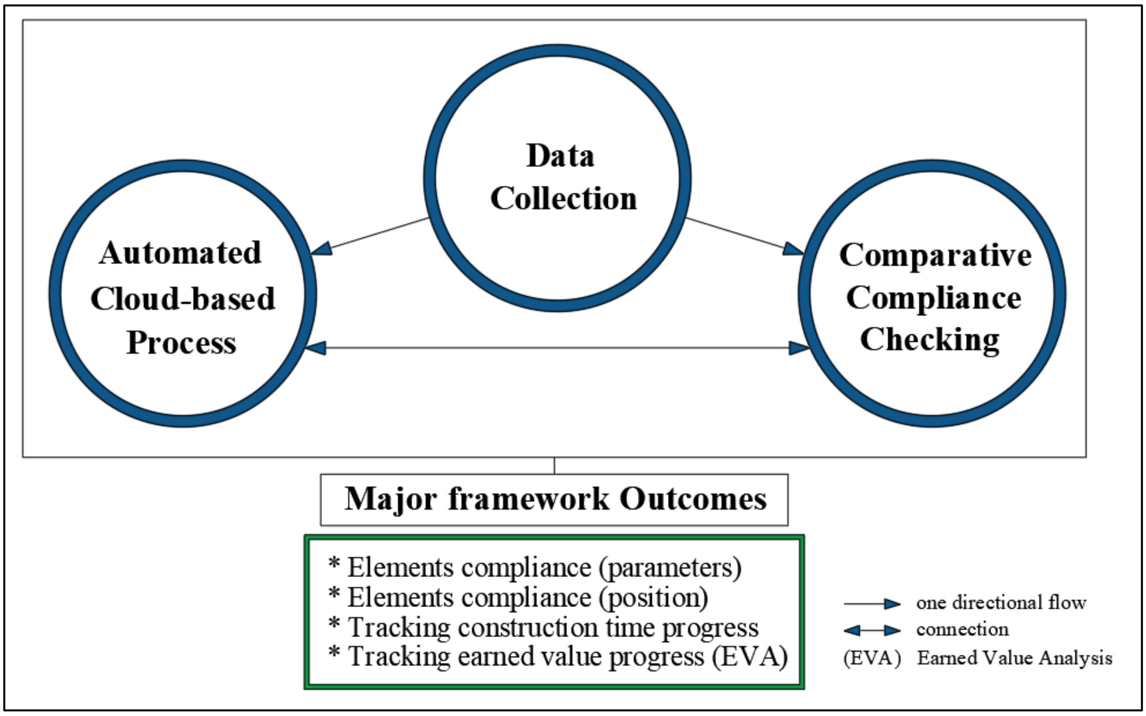


Figure 3: Proposed conceptual framework

Furthermore, this conceptual framework entitles a sequence of activities on construction sites for the sake of data processing. These activities include laser scanning, processing of 3D point cloud data, exporting and importing data, etc. The sequence of those activities is shown in a possible order within Figure 4. It can be seen that those activities on the construction site can take place on chosen periodic basis that might differ in accordance to data processing time, i.e. if slow processors then larger periodic basis and vice versa. The possible outcomes of such a conceptual framework might not be only limited to those stated within Figure 3. However, those advantages were taken to limit the domain of this thesis.

Once monitoring through 3D data collection tools commences, the stages described within Figure 4 start applying one by one. In case of any issues arising such as element-based miss-compliance, elements misplacement, incomplete activities, or any detected falling hazards the framework will be able to reschedule the current construction schedule activities in order to fit in corrections within it. It could give many construction activity schedule options. Then selecting the most appropriate/efficient schedule and present it to the concerned parties (i.e. project managers, practitioners, etc.) on the mutual screen.

It is vital to highlight that the activities within Figure 4 are intended for pure automation and the examination of its applicability is based on this notion. However, these highlighted activities can be seen from current construction practices to be partially human interactive, i.e. not fully automated, in terms of its current existence. In this sense, the presented approach is considered sociotechnical in current construction practices while it is intended to be purely technical in this thesis.

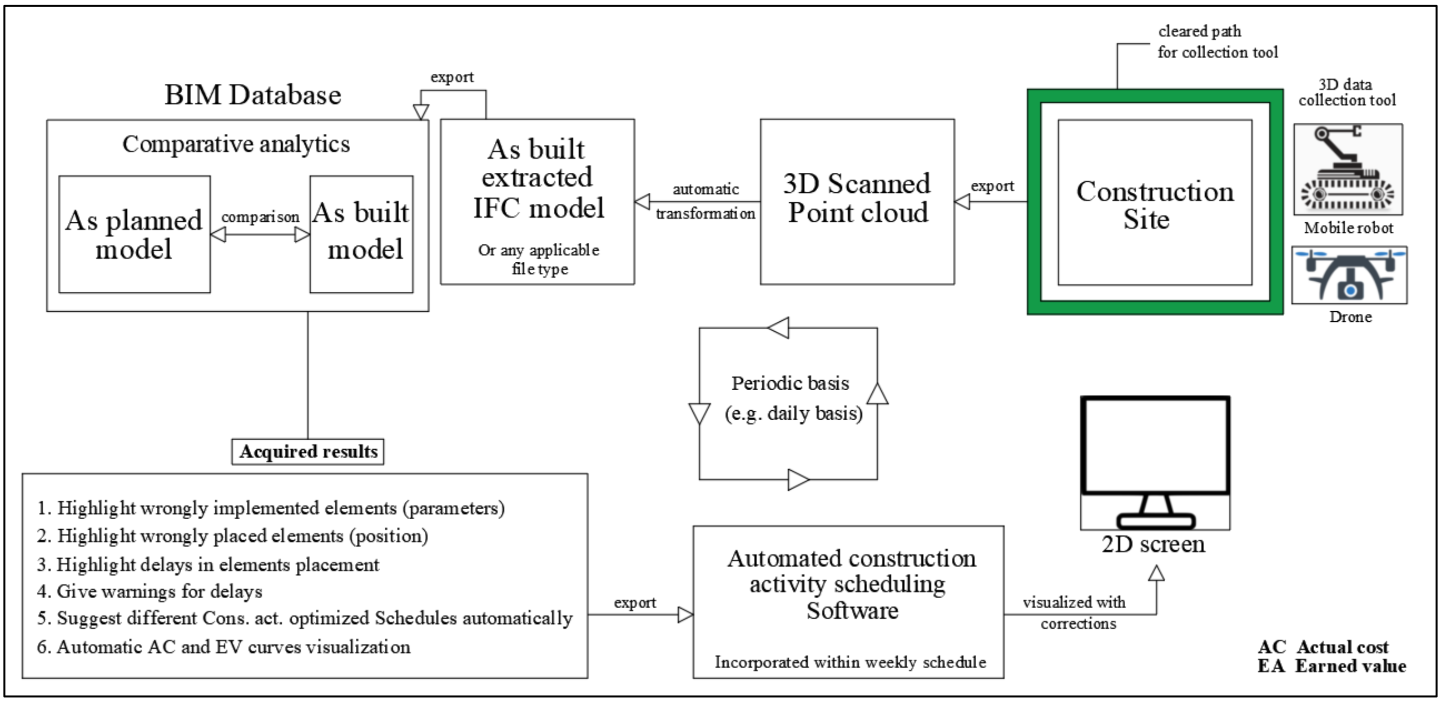


Figure 4: Activities sequential order for the conceptual framework

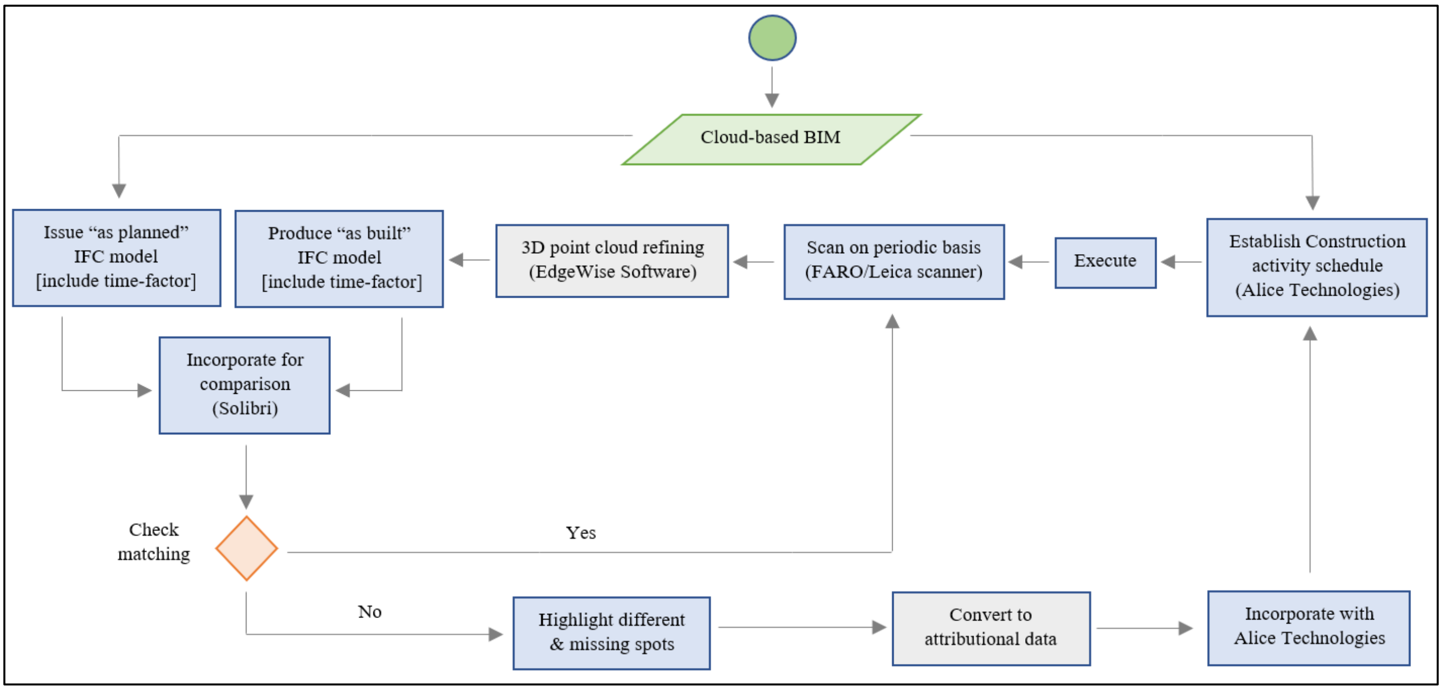


Figure 5: Proposed simplified process for the conceptual

Moreover, in accordance to the current available tools, i.e. laser scanners and software, a possible proposed simplified process workflow is drawn and shown in Figure 5. This figure is drawn in an attempt to show that the presented conceptual framework does exist primitively in separated segments and thereby can be furtherly developed.

Note: This simplified process is not fully automated as the conceptual framework entails. According to literature review all the process can be manageable automatically except for those viewed in grey. The processing of point clouds to 3D BIM model is semi-automatic. While attributional data conversion doesn't currently have a developed tool for such a purpose (Gilani et al., 2018).

4.5 Possible framework outcomes

Frequent construction monitoring and feedback is labelled to be significantly important for maintaining the main limitations within any construction project time, cost, and quality objectives. Bosché et al. (2015) showed some vital benefits out of tracking construction progress automatically. These included the following:

- Getting early warnings in case of deviation between the as-planned and as-built models. This can prohibit high correction costs involvement by applying immediate actions.
- Faster processing of procedures from main contractors towards sub-contractors. Payments don't need to be frozen for procedural reasons.
- The ability of rescheduling activities in case some elements were missing.
- Saving a lot of time and effort in producing shop drawings. Updating the as-built BIM model in order to reflect the as-built condition. In some cases adding new elements that weren't there in the original as-planned model.
- In terms of safety planning, it can give opportunity to plan more precisely than it can with the traditional construction tracking methods.

The drawn conceptual framework was constructed for revealing some hidden potentials in incorporating different data sets with each other. Some of its privileges were discussed briefly in the previous sections. But here the advantages of this conceptual framework will be discussed in much detail. Nevertheless, the shown merits are taken as main representatives of the framework's potential for the simplicity of this thesis. In other words, in more aggregated levels of investigation the merits of such framework can hold other minor aspects.

