Total BIM on the construction site: A dynamic single source of information

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TOTAL BIM ON THE CONSTRUCTION SITE: A DYNAMIC SINGLE SOURCE OF INFORMATION

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SUMMARY: *Digital technologies are rapidly transforming the construction industry, offering new opportunities to improve site work performance. Traditionally, site workers take information from static construction documents such as 2D paper drawings. However, in the Nordic region, a dynamic approach known as Total BIM has gained interest. Total BIM is a model-based approach to construction where BIM replaces 2D drawings as the contractual and legally binding construction document, and site workers use production-oriented, cloud-based BIM, on mobile devices to extract construction information. By having a dynamic single source of information, site workers face new demands as they independently extract construction information directly from BIM. This paper investigates the impact of Total BIM on site work methods through four real-life case studies, site visits, workshops, seminars and semi-structured interviews. The findings indicated that Total BIM provided site workers with a more dynamic construction process where the mobile BIM-viewer software became a central communication and management platform. Key digital Total BIM features were investigated that site workers used to perform new work methods, including measuring, filtering, visualizing, communicating, checklists, and requests for information. By using Total BIM instead of static 2D drawings, site workers interacted dynamically with BIM on mobile devices, changing the process of how work was implemented on the construction site. The practical implications of these findings can be used to support the on-site implementation and strategy work of Total BIM. Furthermore, this paper contributes practical concrete examples of on-site Total BIM use and addresses issues commonly found in state-of-the-art BIM projects.*

KEYWORDS*: Total BIM, Model-based construction, Drawingless construction, BIM on-site, Building Information Modeling, Digital construction.*

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1. INTRODUCTION

How could BIM (Building Information Modeling) be used throughout a construction project as the dynamic single source of information on the construction site, i.e., Total BIM? Although research has shown benefits of using BIM in construction projects (Azhar, 2011, Sacks et al, 2018), we lack examples of empirical cases that successfully use BIM as a dynamic single source of information in the construction phase (Brooks et al, 2022). Furthermore, research concerning BIM implementation in the construction phase is scant (Davies and Harty, 2013, Tu et al, 2021).

To date, BIM is mostly used in the design phase for coordination and clash detection (Eadie et al, 2013, Tu et al, 2021). As focus shifts towards the construction phase, 2D drawings and documentation are produced, and consistent updating of BIM ceases (Gaunt, 2017). When BIM is not updated consistently, it no longer accurately reflects what is to be built; therefore, trust in BIM is lost, and it cannot be used effectively on-site (Perera et al, 2023, Påsse et al, 2022). This occurs due to a lack of demand for BIM, which means that designers focus on delivering 2D drawings since, in most countries, they are legally obliged to do so (Ghaffarianhoseini, 2017, Tu et al, 2021). The parallel processes of creating both 2D drawings and BIM are costly and lead to errors (Disney et al, 2022a).

2D drawings have traditionally been the dominant means of communicating construction information (Davies and Harty, 2013). Drawings have long been criticized for being inefficient, inconsistent, wasteful, error prone and limited in what they can represent (Brooks et al, 2022, Davies and Harty, 2013, Jahn et al, 2018, Sacks et al, 2018). These issues with 2D drawings lead to unanticipated costs, delays and lawsuits (Sacks et al, 2018). However, model-based construction eliminates abortive drawing production, and the model becomes the single source of information (Gaunt, 2017). Therefore, it has the potential to overcome the problems associated with 2D drawings. Total BIM is understood as a model-based approach to construction where BIM is "embraced in its totality" (Cousins, 2017, Disney et al, 2022a). In a Total BIM project, BIM is used throughout all project phases as the single source of information; it is the legally and contractually binding document; and information is accessed from the cloud (Disney et al, 2022a). In the construction phase, site workers use BIM on mobile devices to create and extract the construction information (e.g., measuring, object information, views and sections) they need to carry out their work. Total BIM sets new demands on project stakeholders and has only recently become possible due to advancements in hardware, software and connectivity.

The paper is structured as follows: A background study on model-based construction literature is conducted and on-site limitations in previous state-of-the-art BIM projects are reviewed. This is followed by an investigation into four case studies where Total BIM was implemented as the dynamic single source of information on-site. The key Total BIM features that were implemented for site workers and management to achieve on-site construction without requiring 2D static drawings are highlighted. This study can provide insight and strategies for researchers and practitioners regarding how Total BIM can be successfully implemented in the construction phase as a dynamic single source of information.