Under section 3.5, the concept of comparative compliance checking was clarified in connection with other literature highlighted on cloud-based BIM usage. Comparative compliance check is planned to be held simultaneously with the reset of framework's elements on periodic basis. It is meant to highlight the following:

1. Checking element-based compliance for all the elements within the construction project. This should cover all division from structural elements to MEP elements, etc.

The chosen term "element-based" compliance within the framework of this thesis means that element checking is based on their parameters and characteristics in terms of which type is being used. For instance, a specific ventilation pipe (e.g type B-Gas-Vent pipe 3") is to be used and implemented at a specific spot in the project, then according to the captured 3D “as built” model it was found out that the identified element in the model for that element that is supposed to be in that spot is another type (e.g type B-Gas-Vent pipe 4”). Thereby the framework will be able to label this difference/deficiency between the two models and highlight it.

2. Checking element-based compliance in accordance to its intended position.

Each element within the construction project whether it is structural, MEP, or any other discipline’s element has a specific position/location to be placed in. In some cases, executors fail to place some elements such as walls, windows, pipes, etc. as accurate as they should be. Element’s location error should be mitigated as much as it could to reach the point of zero tolerance (i.e. error in location is zero). The comparison made between the “as built” model and the “as planned” model is able to identify such errors in placement and can highlight them.

3. Tracking construction progress in relevance to the planned plans and reporting it.

This means that through frequent comparisons between the two models, the framework will be able to measure the planned percent completed (i.e. how much of the activities that should be done is actually fully implemented at that certain point of time). This has a significant privilege which is the ability to frequently assess the earned value of work done on field. Such automatic unmanned machine interaction is assumed to reduce significantly error margin in comparison with the previously done approaches (i.e. an inspector assess the amount of construction progress done on field).

4. Checking compliance in terms of project timeline.

This means checking progress in terms of the existing elements according to their planned positions in terms of project timeline. For instance, at a certain time of the project some work must be done concerning tiles implementation for the whole area of the fourth floor of a building. If according to the captured 3D as-built model, it was found out that only 85% of the area of the fourth floor was tiled while it should be 100% completed at that certain point of time, then the comparison between the two models “as-planned” and “as-built” will be able to highlight such differences/deficiencies.

5 Empirical findings

As it is already known, interviews were taken as a major source for constructing an empirical part for this thesis for the sake of comparing the structured framework in terms of applicability and spotting deficiencies within the construction industry that hold it back from this framework. Within the following sections, the important and most relevant parts of interviews will be mentioned in high detail.

5.1 Interviewee A

Brief description of interviewee: Interviewee A works as a BIM strategist with 3 years of experience in the field at one of the most relevant and leading companies, if not the leading and most relevant, in Sweden within the field of BIM, photorealistic visualization of structures, and 3D laser scanning for construction. His work mainly includes close communication with property owners and contractors.

This company promotes nearly the same concept presented within the conceptual framework in terms of contributing towards facilities management based on capturing data. However, it is handled primitively and the laser scanning tools are maneuvered by humans. The general approach is semi-automatic, and scanning isn't done on periodic basis (e.g. daily basis). The work done currently is basically scanning a building throughout different stages, most commonly three stages. The first stage is when the interior walls are mounted but not yet completely finished (i.e. the wires of electrical work and hoses for water supply and other interior elements can be seen through them). This stage is made to help facilities management later on when maintenance is required. The second stage is when ceiling insulation is implemented. The final laser scanning is executed when the day before handing over the project. Afterwards, construction BIM models from the planning phase are imported to the central BIM database where both models "as built" and "as planned" are broken down to their smallest elements and compared to each other in an attempt to validate the data (i.e. validate "as planned" model). In case the two models do not coincide with each other corrections are made on the "as planned" model in order to attach it after validation to the product information (i.e. construction documents).

The previous processes are currently done within the company semi-automatically (i.e. human interaction is highly involved) but they are trying to automate the process gradually. The company starts its work by drawing up a complete process, which involves their high technology-instruments, which can be incorporated with the construction work on field in order not to hinder construction progress on site and then gradually trying to optimize it through higher degree of automation (i.e. working on machine learning).

The most common tool used for 3D laser scanning currently within the company is NavVis M3 Trolley. This is a trolley which can be simply pushed by one person and works in two manner simultaneously, 360o degrees camera capturing pictures and a lasers scanner creating 3D point cloud of very tightly packed points (2 mm distance). They scanned Samhällsbyggnad at Chalmers University of Technology with this tool and it took them 6 hours to scan the whole building, see sample in Figure 6. The data from scanning are saved on a hard drive and data are transferred manually without any cloud-based connection (i.e. no direct contact between the 3D scanning tool and the processing computer). Data processing is highly dependent on the amount of data and rendering needed. It usually takes a processing period between two to seven days in order to retrieve the “as built” model for further use.

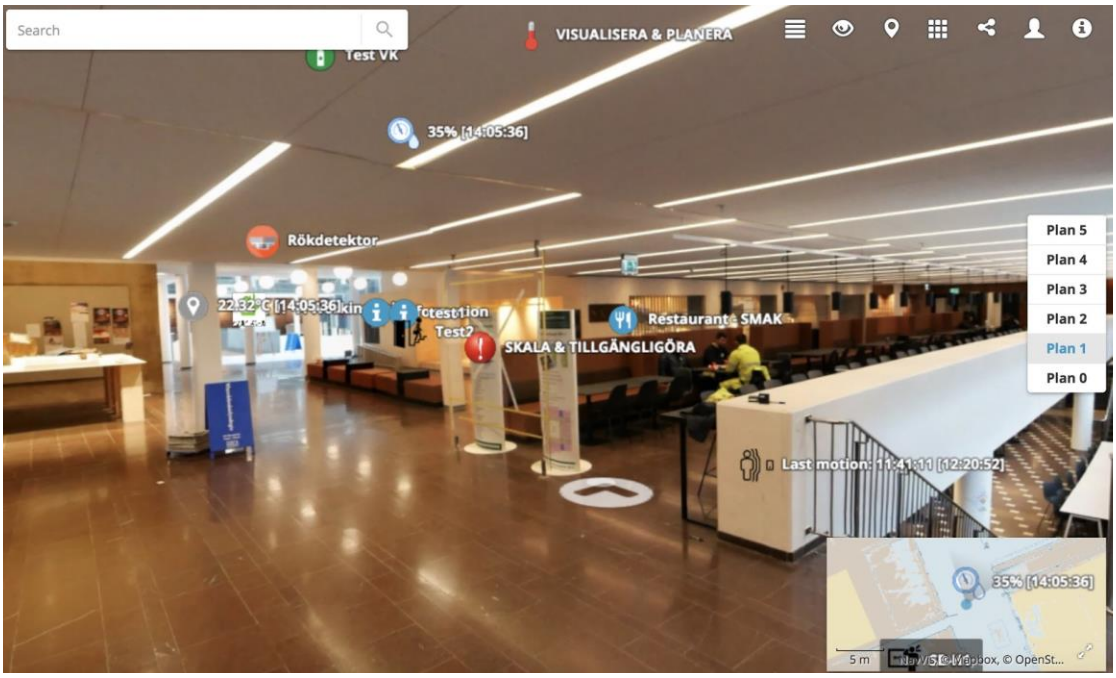


Figure 6: Sample of 3D scanning using NavVis

Lately, they have been trying to incorporate other 3D laser scanning tools in an attempt to optimize their processes even more. Drones from high quality brands such as DJI Pro and Trimble were tested for 3D scanning on the field but their results were not satisfactory. The main issue was in picture dazzle and turbulence when it comes to scanning highly detailed elements since the problem is in identifying the exact position of element’s details. However, interviewee A emphasized his believe in technology on how it is able to reach the needed 3D scanning accuracy with the coming years.
One major obstacle in surveying (3D laser scanning) a building is clearing the site from things that might cause disruptions. This process was emphasized by interviewee A to need very high level of coordination with the constructing teams and their working schedule. This is why it is mainly important, in interviewee A’s opinion, to create a process that makes the framework compatible with the working environment. The company does only three stages of scanning, where it can be done more than just three times, because of the difficulty of coordinating plus the fact that those three stages are considered to be the bare minimum requirement for facility’s management later use. Facility managers need to know some basic data such as what is inside the walls, shafts, and underneath the ceilings. Moreover, emphasis were put on coordinating the first two stages mainly because of the high complexity of sites at those two stages. The final

stage is seen simple since it comes before project handover and inspections are already done. But coordinating such a process on periodic basis as suggested in the framework was seen to require precise planning for the process.

Concerning the automatic transformation from 3D based image to a complete sharable BIM model where it can be used for the rest of framework. Interviewee A expressed his belief that the only problem is in achieving this automatically. On major problem is that even if the captured data, i.e. 3D laser point clouds or 360-degree images, were transformed into a BIM model form, it is still completely geometrical data with no attributional information (i.e. no parameters describing model's elements). Concerning the format of BIM model.

> *"Following a specific file format to make the whole process work should not be prescriptive. We can use 3D point clouds and images that we gathered to extract mesh formats instead. Then we can make analytical tools but it is not a thing you can buy out of the shelf of a software developing company…It doesn't need to be an IFC or you generate IFC from mesh for instance. There is no commercial product for this but we have done it. Point cloud scanning plus 360º photography can generate really high quality mesh formats and then you can create logic out of it (this is a wall, floor, window, etc.) and then you can convert it to IFC. But still, it doesn't have any non-geometrical information."(Interviewee A)*

The major issue for not having a complete product for such a specific purpose is that the whole approach is not used by the construction industry since it is not considered a need. Thereby, demand is significantly low and software developing companies rarely commence research with a focus on reading 3D images with an ability to insert attributional data.

The major dilemma considered by interviewee A that takes the construction industry away from incorporating high technology tools and process was seen to be the human factor. People are generally seen to be afraid of change. The company itself invests a lot of time in proving that what it's doing is valuable both technologically and economically. Since practitioners will always question its economic feasibility and in case it is not feasible they prefer the current approach which is seen profitable and efficient enough for the industry. The second biggest factor is needed process changes. Since such a survey on regular basis for scanning purposes will eventually mean clearing up a specific track on site where practitioners were not used to this before. But now there processes have to be changed.

The current technological gap in 3D scanning and automatic modeling was not regarded as a big dilemma by interviewee A. He claimed that the needed products for constructing the mentioned framework, if dismantled to its smallest elements, do already exist to a high extent. Regardless of how precise the existing products already are, it is believed that development and innovation can improve products drastically where it is only a matter of time to reach the required precision. But comprehensively speaking, there is no one commercial product out in market that gives the same outcome of the mentioned framework because of the lack of demand which is linked to convincing the human factor.

> *"Technology gap is the least ranked issue in the hierarchy of problems here." (Interviewee A)*

On the short run, however, the current technology was not seen feasible enough for such a framework even if a complete product was developed. Since the amount of scanning needed within this framework can be irrational if it's being done on short periodic intervals (e.g. daily basis). Scanning means a lot of processing which the current processors cannot withhold.

> *"It is hard because when we scan a building it takes sometimes about a week to process the data and get a beneficial outcome of it. But that is improvable with the coming years and technology development." (Interviewee A)*

Concerning construction stage activity scheduling, the used approach by the company is to apply 5D BIM simulations, which is a linkage among 3D model components with time schedule and cost-linked data, through different kinds of software. The sequence of activities is already known from the 3D BIM model and is only adjusted to the chosen launching date. In other words, only a time factor is being added to each element to be implemented within the model. A lot of synchronization is needed sometimes to visualize the last version of 3D "as planned" model, in case corrections were made.
Construction activity scheduling is mainly done within the planning phase in the highlighted company. No interaction with the construction activity schedule is made during the construction phase for corrective reasons. A different scenario happens when the project manager requests, in case of wrong implementation of some elements, a model that visualizes the consequences of that wrong implementation. But it is up to him to correct the construction activity schedule manually. Explicitly put, the company doesn't interact with scheduling management but only visualize the "as planned" model at different constructing scenarios.
Nowadays, construction companies usually schedule through Microsoft Excel files where it is possible to link with a 3D BIM model and manage the changes on both of them simultaneously. But this Excel file must be manually sent on periodic basis from project managers to the company. In better case scenarios, SQL databases that are web-based can be used where changes can be inserted from a web-viewer, from practitioners. Then they will directly change in other parts of the database.
Element's parameters/characteristics compliance between the "as planned" and "as built" models is mainly not the focus of the company. However, elements' position compliance between the two models is one important aspect of its work. Usually, the work focuses on matching the "as built" to previously known "as planned" model in order to validate it (i.e. "as planned" model). They start by scanning a building and getting the 3D point cloud file out of it and then process the existing data in order to export an IFC file with all the needed geometric and non-geometric data for all elements. Then they process the matching of those two models through different software tools. The most used software tool is 3DResharper where some parameters need to be set such as the domain of tolerance. This means the interval in which deviations between the "as built" and "as planned" models should be detected (e.g. $1mm \leq Deviation \leq 50mm$). Then all the spotted differences between the two models will be highlighted in red with some extra attributional descriptions about the deviation.

The type of contract involved among different parties is a highly crucial aspect. If there is a significant separation and formal procedures between the designers (i.e. consultants) and implementers (i.e. contractors), it will eventually result in a lot of access permissions needed for such a common cloud-based BIM database. On the other hand, partnering projects were seen to have high potential for such a framework since common goals/technologies/processes are explicitly shared among the different parties involved. This is most apparent on site where practitioners will not care about helping consultants (i.e. scanning team) in their needs unless it’s a partnering project and they are already educated about the things that will happen on site.

> *“The type of contract is seriously a big deal that we can’t underestimate.” (Interviewee A)*

5.2 Interviewee B

Brief description of interviewee: Interviewee B works as a BIM coordinator and a team leader with 5 years of experience in the field at one of the most relevant and leading companies in Sweden within the field of BIM, photorealistic visualization of structures, and 3D laser scanning for construction. The interviewee’s main focus comes in the sense of coordinating and coinciding the different 3D BIM models gathered from different departments in order to ensure smooth workflow in processes. His role also includes coordinating the work among different divisions within the planning phase in accordance with BIM databases.

The current approach used in achieving inspection and compliance checking on construction sites is throughout a protocol. A document with specific criteria should be filled by an inspector. Then everything should be updated manually on the digital database by an individual. This makes this process time and effort consuming. Lately, an application was introduced called Dalux BIM viewer, see Appendix section 9.1 for description, which can enable you to skip some formalities and duplicated tasks. According to the interviewee's experience with using Dalux BIM viewer in construction projects, allocating a portion of time to educate subordinates on using a new technology will eventually increase the gained value from using the new technology. Otherwise the reliance of the new technology will degrade with time since users will not be enlightened to its hidden potential.

Furthermore, continuous changes in the planning phase must be taken into consideration for this framework to be valid. This is seen as an issue since, in most cases, the planned construction models aren’t completely finalized when the construction phase commences in Design-Build DB contracts (Chen et al., 2015). This is mainly a result of the needed flexibility, especially in the final construction phase, real estate owners want to have in order to meet tenants’ variation in preferences. This flexibility can eventually result in radical changes especially with installations where they might be needed at new locations within the construction, e.g. new locations for toilets and kitchens or even more ventilation is needed in some halls.

The interviewee highlighted the potential advantage of using the presented framework on construction projects that can tackle the lack in some data. For instance, it is vital to know the length of each activity where it is relatively harder to know for new unique construction projects. This can make the scheduling process harder for unique complex constructions. Thereby, this framework was seen to substitute the traditional approach in managing sites with a new automated human-free approach, i.e. experience on site can be gradually diminished on behalf of data measuring dominance and computer analysis.

However, some aspects within the framework were criticized such as considering Alice Technologies as a pillar within it. It was deemed inconvenient since it doesn’t conform to international standards but rather was built to meet local specifications (Alice

Technologies, 2019). Such differences in specifications can be a result of different practices, safety standards, risk management, etc. Thereby, more flexible standard-based platforms were advised by interviewee B in order to let it be applicable globally.

Interviewee B argued that the transformation of 3D point cloud data into a complete model that contains both geometric and non-geometric data might be the most significant technical gap in the presented framework. Form the interviewee's perspective, building an algorithm that can replace human intellect in recognizing similar looking objects, especially with technical installation of similar sizes (e.g. ventilation pipes and big shafts) can be the critical dilemma in the framework. This is because the automation of the presented framework is built upon this aspect. A speculated approach for mitigating this gap, from the interviewee's perspective, is to combine 360-degree images with 3D point clouds and comparing them to a pre-identified 3D "as planned" BIM model. This was seen to have a possibility to facilitate the recognition of non-geometric data of the detected objects. The incorporation of 360-degree images is seen to help in texture identification and thereby giving a hint on element's characteristics.

Interviewee B emphasized that funding a development process of a product is essential. In the case of the needed algorithm, mentioned earlier, it is assumed that constructing such an algorithm will need significant funding and thereby can be expensive. Thereafter, it was clarified that the technical gap in this aspect is based on a financial gap rather than knowledge shortage in building an algorithm. It is seen, by the interviewee, as a result of the difference in business structure between the construction industry and other industries. In other industries, such as vehicle manufacturing, the manufacturer develops the product and sells it to its end-users. On the contrary, the developer of technological tools in the construction industry advertises his products to a mid-user, i.e. Contractors, who will deliver a product regardless of the financial benefit taken from using the new technology.

The most significant barrier, according to the interviewee, is the human factor. Practitioners are seen to embrace traditional methods in the construction industry. Practices in the Swedish construction industries are seen to be nearly unchanged since the 1960s. 2D printed documents are still being the guiding instrument on construction sites. Changes are taking place in a slow manner in some developed countries by introducing new tools on construction sites such as tablets and mobile applications.

> *"But generally speaking, at least 90% out there are using paper drawings on site ... Even though they know it has some flaws such as not printing out the latest version of a drawing" (Interviewee B)*
>
> *"Here is where the gap comes. A technology is introduced that needs to be put in usage. But the real case is that they barely handle tablets with digital drawings because they think it's too much technology to use" (Interviewee B)*

The extent to which new technologies are being used on construction sites is thought to be highly linked to organizational hierarchy. Project managers own the crucial decisions on construction sites, and they insist to deliver construction projects within its three essential pillar quality, time, and cost. This doesn't give them enough room to examine new instruments and methodologies, especially new technologies that might have marginal error. Convincing project managers is a task that can't be underestimated where it requires individual of nearly the same understanding of project's complexities.

"the guys who run the business say we have done this for the last 40 years and it is going well for us. I made sufficient profit and the guys know what they do?" (Interviewee B)

Another part of the barrier holding the construction industry backwards is considered to be an educational gap. A speculated reason hindering practitioners from embracing new technological innovation is that they don't perceive comprehensively the gained value of adopting it. Consequently, efforts are made to seek and educate individuals within the construction industry who are innovation driven and willing to adopt new approaches within the construction process. However, most of the individuals found within the construction industry, who are willing to change, aren't decision makers.

Contract type affects the level of cooperation in using a technology on construction sites. Interviewee B emphasized that contractor's involvement in the planning phase can contribute to facilitating work and cutting extra costs. Another seen privilege of incorporating contractors at early planning stages is the ability to offer educational workshops, in case new approaches/technologies are to be used (Chen et al., 2015).

The type of contract that supports contractor's involvement in early planning stages in Sweden is called "Samverkan Entrepreneur" which means "partnering". This type of contract is considered by the interviewee to be the most suitable in term of construction projects where new technologies are being involved. The usage of contractor's expertise in the planning phase with planning teams is seen to increase the mutual understanding of project's complexity which can minimize some implementation costs. This contract type helps in knowledge sharing and therefore is seen, by the interviewee, suitable for introducing new tools on construction sites where educational sessions can be promoted.

"Involving contractors at the early stages, can save you a lot of expenses. They can provide advice that won't affect the shape or function of an element with up to 10% of the original price limit" (Interviewee B)

Involvement of new technologies on construction sites needs a lot of investment where practitioner argue that such new expenses minimize the net profit of a construction project. However, partnering contracts that can involve contractors at early planning stages can benefit the construction project financially, i.e. by reducing implementation costs when it's possible. Consequently, such contract types can provide a room for financial tolerance and willingness for investing in the new instruments/technologies.

5.3 Interviewee C

Brief description of interviewee: Interviewee C works as data coordinator BIM/CAD with nearly 8 years of experience in this field at one of the leading consultants in Sweden. This company is a big consultant office which is engaged to a high extent with designing and planning in accordance to UN sustainability goals and is considered Europe's leading architecture and engineering consultant. The interviewee's main field of work includes managing, structuring, and controlling the flow of data during the construction phase to meet future facility management requirements. The type of data being managed includes BIM/CAD models, project documentation in connection with company's customers.

The highlighted company had some aspects of the presented framework as a major interest within their development division. Such aspects are the ability to create a 3D model from 3D point clouds and the ability to compare models automatically without human interaction. The interviewee expressed company's desire in having a complete product that can offer such aspects but the current market doesn't offer one.

The current approach in using laser scanning technology within the highlighted consulting company follows the following steps. First, construction fields are being laser scanned through Faro Focus (i.e. stationary scanning tripods, fragmented and gathered afterwards) (Faro, 2019). Recently, drones have been introduced in their work as well and reliance on them is taking place gradually. The scanning process varies in duration as a result of two main factors as the interviewee suggested. These are size of construction being covered and the intended area to be scanned, i.e. scanning from exterior or scanning from interior. Afterwards, the gathered data are being processed to get ready for the modelling stage. Processing the data is a lengthy process and depends on the amount of data gathered. The modelling stage is considered expensive since its time consuming and varies in duration depending on the differences in individuals' capabilities. Recently, the company sends its data to foreign countries because of differences in labour wages, discussed later. It is good to mention that this consulting company uses the scanning technology to generate an "as built" 3D model only for already built constructions and not for checking the progress of execution on field in accordance to the 3D "as planned" model.

The latest technology in inspection used in few projects in the Swedish construction industry is through using an Augmented Reality (AR) software, developed by Information Experience, used in cooperation with Microsoft Hololens 2 as its hardware. This technology is referred to as Holoportation (Information Experience, 2019). The inspector wears these glasses where the 3D "as planned" model is visualized through the AR added feature with inner location privilege. Then the inspector can check if the construction elements are implemented or not throughout walking on the construction site and comparing it to what he/she sees on the "as planned" BIM model. The considered advantage is to generate inspection reports automatically once the inspector is done. This prototype software was tested by the biggest construction company in Sweden. The software was developed by Information Experience and it isn't finished yet since a lot of improvement is needed. In detail, augmented reality has a low level of precision in overlapping digital objects on reality. The marginal error can be up to 5cm difference.

Concerning compliance checking, the current available tools only allow to achieve such a feature manually or semi-automatically. In more detail, after laser scanning the 3D point cloud is being converted into a mesh and then the 3D "as-planned" BIM model is being taken as a reference in order to generate the 3D "as-built" BIM model which is taken is a reality representative in the stage of compliance checking. This procedure takes place mostly manually with the naked eye, which makes it vulnerable to error in the assessment of compiled elements.

This current process is considered lengthy and expensive where it is not of companies' favour to spend more than needed on just the time factor. Individuals vary in the amount of time needed for them to accomplish their tasks and it depends on their individual skills in using the needed software. Moreover, since the current processor is expensive, it is only being done when its highly needed and in some cases being sent to India to achieve modelling where they do nearly the same work, apart from differences in some standards in work among countries. Their finalized work is nearly a complete BIM model, i.e. includes both geometric and non-geometric, where non-geometric data needs sometimes adjustments according to the local specifications. This is considered the fastest and cheapest alternative the company has at the moment even though it is not completely efficient because of the need to apply some refinement on the received “as built” BIM models.

Other than being a lengthy process, it takes a lot of time, cost, and effort to even notice, if noticing took place, some divergences between the 3D “as planned” model and the 3D “as built” one. These are the reasons why some consulting companies are in favour of automating the process. Furthermore, the causes of expenses vary but the most common ones are the needed coordination on the construction site for scanning, and the time spent throughout the modelling stage which will mean extra expenses on the project. Nevertheless, all these expenses on the current process don't guarantee a fully accurate 3D “as built” model.