2. BACKGROUND

2.1 Advantages and disadvantages with model-based construction

BIM is not simply a replacement for 2D drawings (Lu et al, 2018), it can be a live, dynamic platform that can contain much more information (Eastman, 1999). Model-based construction is an extension of typical BIM use where construction occurs from the model rather than drawings. There has been a lack of research about BIM in the construction phase (Davies and Harty, 2013, Tu et al, 2021), but it is starting to gain interest. In a recent study investigating the future of model-based construction in the UK, Brooks et al. (2022) highlighted several advantages and disadvantages with model-based construction. The advantages included time savings from not producing 2D drawings, coordination improvements due to a single source of information, increased quality and accuracy of the construction, and the potential for increased efficiency (Brooks et al, 2022). The disadvantages included, increased time and cost of producing a detailed model, the training required to be able to work straight from the model, cost of hardware and software, unrealistic expectations may lead users to workarounds, lack of current skills, small and medium sized companies may struggle to compete, and drawings are still legally required for contracting (Brooks et al, 2022). In a study with designers and builders Perera et al. (2023) also found that costs were the main barrier to implementing digitalization in the construction industry. However, in a recent model-based project, Celsius, a new office and laboratory building, whilst design costs increased by 18 percent, the project was delivered under budget due to cost savings in the construction phase (Disney et al, 2022a). Gaunt (2017) also found that any “savings realized during design are insignificant in comparison to the potential for savings during construction.” Therefore, it might be costly to implement the hardware and software for a model-based approach but as highlighted, there is the potential for significant cost savings in projects.

The study by Brooks et al. (2022) investigated the future of model-based construction, assuming that 2D drawings are legally required for contracting and procurement. While this may be the case in some countries, in the Nordic region and during the construction of the Röfors bridge in 2013, it has been demonstrated that it is possible to have BIM as the legally binding document (Disney et al, 2022a, Trafikverket, 2013). A small Swedish construction management company has even implemented Total BIM, indicating that it may be easier for small companies to adopt this approach (Disney et al, 2022a). Brooks et al. (2022) further state that they did not identify any building projects using drawingless construction, the only ones that were identified were in the civil engineering sector. This research addresses these concerns by first exploring limitations in previous state-of-the-art BIM projects and later case study findings from four Total BIM building construction projects.

2.2 On-site limitations in previous state-of-the-art BIM projects

The idea of using BIM on the construction site is not new (Bråthen and Moum, 2016). Various attempts have been made throughout the last twenty years to bring digital design information to the construction site (Bråthen and Moum, 2016, Davies and Harty, 2013, Johansson and Roupé, 2019, Johansson and Roupé, 2022). These attempts involved tools such as virtual reality, BIM kiosks, laptops, tablets and smartphones. However, as highlighted in the examples below, implementation on-site has been rather limited. These limitations are sorted and discussed chronologically, in relation to the incremental development and maturity of the technology over the last decade.

The 2013 Röfors bridge project in Sweden was a unique project where work on-site was expected to occur directly from BIM by viewing and extracting information from BIM on tablets. It was the first project in Sweden to use BIM rather than traditional 2D drawings as the legally binding construction document (Trafikverket, 2013). Due to limitations at the time with BIM-viewer software, site workers were unable to extract measurements and specific construction information on mobile devices. A structural engineer was needed on-site to create Production-Oriented-Views (POVs) (Johansson and Roupé, 2019, Trafikverket, 2013). These POVs were screen captures from BIM with measurements, dimensions and object information attached. The initial vision for the site workers to interact directly with BIM was therefore not achieved as the screen captures were not interactive. Even though Röfors bridge was a pilot project, several benefits were still realized, showing the potential of model-based construction. The benefits of the model-based approach included, improved early visualization, facilitated communication, increased engagement of suppliers and site workers, improved access to a single source of information, simplified quantity take-offs, reduced errors and easier to work with than traditional methods (Trafikverket, 2013). However, they also experienced several challenges including, technical difficulties using a cloud-based approach, lack of guidelines for archiving, lack of interoperability between software programs, lack of rules, regulations and guidelines describing how to work with model-based methods (Trafikverket, 2013). The Röfors bridge project can be seen as an early attempt at implementing the model-based approach, where they recognized many benefits, but they also encountered many challenges due to being one of the first projects of this kind.