Practitioners within the construction industry argue that relying on experience is more efficient than investing a lot in developing a tool that might not meet their expectations. However, experience on its own doesn’t imply flawless work since humans are subject to errors regardless of how significant the error is. Moreover, it was pointed out, by the interviewee, that experience can’t be fully reliable in big projects since the chain of consequences for minor errors can’t be underestimated and the corresponding cost can be inconceivable.

The development division within the company is subject to customers’ desire of focus for worthiness purposes. In other words, approval to development projects is restricted to customer’s desire which doesn’t allow for room of flexibility in research. However, it is seen that in case of partnership with academic institutes, more room for flexibility can be achieved. Since in such case the academic body and the company can share responsibility towards development in a cooperative manner.

The most apparent barrier holding the construction industry from embracing more technology on site, from the interviewee's point of view, is the lack of attention towards product developers. In other words, development divisions have different types of development projects that are at the stake of financial boundaries, where sponsorship is seen as a vital component to keep these projects running. Lack of sponsorship towards development within the construction industry is seen majorly because of an ownership issue.

> *“The hard part in this process is to convince a company to participate with you in your project ... If sponsorship is to happen ... then who’s going to own the final product?” (Interviewee C)*

For instance, if collaboration happened among different parties such as construction companies, universities and public donors. The more the needed investment is, the harder it will be to settle ownership of the finalized product.

> *“If you request partial sponsorship from a company they might say ... after it's developed its us who owns this product ... then dispute/conflict can happen in agreement ... probably we want to sell this product to who’s willing to pay for it” (Interviewee C)*

On the other hand, another point preventing construction companies from investing in development projects is that development process is time consuming which implies a lot of cost with no guarantee that the final product will meet the set expectations. It is seen that construction companies prefer to buy finished products after investigating their feasibility since it is seen less expensive than getting involved in a complete development process.

In addition, the human factor from the interviewee's point of view is subject to the outcome of the business factor. For instance, if a new developed instrument was proven to be financially feasible then it will be a matter of time to educate different teams to accept the new technology.

5.4 Interviewee D

Brief description of interviewee: Interviewee D works as a BIM coordinator with 2 years of experience in the field at one of the most relevant and leading companies, if not the leading and most relevant, in Sweden within the field of BIM, photorealistic visualization of structures, and 3D laser scanning for construction. The interviewee's main focus comes in the sense of coordinating and coinciding the different 3D BIM models gathered from different departments in order to ensure smooth workflow in processes.

The current approach in creating 3D "as-built" model starts by scanning the required construction through a 3D scanning trolley called NasVis M6, see section 5.1. It should be highlighted that in the interviewee's opinion using a trolley scanner isn't the most efficient option since in some cases it is not applicable to walk with the scanning trolley in some parts of the construction site such as slaps, where components are structured in a definite manner and don't have proper path for a trolley scanner. When using 3D laser scanners, the resulting point cloud needs processing. The time needed for this stage varies among different construction sizes (e.g. it takes nearly 12 hours for a typical house with approximate area of 110 m2). Within this company AutoDesk ReCap is being used to create 3D mesh and then the file is being exported to AutoDesk Revit where all the modelling can happen manually. However, 3DReshaper is being used for its capability to generate volumes from the point cloud data automatically. Importing the "as-planned" model can facilitate its work by comparing the point cloud to it and thereby automatically execute modelling.

Checking compliance between what is planned and what is implemented is being held manually in the Swedish construction industry. It happens throughout frequent tours within the construction site that is called "säkerhertsrundor" in Sweden which stands for "security rounds" where inspectors have a checklist with all construction elements to be inspected and they check them one by one manually. Inspectors' job is connected to the job of "installationsledare", which stands for installations leaders, who are present on construction sites on a daily basis just to ensure that the implemented work is coincided with construction drawings.

The presented framework doesn't seem compatible with current computer processors' capabilities. Currently, the longest stages within the different stages in the Scan-to-BIM process within this company is the stage of processing the 3D point cloud into a mesh and the stage of manual modelling. Consequently, a logical approach in accordance to the presented framework is seen to be by adjusting the amount of scans performed by the amount of scans needed. In other words, Interviewee D suggested that the complexity of a construction building increases gradually as the construction project resumes. At the start of any construction project, the level of construction details is low. Thereby, the amount of scanning needed will be low too. As the complexity of a project increases, the amount of needed scans will increase gradually. Consequently, it was suggested to achieve the amount of scans performed on necessity basis instead of periodic basis.

Technically speaking, the automatic conversion of 3D point cloud data into an “as-built” BIM model is seen as a dilemma because of technical issues as highlighted previously by Bosché et al. (2015). However, some software can help partially in automatically defining volumes from a point cloud file such as 3D Reshaper. But it is still not fully reliable nor fully automated. Another downside is that the identification of volumes from point clouds is completely geometrical where non-geometric data won’t be available. Adding non-geometric data to the elements must take place manually. Inserting both the “as-planned” model and the 3D refined mesh, i.e. from point cloud, is believed to be an efficient approach in identifying objects, i.e. both geometrically and non-geometrically. In other words, it is believed to be easier to identify objects on a vague set of point data if it was compared to a pre-identified model that is supposed to reflect the reality of these taken points, i.e. point cloud.

However, in some cases it might hard to distinguish some construction elements that appear similar externally but have different parameters (e.g. electric pipe that looks the same as telecommunication pipe). Nonetheless, it was still believed by the interviewee that technological development should be able to overcome such an obstacle at a certain point in the construction industry. Face recognition feature in mobile phones’ industry was taken as tangible proof. All human faces are nearly the same in terms of components (i.e. eyes, ears, etc.) which is similar to the case, mentioned earlier, of similar looking pipes in construction industry. However, the investment put in mobile phones industry within research and development has taken such new features, i.e. face recognition, to another level of precision by defining the human face once at the start. Thereby, it was assumed that the construction industry can reach the needed point of development in case investment is well placed in research and development.

Although this is valid, it is vital to highlight a difference between mobile phones industry and construction industry. In mobile phones’ industry, phone manufacturers invest in product development, manufacture the product themselves, and eventually selling it to its targeted customers. While in the construction industry, contractors are mainly consumers of the developed technologies and they don’t get rewarded directly from using it.

> *“So in this case it has to be a third party that develops this technology such as Faro Technologies and then sells it to its customers which will be the contractors… many parties are involved in the process within the construction industry which makes it harder to try out technology than in other industries” (Interviewee D)*

From Interviewee D’s point of view, the significant gap holding back the construction industry from the implementation of such a framework and other similar technological approaches is that dominant construction companies don’t exert enough effort in testing new technologies. Since those companies are the most qualified financially and organizationally to test new innovations. And if those companies, in case new innovations were tested, realized that the newly tested technology wasn’t efficient they won’t be significantly affected financially nor organizationally.

Interviewee D sees that the financial value of a developed technology diminishes with time, i.e. financial worthiness diminishes with time as a product. Thereby, new small companies can’t invest in newly developed expensive technologies that might get significantly cheaper within a short timeframe. The general case is that most medium-sized and small-sized companies view big-sized companies as a role model that leads the industry. Thereby, it is mostly that they expect them to be the first risk takers in testing new products/approaches/technologies. Nevertheless, some small companies try their best in cooperating with technologies. But their cooperation is partial and not complete. A major point they consider is organizational processes might change as a result of adopting a new approaches and technologies, which can cost a company much more than just adopting a technology. An actual example is Dalux software, see Appendix section 9.1 for description. This software was developed, ready for usage, and available on the market for nearly five years. Lately, it has been put into usage and companies are gradually adopting it even though the software itself was not expensive. But the reason it took so long for it to integrate in the construction industry is that it was viewed as an unnecessary added cost to projects and the dominant companies didn't cooperate in using it at its early stages as well disclaiming its need in their processes.

> *"It has been working well for them previously and they don't see a need for change" (Interviewee D)*

In accordance to the rigidity of practitioners towards adopting technology, the main issue is that they don't see as much value in the presented concepts as product developers see in it. Another dilemma is that they don't get convinced easily with the value of work. For instance, this company's domain of work includes scanning constructions and practitioners themselves can't believe the differences in the performed work, i.e. the amount of error included, until they see the "as-built" model. In other words, practitioners don't get aroused to the conveyed value of work until they see an actual evidence of its worthiness.

In the interviewee's point of view, it is justifiable for an industry to take a while before shifting to a new approach or technology. But the construction industry is claimed to take longer than other industries in that sense. A possible explanation, from the interviewee, is that the construction industry nowadays has two options to choose from. One being sticking to the traditional approaches and processors in accomplishing construction. The second is moving in a synchronized manner with construction technologies and developments.

5.5 Interviewee E

Brief description of interviewee: Interviewee E works as a BIM manager with 8 years of experience in the field at one of the most relevant and leading companies in Sweden within the field of BIM, photorealistic visualization of structures, and 3D laser scanning for construction. The interviewee's main focus comes in the sense of planning and executing the training sessions for employees to increase their competence in using BIM databases. His position also includes being responsible for BIM forums that highlight interesting topics in recent innovations within BIM, some BIM issues that need to be tackled, and their possible solutions.

One of the major problems the company encounters in its field is the lack of interaction with practitioners in terms of data exchange and feedback on delivered data. In other words, this company is responsible for delivering BIM data to contractors. But this entity doesn't get an assessment of the delivered data which leaves their planners in ambiguity. The lack of good communication between practitioners and planners is seen as a barrier. More collaboration between both parties is anticipated to boost the process of detecting errors within the planned models and documents at an early stage. Thereby increasing the efficiency of both delivered data by consultants and the implemented construction by construction contractors, i.e. avoiding repetitive corrections.

The construction industry nowadays depends heavily on 2D construction drawings. According to the interviewee's experience, this is taken as a reference for measuring the amount of work achieved work by architects, i.e. number of drawings being delivered. This is seen as a hindrance for the progress in adopting 3D BIM models instead. However, practitioners have gradually started to use new tools on construction sites that promote digital construction models such as tablets and mobile applications. However, practitioners see a shortage in the delivered digital BIM models that is they are not fully detailed in every single aspect.

> *"Where I see the level of detail in the delivered BIM models is very connected to the type of contract" (Interviewee E)*

The type of contract is seen to have a major impact on the delivered data in terms of detail's level and on the collaboration among different parties in using new methods and technologies. The contract divides roles and responsibilities and determines the collaboration among all involved parties within its regulations. From the interviewee's perspective, it is essential to involve contractors at early planning stages when new instruments/approaches are introduced on construction sites.

"Samverkan Entrepreneur" which is equal to "partnering" is a type of contract that supports contractor's involvement in early planning stages in Sweden. This contract is advised by the interviewee where new approach/technologies are to be implemented on construction sites. Contractor's early involvement in early planning stages is seen enlightening towards possible unpredicted obstacles in using the new approaches/technologies on construction sites. Another privilege of involving contractors in the planning phase is to exploit their previous expertise in avoiding expensive mistakes in terms of buildability and long-term durability.

The lack of reliance from practitioners on digital BIM models is considered a consequence of some reasons. According to the interviewee, current delivered BIM models among different consultant companies don't have a protocol that unifies them in terms of interaction with practitioners. For instance, the level of development (LOD) is currently not unified for all elements within the delivered BIM model. On the other hand, construction contractors expect to have finalized BIM models that fulfil the required LOD for all the model's elements at the same level. From the interviewee's point of view, previous inconvenient experiences by construction contractors in interacting with delivered BIM models will not build a suitable reputation in depending on digitalization instead of traditional documents. Consequently, establishing mutual standard in delivering BIM models is seen vital and beneficial.

According to the interviewee, the major barrier lowering the pace at which the construction industry embraces new technologies is the human factor. The construction industry is seen to have a traditional context in managing its processes where practitioners consider it unnecessary to change the current processes, especially if it is accompanied with extra costs. Another argument in explaining this attitude includes people's mentality in resisting change. People tend to seek development and progress, but they are still psychologically connected to ideas such as safety and comfort (Clegg et al., 2016).

“People are generally afraid of change” (Interviewee E)

The human factor has different sides from which one is job opportunities. The presented framework is based on automating processes such as inspection, scheduling, auto management, etc. This will eventually mean losing opportunities even if other vacancies might open to monitor the new adopted technology.

“This might be seen as a lobby on those who adopt change. But it is not as big as the mentality issue” (Interviewee E)

Another barrier that shouldn’t be underestimated is the technical gap. From the interviewee’s point of view, finalized products that can be put directly into usage are an excellent way in convincing practitioners. On the other hand, product development processes are known for being time consuming where they need continuous financial support. Thereby, construction contracting companies, especially smaller ones, try to avoid getting involved in such development processes.

Furthermore, it is considered, by Interviewee E, a dilemma to persuade construction practitioners to incorporate new products/approaches that are outside the traditional frame of construction processes. Using new approaches/technologies must be accompanied by an add value to the construction project. According to his experience, construction practitioners tend not to pay attention to new tools/products that won’t return on the project with financial benefits equal to the expenses in adopting them. Nevertheless, construction practitioners tend to underestimate the pace at which new technologies develop with time and consequently getting more affordable and efficient.

5.6 Interviewee F

Brief description of interviewee: Interviewee F works as a VDC engineer with 4 years of experience in this field at one of the leading consultants in Sweden. This company is a big consultant office which is engaged to a high extent with designing and planning in accordance to UN sustainability goals and is considered Europe’s leading architecture and engineering consultant. The interviewee’s main field of work is about incorporating BIM in different construction phases. It’s mainly about clarifying the different usages of BIM database to different targeted groups within the organizational hierarchy. Another part of the work comes in the sense of clash detection among different disciplines and applying corrections.

The current followed approach in creating 3D “as built” models from 3D point clouds is manual. It includes a series of steps starting with managing the 3D point cloud data through Autodesk ReCap. This stage includes excluding all unnecessary points within the point cloud that are not related to the intended objects to be modelled, e.g. if it’s a wall to modelled, there will be points on it and beyond it the vacuum space in front of it. Afterwards, the file is being forwarded manually towards Autodesk Revit where it hosts both the 3D “as planned” model and the refined 3D point cloud. For precision reasons some datum points, i.e. reference points, must be defined between the two file in order to get as high precision as possible. Then modelling/defining construction elements takes place manually through comparative inspection. The adjustment of elements is only held on the 3D point cloud file since it will represent the “as built” model later on.

The current procedure in 3D modelling from point clouds is claimed to be time and effort consuming. Moreover, its progress pace depends heavily on the variation of individual skills in using the required software. Companies themselves are claimed to be responsible for educating their staffs on regular basis on the recent developments/technologies in building information modelling since the lack of skills is claimed to be linked with the lack of comprehensive understanding on how BIM databases can be technically used. This is especially true for the lowest level in organizational hierarchy of contractors, which is labour themselves. In most cases labour is clueless on what BIM is and how it's supposed to work. While it is believed that if labour can comprehensively interact with BIM, the potential of using BIM database will be boosted. This is because labour have the main interaction on construction sites, and they know the major issues arising within their field of work. In conclusion with the previous highlighted points BIM database was seen by Interviewee F to be currently more dominant in the planning phase where its usage in the construction phase is currently quite insignificant.

The current approach in modelling has some advantages and disadvantages according to Interviewee F. Its advantage comes in the sense of understanding the 3D BIM model better, however, this is only true for few individuals who deal closest to the model such as BIM coordinators and VDC engineers. The disadvantage is that BIM models are not as unleashing as they might sound since they need to confirm some specifications before being used for a specific purpose. For instance, if a model is to be used for quantity take-off the model itself needs to confirm some pre-requirements (e.g. check there is no duplicated objects in the model, quantities can be doubled if this step is ignored) to make it qualified for this purpose.

Concerning the process proposed and presented in section 4.4, see Figure 5. It was seen to be conceptually satisfactory but technically flawed. The usage of Solibri as a tool for achieving automatic comparison between the gained “as built” model and the “as planned” model is not thoroughly achievable. Solibri needs nomination of specific specifications in order to check clashes in accordance to these specifications but eventually it needs human interaction (i.e. to check the detections) which will hinder the automation of this process. However, the usage of Solibri as a contemporary tool was seen conceptually correct since one of its privileges is that there is an ability to extract the highlighted construction elements in terms of quantities and export it as an excel file which is compatible with Alice Technologies that deals with numeric data, see Figure 5.

Considering the gap that hold the presented framework apart from the construction industry, it was seen by Interviewee F that the technical factor plays the major role in this. The ability to transform a 3D point cloud file to a 3D “as built” model is not currently available. Thereby, there is no efficient tool that can be used to visualize the value and potential of such a framework. From the interviewee's point of view, the social factor is destined by the technical factor. It can be flexible on the long run and subject to change as long as there is the needed technical tool to convince them. Meanwhile, the contemporary view of most practitioners to the technology used within BIM is that it doesn't give significant added value for the construction industry since the industry itself is considered sufficiently profitable.

The organizational structure is anticipated to change in case the presented framework was implemented, especially at the subordinate level. Many occupations that already exist are expected to vanish because of the automation in processes. However, some other new occupations are expected to be created instead for efficient flow in the processes. For instance, inspector's job will disappear since inspection will be handled by the automated process. Meanwhile, some other technical job occupations will show up such as, hypothetically assumed, controllers whose jobs might include applying flying inspections to check if the presented automated system works efficiently or not.

The speculated gained value of automating construction processes was seen to be worth investing since investing in a lot of developing researches and experiments is a question of worthiness. The anticipated value for such automation comes in the sense of facility management. If all construction components were identified and registered in a final 3D BIM model that reflects the exact status of a construction then most confronted future maintenance issues can be solved easily and efficiently with lowest possible costs.

Concerning construction activity scheduling, it is being achieved manually nowadays based on construction drawings with the assistance of experienced individuals in the construction industry that had interacted with many previous similar projects. The practitioner within construction industry choose to do it manually even though the tools exist for automating construction activity scheduling base on 3D models. Currently very few companies use Asta Powerproject or Synchro software, which are scheduling software that are based on 3D construction models, in scheduling. The anticipated reason for this is that those scheduling software handle corrections to the construction activity schedules only to a low extent where complicated issues can't be solved through them.

The used scanning techniques vary in Sweden. The most used instruments are trolley scanner (e.g. NasVis M6), station scanners, backbag scanners, and recently drones scanners have been introduced to the construction industry. The selection of a scanner type is so dependent on the purpose and the nature of construction site. It needs to be compatible with it since cleaning the site is not only a tough task but expensive as well. A highly promoted scanning tool that has been lately introduced to practitioners is the Spot Robot, see Figure 7, developed by BostonDynamics, which is used for many purposes which among is construction scanning and is mounted with an auto navigation system for improvising on construction field (BostonDynamics, 2019).

Figure 7: Spot Robot with scanning features

Scanning the construction site on periodic basis, e.g. once a week, can be seen as a cost question. Scanning the site implies different types of costs such as ceasing work temporarily, cleaning the construction site, modelling the gathered 3D point clouds, scanning consultant's expenses, safety issues and safety management etc. These costs need to be considered on a project budget level since scans that won't contribute to any additional value will be considered lost costs on the project. It is good to mention that current computer processors won't be able to process the data on high pace, e.g. daily basis. But this issue is expected to be solved gradually within the coming years through computer development.

The type of contract also can affect the flow of processes of such a framework. Design-Built (DB) contracts are seen, by the interviewee, to provide more room for flexibility and tolerance since the contractor has higher access all throughout the different construction stages. For instance, in case some corrections were applied on the "as planned" model the contractor will have instant access to it and thereby the flow of processes is predicted to be smoother than in Design-Bid-Built (DBB) contracts. Another aspect is that if the contract was Design-Built then the contractor can ensure that all subordinate parties use the same level of specified technology, i.e. dealing with 3D models instead of traditional drawings.

Design-Built contract was believed to be more flexible than Design-Bid-Built since it doesn't have the same level of restriction in accordance to cost. The fixed price acts as a pillar for DBB contracts which will act as a restriction for main contractor's flexibility. This is because the main contractor in most cases have similar contracts, i.e. fixed price contracts, with subordinates which will restrict their flexibility too.

Partnering project agreement was seen as the best option for smoother workflow. It was argued that in this type of contracts all joining parties are mutually responsible for the project and thereby will work for the sake of its success. Consequently, it will be a major requirement to apply the agreed technological standards by all the parties involved.

6 Analysis and discussion

After analysing the obtained data from both the literature review and empirical findings in order to present relatively close suggestions that contribute to answering the previously highlighted research questions as the main aim of thesis, the discovered main barriers slowing down the construction industry from progressing at a similar pace to other industries can be listed under three categories. These are human interaction factor, technical shortage factor, and the business cycle factor. These factors are elaborated and explained in accordance to the obtained data from both literature review and empirical findings. Later on, each factor is analysed in order to provide suggestions that focus on mitigating the highlighted issues under each factor.

6.1 Human interaction factor

The first exposed barrier holding the construction industry apart from progressing with technologies and applying frameworks such as the presented conceptual framework is the social aspect, i.e. construction industry practitioners. The human factor holds within it many aspects to cover in order to investigate the hindrance it holds toward the construction industry.

By reviewing both literature review and empirical findings on the topic of 'individuals and their interaction with organizations and development'. A mutual consensus can be noticed between these two sources on some detailed aspects within the human factor. In the following three sections discussion will be made on organizational structure's effect on individual, the perception of change, and the need for process change.

6.1.1 Individuals & organizational structure

As demonstrated by interviewee B that some construction practitioners are willing to adopt new approaches/frameworks within their daily tasks. While the hindrance holding them from influencing the overall organizational process is their limited authority to make decisions. This is related to their occupation/position within the organizational body, i.e. contracting company.

This coincides with the presented literature of Clegg et al. (2016) mentioned earlier on the effect organizational structures hold toward the interaction of employees with organization's development. Clegg et al. (2016) covered a wide range of new organizational forms. The most important under their coverage are the two main organizational structures, hierarchical and flat organizations and their influence on their individuals.

Construction companies, as reviewed in literature, are recognized by their hierarchical structure. This is a highly anticipated reason for hindering the construction industry from moving forwards in a coincided manner with new technologies and practices. In detail, hierarchical organizations prevent their sub-ordinates from being influential and decisive.

Apart from organizational structures effects, and focusing on individuals themselves. Clegg et al. (2016) highlighted the possible lack of understanding of many individuals for their roles in terms of contribution towards their organizations. In other words, some individuals rather following the usual norms within their organization than changing it. A possible explanation for this phenomena is that some individuals, who belong to hierarchical organizations, might perceive going out of traditional processes as being vulnerable to job insecurity rather than positively contributing towards an organization.

After analysing the literature review and empirical findings in accordance to the previously highlighted two points. A possible suggestion to mitigate this dilemma caused by organizational structures is to make these companies more flat by a variety of actions. These actions can include mutual workshops that withhold all company's individuals in an attempt to increase the level understanding and interaction within the construction company. These workshops can also be exploited to make referendums in cases where new policies, approaches and technologies are being involved. Another vital needed change is to give sub-ordinates higher degrees of autonomy in combination with educational sessions to clarify clearly their influential capabilities within their construction companies.

Last but not least, increasing the influential ability of construction companies' sub-ordinates. This can be done by implementing the previously mentioned referendums. Another efficient way to increase sub-ordinates' power within an organization is to make them partial shareholders. This approach is proved to decrease the gap in power between companies' superiors and inferiors. Simultaneously, it gives organization's sub-ordinates higher access to organizational decisions (Creighton, 2019). In this manner, they will be more influential even if they have primitive organizational positions.

6.1.2 Individuals' perception of change

Covering the interaction of practitioners with process change. A mutual ground between literature review and empirical findings can be noticed in this sense. It is that the construction industry is significantly slower than the majority of other industries in accepting process changes. In detail, if the scope of analysis is aggregated to cover the 'perception of change' on individual's level, some key points can explain the slowness of change in the construction industry.