In the 2016 Norwegian Urbygningen project, the refurbishment of a building at the Norwegian University of Life Sciences, BIM kiosks were used on-site as it was found that 2D drawings did not provide sufficiently detailed information (Bråthen and Moum, 2016). Static BIM kiosks were placed on each floor of the building with wired internet connections and large TV screens to display the BIM in the software, Solibri. Implementing BIM kiosks on-site helped workers with visualization, planning, coordination and provided them with a better, more up-to-date flow of information from design to the construction site (Bråthen and Moum, 2016). The BIM kiosks were placed in static locations due to their size, making them unable to be used directly where work occurred. The kiosks were used as meeting points to discuss, plan and coordinate activities. This was because the model was useful for providing a quick overview of things that are usually difficult to perceive in 2D drawings (Bråthen and Moum, 2016). The kiosks served as a one-way flow of information to communicate the designers’ intent with site workers. They were not interactive, so workers could not provide direct feedback or leave comments (Bråthen and Moum, 2016). Additionally, they were not able to be used to extract construction information at the location work was performed (Bråthen and Moum, 2016). In their study, Bråthen and Moum (2016) recognize the potential of mobile devices to offer construction workers new and interesting ways of working. In the Urbygningen project limitations existed due to the static nature of BIM kiosks and mixed work methods of using 2D drawings and BIM.

The 2017 Oslo Airport Terminal 2 project involved constructing a new terminal building. It was estimated that 50 000 paper drawings and documents would be needed to facilitate reinforcement work. Due to the project's complexity, it was decided to use BIM instead (Mershbock and Nordahl-Rolfsen, 2016). By having all the necessary information accessible in one place (using the Tekla BIMsight software on iPads), it was more convenient and efficient than searching through multiple sets of paper drawings (Mershbock and Nordahl-Rolfsen, 2016). The project was an early attempt at model-based construction, but on-site BIM use was limited to reinforcement work only. Mershbock and Nordahl-Rolfsen (2016) note that practical on-site BIM use in the construction industry is still rare due to challenges with standard contracts as well as limited IT resources and capabilities. Based on these limitations, Mershbock and Nordahl-Rolfsen (2016) suggest that project teams should focus on modelling complex details and assemblies rather than models for entire buildings.

The ongoing Slussen project in Stockholm involves rebuilding a large lock to create a new pedestrian-friendly urban quarter. The project aimed to be delivered 100 percent digitally eliminating the need for over 15 000 paper drawings (Cousins, 2017). However, some early work in the project still used 2D printed drawings. The BIM strategist for the city of Stockholm recognized that in large projects, a significant effort is required to make drawings look good, most of which are never used (Cousins, 2017). Instead, the project aimed to work digitally, enabling designers to focus on solving technical design issues rather than creating drawings. The plan was to use BIM kiosks and virtual reality on-site, supported by printed views from BIM. BIM served as the legally binding construction document instead of traditional 2D drawings. However, construction teams had to resort to surveyors using "total stations" to place structural elements on-site because the software did not function effectively enough for users to take measurements.

Two separate Norwegian hydropower plant projects, SMISTO and Vamma 12, were completed in 2019 with the aim to be delivered without drawings. However, despite it being possible for site workers to create their own POVs, designers in the project created predefined ones with attached dimensioning to facilitate construction (Budarina, 2017). According to Budarina (2017), reasons for this include the lack of BIM competencies on-site and the absence of software tailored for on-site use. Furthermore, it was found that the Solibri software used in the project for viewing the model may be aimed towards skilled users (Budarina, 2017). In another Norwegian hydropower plant project, Nedre Otta, which was completed in 2020, BIM kiosks were implemented. This project used Autodesk Navisworks. Similarly, to the other hydropower plant projects SMISTO and Vamma 12, it was found that the software was not effective for taking exact measurements on-site (Aune, 2018). There were also ambiguities with information on objects, such as quantities and total length (Aune, 2018).