According to empirical findings, if the construction industry was to be portioned, then the majority of practitioners are not concerned with change as far as the current processes are functioning well with efficient results such as acceptable net profit, quality. This unconcern is speculated to be a result of three factors: incomplete understanding of proposed approaches, fear of the unseen, and short run feasibility analysis.

First factor, incomplete understanding of the proposed new technology or approach and the hidden aspects of it. In other words, construction practitioners might not see the long run gained value/privilege of utilizing the promoted approach/technology within their processes. Such gained values can include cutting off further expenses for extra personnel in cases where automation can take over.

In order to minimize the intensity of this anticipated factor. It is advised to perform educational sessions that can be held within either workshops or periodic seminars. These educational sessions should be applied after proposing the desired new technology/approach to show the long term advantages and disadvantages of the complete product/strategy. This can boost practitioner's awareness comprehensively.

While the second factor for not being motivated towards progress is the fear of the unseen. One suitable example can be job instability in cases where new inventions conquered some industries. The first industrial revolution is a real case study that personifies this notion. Many people were tempted by using inventions in the agricultural industry in order to minimize expenses and maximize the profit. Afterwards, job loss was recognized as one of its major consequences (Schwab, 2017). This coincided with the collected data from interviewee E, where he suggested that people might resist technological progress because of feeling insecure towards the futuristic consequences of implementing the technology.

Another possible reason is that practitioners might perform a short run feasibility study on using the new approach/technology. Such feasibility studies can demonstrate the short run financial inefficiency of adopting the new approach/technology. This happens in cases where using the technology is expensive.

6.1.3 Persuading individuals & process change

According to the literature part, a clear connection was noticed between persuading individuals and building a comprehensive process for the planned organizational change as illustrated by Schwab (2017). The same results were seen in the empirical findings as interviewee A suggested previously.

A common explanation for this is that the audience, i.e. construction practitioners, need to make sure that the presenter of a new technology/approach fully understands the advantages as well as the disadvantages of the promoted product. This can be tackled by visualizing the overall picture of organization’s future in connection to the promoted technology/approach. Moreover, building a complete process for a new technology/approach can let construction practitioners rely on the presented product and feel more secure. Since this can portray a sense of understanding for all possible consequences of incorporating the technology/framework. This is to ensure before applying the technology/approach that all possible issues are resolved and the work flow will not be hindered by its application.

As a result, building a comprehensive process for the presented conceptual framework is seen vital in order to facilitate its application in the construction industry. Since constructing a comprehensive process can resolve most of the arguments on the future of using the new technology/framework, which can be highlighted in the convincing stage by construction practitioners.

6.2 Technical shortage factor

The technical factor is considered vital as it is seen the tangible tool that can be utilized in order to convince the social aspect highlighted previously within the human factor discussion.

The following two sections will highlight some technical shortages discovered within the drawn conceptual framework in terms of applicability. The sections will mainly highlight automatic modelling from point clouds and automatic correction for construction activity schedules.

6.2.1 Automatic modelling

After reviewing both the literature review on ‘using data collection tools in order to automatically generate BIM models data’ and the empirical findings, it is fully apparent that there is currently no product that is able to issue complete BIM model elements with their needed data from random captured data from construction sites, e.g. 360 degree images or 3D point clouds. As a result, it is seen at least for the presented conceptual framework that the technical barrier has higher priority than the human factor. This is because there is a need for an existing complete product in order to convince construction practitioners with its usage.

The gathered data on the existing technical issues within the conceptual framework differed between the literature review and the empirical findings. The empirical findings were more generic and the literature review was more detailed.

The technical gap within the conceptual framework is seen partial and not complete. This means that most of the technical aspects presented in the conceptual framework exist nowadays in terms of actual products. However, few crucial aspects within it are still missing in terms of actual products in software market and need to be furtherly developed. This is visualized in detail in the following sections.

The analysis made by Yang et al. (2017) that 3D terrestrial laser scanning is the most suitable current technology for construction sites applications agrees with the findings of the empirical section. The major two instruments used for scanning purposes are Faro Focus and NavVis M series, which are both laser scanning-based tools with a privilege for 360 degrees shooting for the NavVis M series.

In other words, 3D laser scanning technology is a technology that should attract higher attentions of developing research. In detail, all the literature review and empirical data had a consensus that the major dilemma is in converting captured point clouds into complete BIM models without having human interaction within the processing stage. Some studies, however, managed to present simplistic automatic approaches that can interpret unconstructed point cloud data such as the work presented by Bassier et al. (2018).

In this sense, different studies had different angels of focus in their attempts to mitigate this gap. Some studies' major concern was to simplify the captured 3D point cloud data in order to higher the quality of the final processed output such as the work of Vosselman et al. (2017) and their usage of segment-based classification for data taken by airborne laser scanners. On the other hand, other interesting studies tried to focus on creating BIM model elements based on possible logical interpretation of the captured point clouds.

One of those studies is the work done by Nikoohemat et al. (2017) where they exploited the extra feature of using IMLS, which is capturing data in a trajectory manner rather than being stationary as in TLS, to create sense of it. Their work was based on creating information from spatial logic. This had its significant contribution towards 3D point cloud interpretation. In the same manner, Bassier et al. (2018), as shown in literature review, tried to reconstruct wall geometry automatically by exploiting the topology of existing rooms. Even though, extracting such data was hard because of noise and cluttered construction environment, their approach was seen beneficial for gradual interpretation of room vacuums and then partial walls.

The common aspect among all previous literature is that they try to interpret point cloud data according to the most suitable spatial feature that can help in extracting the targeted elements linked to this feature. This differs from the acquired results by interviewee D in the empirical findings. His recommendations of imitating the concept of 'face recognition' feature used by most current mobile phones is seen new and holds high future potential. This promoted feature used 'face recognition' is speculated to have the ability to produce accurate "as built" BIM models in complex construction environments for compliance checking purposes, which can be beneficial for the presented conceptual framework.

In detail, the conceptual idea behind 'face recognition' feature is to provide a complete defined structure of human face as a reference version. This reference version will guide in identifying only one human face among all captured human faces. In relation to this, a similar concept was implemented by Wang et al. (2018). They tried to construct "as built" BIM model and predict the dimensions of precast concrete panels automatically based on previous anticipated dimensions of those concrete panels, which acted as a reference. This research is still a primitive example of applying the base principle behind 'face recognition' feature which is using the "as planned data" in order to guide in creating "as built data".

Thereby concerning future developing research, it is encouraged to investigate the ability to use "as planned" models as heuristic references for creating "as built" models rather than being exact references in creating them. In other words, "as planned" models should not dominate in guiding the creation of "as built" models.

To elaborate this point through exampling, a wrongly implemented 3 inches PVC pipe is to be modelled to reflect its "as built" status. Relying on an "as planned" model that contains a 3.5 inches PVC pipe in the same spatial location of the implemented 3 inches PVC. According to Wang et al. (2018), the final drawn PVC pipe within the "as built" model will be 3.5 inches, which is a mistake and does not reflect the reality of "as built" conditions. This can happen in case of taking "as planned" models as dominating guidance in creating "as built" models. Thereby, the encouraged approach is to take "as planned" models as comparative heuristic references in order to reflect an exact status of the implemented reality.

6.2.2 Automatic activity schedule correction

The second technical gap in the conceptual framework is in automating schedules for managing construction activities corrections. According to the latest reviewed literature and empirical findings, there is currently no complete product on market that interacts with BIM model corrections automatically based on comparing "as built" and "as planned" BIM models.

Alice Technologies is a current software, as mentioned earlier, that deals only with scheduling. It has some limitations such as not applying automatic corrections to schedules, not dealing with BIM data and thereby is not 4D BIM supported. Another limitation is being only limited to local construction standards, i.e. US construction standards, which might not be applicable at other countries that have different approaches in managing construction.

The nearest approach in terms of applicability to the presented conceptual framework is the reviewed work of Hamledari et al. (2017). Their created model had many aspects that cover vital points within the presented conceptual framework. For instance, it links scheduling data directly to 4D BIM feedback. However, their created model has some limitations that should be overcome such as automating manual entry to their model and the type of data that can be entered should be broader than just updating elements' statuses.

Thereby, in order to make the drawn conceptual framework technically more applicable, it is encouraged to build upon the model constructed by Hamledari et al. (2017). The needed improvement and development on their research should encounter more automation in inserting BIM data to their model and the manner in which 4D BIM data are being updated according to construction progress.

Technically explained, the model created by Hamledari et al. (2017) depends on updating the status of inspected elements and their progress throughout a manual entry of their *completion rate ratios*. Adhering to this trait, the following suggestions can help in inserting the outcomes of the presented conceptual framework to their model. First, since construction delays mean construction activities that did not start yet, then their percent completion rate can be set on zero. Continuously, wrongly implemented construction elements, whether in terms of their parameters or spatial position, shall have percent completion rate of zero plus an added task for dismantling these construction elements, i.e. for fixing reasons.

Another point to add in the model of Hamledari et al. (2017) is the inclusion of cost related data in order to take their model from 4D-based BIM to 5D-based BIM. This possible added feature can enable their model to measure ‘construction earned value’ through project’s progress and thereby can demonstrate the results of EVA, which is one outcome of conceptual framework, as an added result for their model.

6.3 Business cycle factor

The financial element is seen the third prominent pillar that is vital for bridging the construction industry a little closer to adopting progress and applying technological-based approaches. Different aspects from variety of perspectives were covered on this factor within both literature review and empirical findings.

The literature review has focused on different factors that can assist construction practitioners in financing developing research for innovation. Some studies went on to provide a detailed description on possible ways for financing projects that are innovation related such as the study made by Chirkunova et al. (2016). Some other literature highlighted the gained reward to companies that finance innovation on the long run. Such reward can be in the form of dominating the market in terms of innovation compared to other smaller competitors (Rus, 2016).

Generally speaking, the data gained from literature review on this matter focused on financing innovative research and development. This coincided with the outcome of interviewee C on spotting the barrier holding construction industry apart from development. Thereby, both literature review and empirical findings agree on the importance of financing developing research, whether through direct or indirect financing tools. However, interviewee D highlighted a point that was not investigated by literature review, which is understanding the business model of the construction industry compared to other industries.

In detail, there is difference between companies in terms of their business models. Companies that are product-based are different than project-based companies, e.g. construction contractors. The difference is in terms of their business models as commercial companies. In the case of product-based companies, it is of high importance to notice that the reason products of such companies are favoured against each other in the market is based on the level of innovation and efficiency of them. By exampling, if two painting companies that majorly produce wall paints are to produce two different paint types, assumingly paint A and paint B. Then one anticipated reason for favouring one product over another is the level of competitiveness each product holds.

On the other hand, by analysing the business model relied on by the majority of construction contractors as highlighted by interviewee D. It is apparent that construction contractors are being involved and authorized to deliver final construction projects, to their clients regardless of the level of innovation and development used within their processes in the production phase.

To elaborate on this by further comparative analysis with mobile phone’s industry. Mobile phone developers/manufacturers have a direct relationship with their end-users, i.e. customers, and their products are being under frequent assessment by their end-users based on many factors which one of them is the level of innovation and development exhibited in the end product (Funk, 2009). In other words, these companies make profit based on the level of satisfaction of their end-users, which is highly related to the level innovation the end product.

On the other hand, in case of construction contractors, the innovative tools are being developed by developing companies, e.g. Faro and Trimble Inc. Those developing companies sell their products to a middle user which is construction contractors, rather than end-users, i.e. clients. Thereby their ability to commercialize their products is subject to the middle user’s desire in consuming them, i.e. construction contractors’ desire to use their products within their construction processes. This is critical since construction contractors, i.e. middle users, are majorly driven by the requirements set by their end-users, i.e. clients in this case.

It is essential to highlight that construction companies are project based organizations, which implies that there financial income is based on the acquired projects. In this sense, it is essential to highlight that this might be a limitation for construction companies to invest in innovation based projects. However, this prospect is beyond the boundaries of this thesis.

Currently speaking, construction clients which are the end user are concerned that the delivered projects meet their contractual specifications regardless of the level of innovation used within contractors’ processes in the construction phase.

A conclusion of this analysis is that construction companies make profit regardless of the level of innovation used in their construction processes since it is not a major concern for their clients. Briefly, construction companies are driven by clients’ specifications. Consequently, it is seen essential to make construction clients more incentivised and driven by development and innovation.