A recent winner of the Tekla Global BIM awards in 2020 for best BIM project, the Norwegian Randselva Bridge is the longest bridge built without drawings to date (Rybus, 2022, Ulvestad and Vieira, 2021, Vieira et al, 2022). Instead of delivering traditional drawings, the project utilized BIM to transfer data through IFC files, which could be viewed on-site through Solibri (Rybus, 2022). Many benefits were reported, including that it may even be the preferred way of working (Ulvestad and Vieira, 2021, Vieira et al, 2022). However, similar issues to the projects described above were also encountered. In the absence of effective BIM-viewer software, filtering and extracting the required data was challenging, and the software was not optimized to present BIM views with annotations (Rybus 2022, Ulvestad and Vieira, 2021). Consequently, on-site workers would take 3D screenshots at BIM stations and then manually add information and descriptions (see Fig. 1) (Rybus, 2022, Ulvestad and Vieira, 2021). In combination with poor weather conditions, it often meant that these screenshots would need to be printed on paper and laminated rather than used on iPads as preferred (Ulvestad and Vieira, 2021). Moreover, the software used in the project began to lag when highly detailed versions of the model were viewed (Vieira et al, 2022). While site workers found the transition to model-based construction relatively smooth, it was also recognized that BIM competencies generally needed to improve in the future (Rybus, 2022).

Construction of the new Stavanger University Hospital in Norway began in 2018 and is set to continue until 2024. The client's objective was to enhance the level of digitalization and foster innovation (BIM Corner, 2022). Therefore, the decision was made to construct the project without paper drawings, and instead, employ model-based construction processes (BIM Corner, 2022). Although the project is still in progress, the construction managers have identified some challenges associated with the model-based approach. These challenges include the high cost of creating a high-quality BIM, interoperability issues between software programs, geometry issues during the export and import of IFCs, and software issues when viewing large models (BIM Corner, 2022).

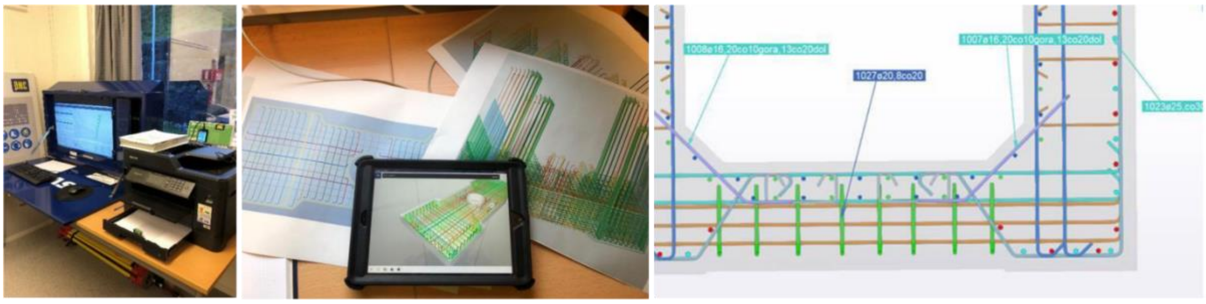

FIG. 1: Randselva bridge BIM use on the construction site (Ulvestad and Vieira, 2021).

The state-of-the-art BIM projects from the Nordic region described above highlight that BIM use on the construction site is not new but is often limited. These limitations include:

- Most state-of-the-art BIM projects are infrastructure projects where BIM is used specifically for reinforcement work. This may occur because software such as Tekla Structures is designed to support a 3D model-based approach for rebar and steel structures.
- It has been difficult to filter and measure objects in software such as Solibri and Navisworks, which do not function effectively for measuring on-site.
- Site workers lack the competencies to use software designed for expert users and there is usually a lack of resources on-site to help overcome these barriers.
- Software and hardware limitations force workers to print views on paper rather than actively use BIM on mobile devices, which is comparable to working with static information sources.
- Software still has interoperability issues and needs to be further optimized for large models.
- Standard contracts need to be modified to support BIM as the legally binding construction document. In some countries it might not be currently possible.

In a Total BIM project, the traditional delivery methods of unconnected static information sources (2D construction drawings, technical documents, bill of quantities) are replaced with a cloud-based, dynamic single source of information. This paper investigates how on-site Total BIM processes and features have been implemented in four Total BIM building projects, effectively addressing the limitations observed in previous state-of-the-art BIM projects.

3. METHOD

This research was part of a broader Ph.D. research project that aims to explore the processes, outcomes and effects of implementing the Total BIM concept. The primary focus of this paper is to explore the implementation of Total BIM and its function as a dynamic single source of information on construction sites. To commence the study, a comprehensive literature review was conducted to identify on-site limitations in previous state-of-the-art BIM and model-based construction projects. As model-based construction projects are relatively rare (Brooks et al, 2022), the inclusion of “grey literature” was deemed necessary to identify these projects. The projects were mostly found in the Nordic region. The outcomes of this literature review formed the foundation for this research and informed the subsequent empirical data gathering process.