One possible way to motivate construction clients to set innovative standards for construction contractors is by arousing them towards the possible hidden potential of using technology on the long run. The long run privileges such as cutting expenses, resulting in more efficient construction projects, increasing precision, gaining more control of facility management data, etc. can thereby motivate construction clients to deal with construction contractors that are more innovation driven.

7 Conclusion

This thesis aimed to draw a conceptual framework that is believed to hold high potential towards the construction industry. This potential can be in the form of saving human efforts, avoiding time lags, increasing the quality and efficiency in delivering construction projects. Furthermore, another objective of this thesis was to analyse the status the construction industry has in terms of development within its processes.

The thesis investigated the main reasons and factors acting as hindrances for applying the presented conceptual framework by construction practitioners. Eventually, it resumes to investigate these factors and elements by further analysis in order to provide possible suggestions that might eliminate or at least mitigate the highlighted barriers.

After performing analysis, the spotted factors acting as major hindrances for the construction industry from applying the presented conceptual framework were three factors. These were the human interaction factor, the technical shortage factor, and the business cycle factor. These factors were elaborated and explained in accordance to the obtained data from both literature review and empirical findings.

Throughout the analysis of human interaction factor, it was seen that organizational structure plays a significant role in shaping its employees in terms of interaction and contribution. It is good to mention that construction companies' majority follow a bureaucratic hierarchical form of organizations that restrict individuals' interaction within an organization.

After analysis, a possible suggestion to mitigate this dilemma is to make construction companies more flat by a variety of actions. These actions' target should focus on increasing employees' involvement in an organization. Thereby, they can include an increased number of workshops that withhold employees at different organizational levels. This can be done in an attempt to increase the level of understanding and interaction within a construction company.

A second exposed factor by the analysis is the technical shortage which was apparent in some aspects of the conceptual framework. The technical shortage had two significant gaps. First, the technical gap was evident in the lack of ability in converting 3D point cloud data into complete BIM models automatically. The second gap was in performing auto-corrective scheduling for construction activities.

In an attempt to mitigate these technical shortages, the findings of this thesis encouraged investigating the ability to use "as planned" 3D BIM models as heuristic references for creating "as built" 3D BIM models rather than being exact references in creating them. In other words, the "as planned" models should not dominate in guiding the creation of "as built" models, as discussed in section 6.2.1.

The last exposed factor within findings was the business cycle factor. This factor demonstrated the effects business models have on motivating companies to use innovation within its processes. According to analysis, it was deduced that the business model for the majority of construction contractors doesn't encourage them to invest in innovation and development. In detail, their clients' specifications does not set specific conditions on the level of innovation and development used in project's production stage.

Consequently, the incentive to boost development and innovation in construction contractor's processes is linked to client's contractual specifications. In order to resolve this, it is advised to arouse construction clients on the possible long run potential of supporting development and innovation. This is anticipated to motivate construction clients and incentivize them to deal with construction contractors that are more innovation driven.

In summary, the factors acting as barriers for applying the drawn conceptual framework in reality are human, technical, business related. After analysing the acquired data from different sources, recommendation for future studies are specifically encouraged for the issues discovered in the technical factor. Elaborately, further research should focus on the automatic transformation of point clouds into BIM models. More specifically, trials should be put on using “as planned” BIM models as heuristic reference in creating “as built” BIM models.

Further research should focus on another technical point. This is to investigate the ability to auto-correct activity schedules through linking it directly to BIM model elements. An encouraged research is to build on the model created by Hamledari et al. (2017) through the recommendations highlighted in section 6.2.2.

References

Adler, P. A., & Adler, P. (1987). *Qualitative Research Methods: Membership roles in field research*. Thousand Oaks, CA: SAGE Publications, Inc. doi: 10.4135/9781412984973

Afsari, K., Eastman, C.M. and Shelden, D.R., 2016. Cloud-based BIM data transmission: current status and challenges. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 33, p. 1). Vilnius Gediminas Technical University, Department of Construction Economics & Property.

Ahmed, M., Haas, C.T. and Haas, R., 2013. Autonomous modeling of pipes within point clouds. *Proceedings of the 30th ISARC, Montréal, Canada*, pp.1093-1100.

Akhmetshina, E.R. and Mustafin, A.N., 2015. Public-private partnership as a tool for development of innovative economy. *Procedia Economics and Finance*, *24*, pp.35-40.

Alice Technologies Inc. (2017), *How ALICE works*, 08/April/2019. Retrieved from URL: http://www.alicetechnologies.com/how-it-works.html

Babič, N.Č. and Rebolj, D., 2016. Culture change in construction industry: from 2D toward BIM based construction. *Journal of Information Technology in Construction (ITcon)*, *21*(6), pp.86-99.

Bassier, M., Klein, R., Van Genechten, B. and Vergauwen, M., 2018. IFC Wall reconstruction from unstructured point clouds. *annals of the photogrammetry remote sensing and spatial information sciences*, *4*(2), pp.33-39.

Beach, T.H., Rana, O.F., Rezgui, Y. and Parashar, M., 2013. Cloud computing for the architecture, engineering & construction sector: requirements, prototype & experience. *Journal of Cloud Computing: Advances, Systems and Applications*, *2*(1), p.8.

Bosché, F. and Haas, C.T., 2008. Automated retrieval of 3D CAD model objects in construction range images. *Automation in Construction*, *17*(4), pp.499-512.

Bosché, F., Ahmed, M., Turkan, Y., Haas, C.T. and Haas, R., 2015. The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components. *Automation in Construction*, *49*, pp.201-213.

Boston Dynamics (2019), *Spot Good Things Come in Small Packages*, accessed 25th June 2019, retrieved from: https://www.bostondynamics.com/spot

Bryman, A. 2016. *Social Research Methods.* New York, United States, Oxford University Press Inc.

Chau, K.W., Anson, M. and Zhang, J.P., 2005. 4D dynamic construction management and visualization software: 1. Development. *Automation in construction*, *14*(4), pp.512-524.

Chen, J. and Cho, Y.K., 2018. Point-to-point Comparison Method for Automated Scan-vs-BIM Deviation Detection. In *2018 17th Int. Conf. Comput. Civ. Build. Eng*.

Chen, Q., Xia, B., Jin, Z., Wu, P. and Hu, Y., 2015. Choosing appropriate contract methods for design-build projects. *Journal of Management in Engineering*, *32*(1), p.04015029.

Chen, S.M., Chen, P.H. and Chang, L.M., 2013. A framework for an automated and integrated project scheduling and management system. *Automation in Construction*, *35*, pp.89-110.

Chirkunova, E.K., Kireeva, E.E., Kornilova, A.D. and Pschenichnikova, J.S., 2016. Research of instruments for financing of innovation and investment construction projects. *Procedia Engineering*, *153*, pp.112-117.

Clegg, S.R., Kornberger, M. and Pitsis, T., 2015. *Managing and organizations: An introduction to theory and practice*. Sage.

Clegg, S.R., Kornberger, M. and Pitsis, T., 2015. *Managing and organizations: An introduction to theory and practice*. Sage.

Creighton, K (2019), Feb 5th. *Benefits of Making Your Employees Shareholders*. Retrieved from: https://hrdailyadvisor.blr.com/2019/02/05/benefits-of-making-your-employees-shareholders/

De Vries, B. and Harink, J.M., 2007. Generation of a construction planning from a 3D CAD model. *Automation in Construction*, *16*(1), pp.13-18.

Eriksson, P.E., 2013. Exploration and exploitation in project-based organizations: Development and diffusion of knowledge at different organizational levels in construction companies. *International journal of project management*, *31*(3), pp.333-341.

Faridi, A.S. and El-Sayegh, S.M., 2006. Significant factors causing delay in the UAE construction industry. *Construction Management and Economics*, *24*(11), pp.1167-1176.

FARO Technologies (2019), *Faro Focus*, accessed 15th Mar 2019, retrieved from: https://www.faro.com/products/construction-bim-cim/faro-focus/

Fereday, J. and Muir-Cochrane, E., 2006. Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International journal of qualitative methods*, *5*(1), pp.80-92.

Fleming, P. (2008) ‘Resistance to change’, in S. R. Clegg and J. R. Bailey (eds), *The Sage International Encyclopedia of Organization Studies*. Thousand Oaks, CA: Sage, pp. 1376-1379.

Funk, J.L., 2009. The co-evolution of technology and methods of standard setting: the case of the mobile phone industry. *Journal of evolutionary economics*, *19*(1), p.73.

Garcia J.C. (2013). Construction Progress Control (CPC) Application for Smartphones. Unpublished Master Thesis, *Department of Civil, Architectural and Environmental Engineering*, Universitat Politècnica de Catalunya, Terrassa, Spain

Gilani, S.A.N., Awrangjeb, M. and Lu, G., 2018. Segmentation of airborne point cloud data for automatic building roof extraction. *GIScience & remote sensing*, *55*(1), pp.63-89.

Golparvar-Fard, M., Peña-Mora, F., Arboleda, C.A. and Lee, S., 2009. Visualization of construction progress monitoring with 4D simulation model overlaid on time-lapsed photographs. *Journal of computing in civil engineering*, *23*(6), pp.391-404.

Golparvar-Fard, M., Peña-Mora, F.A. and Savarese, S., University of Illinois, 2015. *Four-dimensional augmented reality models for interactive visualization and automated construction progress monitoring*. U.S. Patent 9,070,216.

Greenwood, D., Lockley, S., Malsane, S. and Matthews, J., 2010. Automated compliance checking using building information models. In *The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors, Paris 2nd-3rd September*. RICS.

Hamledari, H., McCabe, B., Davari, S. and Shahi, A., 2017. Automated schedule and progress updating of IFC-based 4D BIMs. *Journal of Computing in Civil Engineering*, *31*(4), p.04017012.

Hedlund-de Witt, N., 2013. An overview and guide to qualitative data analysis for integral researchers. *Integral Research Center*.

Hinkka, V. and Tätilä, J., 2013. RFID tracking implementation model for the technical trade and construction supply chains. *Automation in Construction*, *35*, pp.405-414.

Howard, R. and Björk, B.C., 2008. Building information modelling–Experts' views on standardisation and industry deployment. *Advanced engineering informatics*, *22*(2), pp.271-280.

Information Experience (2019), *Holoportation*, accessed 7 th July 2019, retrieved from: http://informationexperience.se/

Jeong, H.D., 2018. Guide to Life-Cycle Data and Information Sharing Workflows for Transportation Assets.

Josephson, P.E. and Larsson, B., 2001, April. The role of early detection of human errors in building projects. In *Proc., CIB World Building Congress-Performance in the Product and Practice*. Wellington Convention Centre.

Kataoka, M., 2008. Automated generation of construction plans from primitive geometries. *Journal of Construction Engineering and Management*, *134*(8), pp.592-600.

Kim, C., Son, H. and Kim, C., 2013. Automated construction progress measurement using a 4D building information model and 3D data. *Automation in Construction*, *31*, pp.75-82.

Kim, H., Anderson, K., Lee, S. and Hildreth, J., 2013. Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology. *Automation in Construction*, *35*, pp.285-295.

Laserdesign (2019). *Scanning Services Buildings & Other Projects around the Globe*, accessed 22nd May 2019, retrieved from: https://www.laserdesign.com/3d-scanning-building-facilities

Leite, F., Akinci, B. and Garrett, Jr, J., 2009. Identification of data items needed for automatic clash detection in MEP design coordination. In *Construction Research Congress 2009: Building a Sustainable Future* (pp. 416-425).

Liu, H., Al-Hussein, M. and Lu, M., 2015. BIM-based integrated approach for detailed construction scheduling under resource constraints. *Automation in Construction*, *53*, pp.29-43.

Liu, H., Altaf, M.S., Lei, Z., Lu, M. and Al-Hussein, M., 2015, June. Automated production planning in panelized construction enabled by integrating discrete-event simulation and BIM. In *5th International/11th Construction Specialty Conference* (pp. 8-10).

Love, P. and Smith, J., 2018. Unpacking the ambiguity of rework in construction: making sense of the literature. *Civil Engineering and Environmental Systems*, *35*(1-4), pp.180-203.