To examine the implementation of Total BIM on construction sites, four real-world case studies from the Nordic region were selected. The chosen research approach involved analyzing these case studies as “forces of example” (Flyvbjerg, 2006), drawing on the interest in concrete examples and experiences gained from applying new technologies in practice (Moum et al, 2009). These case studies were selected as they were prominent model-based construction projects in Norway and Sweden, where advanced on-site Total BIM processes were implemented. In these projects, construction workers independently created and extracted the necessary construction information. The first case study, known as the Celsius project, involved the construction of an office and laboratory building completed in Sweden in 2020. The second case study, Glasblokkene Trinn 2, is an ongoing hospital project in Norway. Additionally, two ongoing office building renovation projects in Sweden named Lumi and SB47 were studied. The Swedish projects were all managed by a small construction management (CM) company consisting of 15 employees, which have received recognition as an industry leader, after winning the 2020 buildingSMART award for their digitalized construction process. Furthermore, all the projects in the study used StreamBIM as the BIM-viewer software on the construction site.

The collection of qualitative data was achieved from interviews, site visits, workshops, and seminars (see Fig. 2). A total of eleven semi-structured in-depth interviews were conducted with two project managers (e.g., responsible for VDC / BIM implementation in the projects), one project leader (e.g., design manager and project manager in the projects), and two site managers who were involved in implementing Total BIM in the Celsius, and SB47 projects (see Table 1). One of the site managers worked first as a concrete and rebar subcontractor in the Celsius project and later became an employee in the CM company.

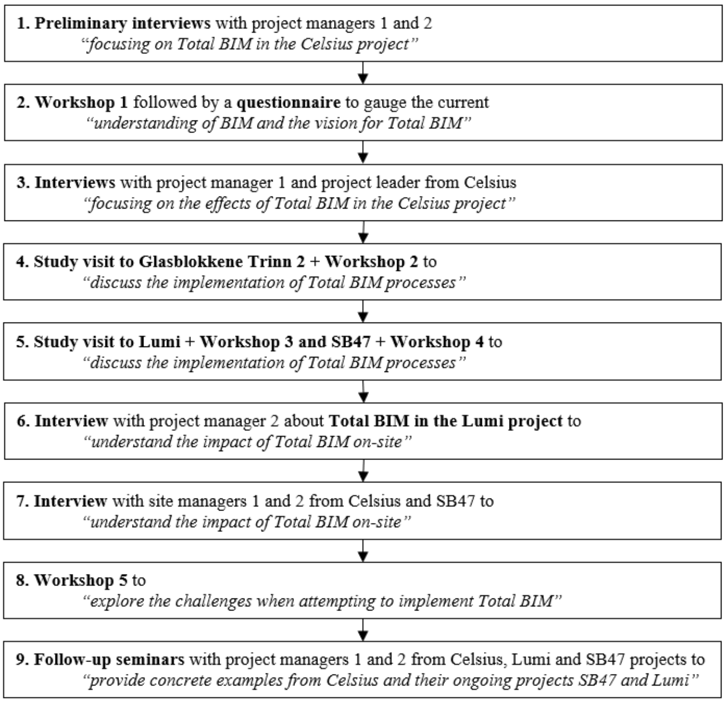

FIG. 2: Empirical data collection process.

TABLE 1: Interviewee main field and job title, experience and the Total BIM projects they have been involved in.

Main field and job title	Industry experience	No. of Total BIM projects involved in
Project manager 1: e.g., VDC / BIM-strategist responsible for implementing Total BIM in the projects, Celsius, Nattugglan, SB47 and Lumi.	12 years	4
Project manager 2: e.g., VDC / BIM-strategist, on-site construction engineer responsible for implementing Total BIM in the projects, Celsius, Nattugglan, SB47 and Lumi.	13 years	4
Site manger 1: used Total BIM in the projects, Celsius, Nattugglan and SB47.	16 years	3
Site manger 2: used Total BIM in the projects, Celsius, Nattugglan and SB47.	22 years	3
Design and project manager involved in the implementation of Total BIM in the projects, Celsius, Nattugglan, SB47 and Lumi.	40 years	4

The interviewees possessed extensive industry experience ranging from 12 to 40 years (see Table 1). They were selected because they were identified as the key drivers and enablers of the implementation of the on-site dynamic Total BIM processes in the case study projects. The interviewees also had experience from an additional Total BIM project that is not part of this study, Nattugglan. A limited number of interviewees were selected as model-based construction processes are not common and few professionals are able to provide meaningful data regarding on-site implementation (Brooks et al, 2022). The interviews were based on open-ended questions, where the interviewees were encouraged to share their own thoughts and insights. The preliminary interviews concentrated on the overall outcomes of implementing Total BIM, which were analyzed and then followed by interviews concentrating on the on-site dynamic processes. Each interview was between one to two hours.