Love, P.E., Matthews, J., Lockley, S., Kassem, M., Kelly, G., Dawood, N. and Serginson, M., 2015. BIM in facilities management applications: a case study of a large university complex. *Built Environment Project and Asset Management*.

Lu, M., Lam, H.C. and Dai, F., 2008. Resource-constrained critical path analysis based on discrete event simulation and particle swarm optimization. *Automation in construction*, *17*(6), pp.670-681.

Lu, M., Zhang, Y., Zhang, J., Hu, Z. and Li, J., 2009. Integration of four-dimensional computer-aided design modeling and three-dimensional animation of operations simulation for visualizing construction of the main stadium for the Beijing 2008 Olympic games. *Canadian journal of civil engineering*, *36*(3), pp.473-479.

Malsane, S.M. and Sheth, A.Z., 2015. Simulate construction schedules using BIM 4D application to track progress.

Matthews, J., Love, P.E., Heinemann, S., Chandler, R., Rumsey, C. and Olatunj, O., 2015. Real time progress management: Re-engineering processes for cloud-based BIM in construction. *Automation in Construction*, *58*, pp.38-47.

Mell, P & Grance, T. The NIST Definition of Cloud Computing, *National Institute of Standards and Technology*, Special Publication 800-15, Gaithersburg, MD, 2011(Available at: http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf, accessed 1st May 2015).

Moon, D., Chung, S., Kwon, S., Seo, J. and Shin, J., 2019. Comparison and utilization of point cloud generated from photogrammetry and laser scanning: 3D world model for smart heavy equipment planning. *Automation in Construction*, *98*, pp.322-331.

Moon, H., Kim, H., Kamat, V.R. and Kang, L., 2013. BIM-based construction scheduling method using optimization theory for reducing activity overlaps. *Journal of Computing in Civil Engineering*, *29*(3), p.04014048.

National BIM Standard, United States, *National Building Information Model Standard Project Committee*, http://www.national-bimstandard.org/faq.php#faq1 Nov. 20 (2013).

Navon, R. and Goldschmidt, E., 2003. Monitoring labor inputs: automated-data-collection model and enabling technologies. *Automation in Construction*, *12*(2), pp.185-199.

NavVis (2019), *NavVis M6 Indoor Mobile Mapping System*, accessed 9th Mar 2019, retrieved from: https://www.navvis.com/m6

NBS (2019), *National BIM Report*. Newcastle, England. NBS.

Nikoohemat, S., Peter, M., Elberink, S.O. and Vosselman, G., 2017. Exploiting Indoor Mobile Laser Scanner Trajectories for Semantic Interpretation of Point Clouds. *ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences*, *4*.

Oberlender, G.D. and Oberlender, G.D., 1993. *Project management for engineering and construction* (Vol. 2). New York: McGraw-Hill.

Odeh, A.M. and Battaineh, H.T., 2002. Causes of construction delay: traditional contracts. *International journal of project management*, *20*(1), pp.67-73.

Pătrăucean, V., Armeni, I., Nahangi, M., Yeung, J., Brilakis, I. and Haas, C., 2015. State of research in automatic as-built modelling. *Advanced Engineering Informatics*, *29*(2), pp.162-171.

Rakha, T. and Gorodetsky, A., 2018. Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones. *Automation in Construction*, *93*, pp.252-264.

Redmond, A., Hore, A., Alshawi, M. and West, R., 2012. Exploring how information exchanges can be enhanced through Cloud BIM. *Automation in construction*, *24*, pp.175-183.

Rudorfer, C. (2013) ‘The benefit of Terrestrial Laser Scanner for archaeology’, 18th *International Conference on Cultural Heritage and New Technologies*, Vienna, Austria November 2013.

Rus, M.I., 2016. Financing Research and Development Activities in the Construction Materials Industry. Comparative Study. *Ovidius University Annals, Economic Sciences Series*, *16*(2), pp.600-604.

Schaufelberger, J.E. and Holm, L., 2002. Management of construction projects. *Precedence Hall*.

Schwab, K., 2017. *The fourth industrial revolution*. Currency.

Shi, Y., Meng, X., Zhao, J., Hu, X., Liu, B. and Wang, H., 2010, October. Benchmarking cloud-based data management systems. In *Proceedings of the second international workshop on Cloud data management* (pp. 47-54). ACM.

Singh, V., Gu, N. and Wang, X., 2011. A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in construction*, *20*(2), pp.134-144.

Sorbelli, F.B., Das, S.K., Pinotti, C.M. and Silvestri, S., 2018, May. On the accuracy of localizing terrestrial objects using drones. In *2018 IEEE International Conference on Communications (ICC)* (pp. 1-7). IEEE.

Stewart, R.A., Mohamed, S. and Marosszeky, M., 2004. An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry. *Construction Innovation*, *4*(3), pp.155-171.

Tallgren, M.V., 2018. Developing a collaborative planning tool for construction.

Tan, X., Hammad, A. and Fazio, P., 2010. Automated code compliance checking for building envelope design. *Journal of Computing in Civil Engineering*, *24*(2), pp.203-211.

Tang, P., Huber, D., Akinci, B., Lipman, R. and Lytle, A., 2010. Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques. *Automation in construction*, *19*(7), pp.829-843.

Tserng, H.P., Ho, S.P. and Jan, S.H., 2014. Developing BIM-assisted as-built schedule management system for general contractors. *Journal of Civil Engineering and Management*, *20*(1), pp.47-58.

Tulke. J, Hanff. J, 4D construction sequence planning — new process and datamodel, http://www.inpro-project.eu/media/4d_jantulke.pdf 2007 (Mar., 2014).

Volk, R., Stengel, J. and Schultmann, F., 2014. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in construction*, *38*, pp.109-127.

Vosselman, G., Coenen, M. and Rottensteiner, F., 2017. Contextual segment-based classification of airborne laser scanner data. *ISPRS journal of photogrammetry and remote sensing*, *128*, pp.354-371.

Wang, Q., Sohn, H. and Cheng, J.C., 2018. Automatic as-built BIM creation of precast concrete bridge deck panels using laser scan data. *Journal of Computing in Civil Engineering*, *32*(3), p.04018011.

Wang, W.C., Weng, S.W., Wang, S.H. and Chen, C.Y., 2014. Integrating building information models with construction process simulations for project scheduling support. *Automation in construction*, *37*, pp.68-80.

Wang, X., Love, P.E., Kim, M.J., Park, C.S., Sing, C.P. and Hou, L., 2013. A conceptual framework for integrating building information modeling with augmented reality. *Automation in Construction*, *34*, pp.37-44.

Weygant, R.S., 2011. *BIM content development: standards, strategies, and best practices*. John Wiley & Sons.

Wong, J., Wang, X., Li, H. and Chan, G., 2014. A review of cloud-based BIM technology in the construction sector. *Journal of information technology in construction*, *19*, pp.281-291.

Yang, H., Omidalizarandi, M., Xu, X. and Neumann, I., 2017. Terrestrial laser scanning technology for deformation monitoring and surface modeling of arch structures. *Composite Structures*, *169*, pp.173-179.

Appendix

Two elements are demonstrated in the following two section 9.1, 9.2. The first being clarifying the different usages of a variety of software/instruments that were frequently highlighted in the thesis main part, specifically the creation of conceptual framework. The second being a demonstration of the schedule followed in interviews, in a guiding rather than prescriptive manner. This part includes interviews objectives, questions, and closure.

Software & instruments description

The following table, Table 1, illustrates the main purpose of different software/instruments highlighted in different sections of this thesis. Illustrations are meant to visualize the objective of software/instrument in relation to its relevant role in the drawn conceptual framework.

Table 1: Software & tools' brief description

Software/Tool name	Purpose
Autodesk Revit	This software allows a user to design a construction and its components in 3D, annotate models with 2D drafting feature, and access construction's information from the building model's database
Solibri	This software allows for quality assurance throughout combining different BIM models and perform different types of checking among BIM models
Navisworks	This software is used primarily in construction industries to complement 3D design packages, it allows users to open and combine different 3D models, navigate among them with real-time privilege
Dalux BIM viewer	This software makes it possible to combine views and see 2D drawings and 3D models together. Create links between your objects in the model and the 2D documents.
Trimble RealWorks	Point cloud processing software. It is used in processing 3D laser scans in order to issue sharable BIM models.
Autodesk ReCap	This software deals with imported photographs and laser scans. It is used concerting these data into a 3D models or 2D drawings for further processing and design.
ClearEdge3D EdgeWise	This software allows, to certain extent, for automated creation of "as built" models from different datasets through automated data extraction with relative high accuracy
3DReshaper	This software is dedicated to process different types of point clouds for a variety of applications. It is used for 3D modeling applications and inspection related reasons
ALICE Technologies	This software is used for automated scheduling based on accurate construction descriptions. It allows users to update construction activity schedules in linkage to needed equipment

Asta Powerproject	This software allows for scheduling construction activities based on a BIM model. It can boost 5D BIM
Synchro software	This software promotes planning, managing and tracking 4D BIM. It is used by practitioners mainly for scheduling construction activities
Faro Focus X-series	Laser Scanner Series: instrument used for 3D Documentation and Surveying.
Leica scan station P-series	Laser Scanner Series: instrument used for 3D Documentation and Surveying.
NavVis M-series	Trolley used to capture 360° immersive imagery and point clouds with high data quality

Interview schedule

The questions are structured in a sense of relevance and priority. As a start, there is a brief description of the formed framework in order to let the interviewee have a glimpse of the interview' scope. Then the questions discussed first should be the ones of the interviewee's most interest in order to take the most out of his experience. The questions act as a guideline and thereby are not prescriptive. The expected length of interview is between 50 to 75 minutes.

Interview objective

Getting different perspectives on the current approaches used in construction, understanding current faced challenges (for their current approach) and predict future challenges (for the new approach), getting suggestion from practitioners that can facilitate the integration of the new approach in real construction nowadays, etc.

Simple framework description

The framework is intended to be a net of connected data that works simultaneously together on regular periodic basis, e.g. daily basis. It is simply about extracting data from site automatically and export it directly to a BIM based database to compare the taken data from site "as-built" and the readily existing construction data from the planning phase. This comparison might have a lot of privileges such as … checking construction elements' compliance in terms of parameters and position, tracking construction progress in accordance to the planned schedule and give warnings in case of any delay, automatic rescheduling in case of any overlaps, and identify some hazards that might arise in the workplace that threatens labour's safety in the construction stage.

1. How is construction activity scheduling being done in your company (manual/computer based)?
2. How do you see the current methods of achieving inspection of elements on construction site (i.e. current data collection techniques whether it's by an inspector or something else)? Efficient, not efficient, any shortages within it?
3. How can/are delays in construction schedule activities be/being tackled with & without the assistance of BIM based database? (comparative question)
4. What is the current approach of achieving construction elements compliance on site with planned documents in the construction industry?
5. How do you see, or criticize, the current approach of achieving construction elements compliance on site with planned documents in the construction industry?
6. How is construction elements miss-compliance between the "as planned" model and the "as built" model being tackled?
7. To what extent is laser scanning based data collection used in the construction industry and how is it used?
8. What is the latest to date technology used in the construction industry in cooperation with BIM in the sense of construction scheduling and compliance/inspection checking?
9. How does the type of contract control the usage of BIM based tools on field and among different parties? (DBB/DB contracts)
10. To what extent is personnel (in construction context) open to integrate technologies such as tablets in their field? If not much, why do you think?
11. What gap, from your own perspective, does the construction industry have nowadays that makes it rigid for fully incorporating technology (i.e. BIM tools) in its daily basis activities?

12. From your perspective, what should the construction industry focus on, on the short run, to minimize such a gap?
13. From your perspective, what do you think of the presented framework in terms practicality and helpfulness?
14. From your perspective, how applicable is the presented framework? What hinders this model from being applied in real life?

Interview closure

I appreciate the opportunity of discussing this topic with you and the time you set aside for having this interview. Please do not hesitate to comment if there is anything else, from your own perspective, you think I need to encounter through studying this topic to fulfil its success. Would it be alright to send you an email if it happened that I have some extra inquires or questions to ask? Thanks for your time again and I'm looking forward to make the best out of what I got from this interview