In addition to the interviews, and as part of the broader research project, a study group of industry experts in construction digitalization from Norway and Sweden were invited by the researchers (see Table 2) in the paper to participate in study visits and workshops focusing on exploring and discussing Total BIM. The study group, which started with 20 individuals, grew to 35 during the research project. The participants came from two universities and sixteen different companies. These companies included four construction companies, nine design engineering companies, one real estate company, one government agency, and one software development company. 21 of the participants had job titles and worked as VDC / BIM strategists, specialists and coordinators, with work experience ranging from 4 to 33 years and a mean of 13.9 years of experience in the field (see Table 2). In addition, two of the other participants worked as site managers, two as MEP engineers, one as a MEP project leader, and five were involved in implementing digitalization and innovation in their companies.

TABLE 2: Workshop (WS) and study visit (Site) attendees by main field, job title and type of company, number of participants, industry experience and the number of participants involved in Total BIM projects.

Main field, job title and type of company	**No. participants**	**Industry experience in years**	**No. participants** WS1	**No. participants** *Site2 + WS2*	**No. participants** Site3 +WS3 Site4 + WS4	**No. participants** WS5	**No. of participants involved in Total BIM projects**
VDC / BIM-strategists, specialists and coordinators *(Construction=7, Consultant=8, CM=2, Government=1, Software development=3)*	21	Mean = 13.9 (SD = 7.7)	12	13	13	15	9
Site managers *(Construction=1, CM=1)*	2	16, 22	1	2	1	2	1
Design and project mangers *(Construction=2, CM=1, Real estate=1)*	4	20, 20, 22, 40	2	2	2	3	1
MEP project leader and engineers *(Subcontractor=1, Engineer=2)*	3	17, 20, 28	2	-	1	2	-
Digitalization and innovation *(Construction=2, Consultant=3)*	5	Mean = 17 (SD = 7.1)	2	-	-	3	-

The initial workshop, which was also followed by a brief questionnaire, aimed to gauge the participants' current understanding of BIM and their vision for Total BIM. This workshop and questionnaire were used to frame future workshops and discussions. The subsequent workshops (2, 3 and 4) took place during study visits to the case study projects and focused on the implementation of Total BIM processes. Workshop 5 was centered on exploring the challenges faced or anticipated by construction companies when attempting to implement Total BIM. These workshops facilitated the gathering of data through observations and discussions related to the processes of implementing on-site BIM. All interviews, site visits and workshops were recorded for later analysis. The researchers also had access to the ongoing Swedish project's on-site BIM-viewer software, which provided additional data throughout the research process regarding dynamic Total BIM processes. For approximately six months, the researchers observed the daily processes, communication, and work methods using the BIM-viewer software.

The findings from the interviews, study visits and BIM-viewer software were triangulated (Bryman, 2016) and collectively discussed during the workshops. These workshops offered valuable insights into the implementation of Total BIM and the ongoing challenges, helping to highlight the key on-site dynamic processes in a Total BIM project. These findings were further analyzed in the context of the limitations found in previous state-of-the-art BIM projects, to identify the essential Total BIM processes for a dynamic single source of information on the construction site.

Towards the latter part of the study, after analyzing the cases, two follow-up seminars were conducted with project managers 1 and 2 that were responsible for the VDC / BIM implementation in the Swedish projects. During these seminars, the identified essential on-site Total BIM dynamic processes were presented to stimulate deeper understanding and discussions about the on-site implementation of Total BIM in their ongoing projects (Lumi and SB47). During these seminars, the project managers actively contributed to this research by providing concrete examples of Total BIM and how it was utilized and implemented as a dynamic information source.

4. FINDINGS AND DISCUSSION

Implementing Total BIM sets new demands on management, users, hardware, and software. Construction processes are dynamic, relying on dynamic information sources rather than static ones commonly found in traditional project deliveries. To deliver a dynamic single source of information, design and construction processes must be adapted from those found in traditional projects. The key features of the Total BIM process and delivery are shown in Fig. 3. The design focus and delivery require high-quality production-oriented BIM, which becomes the legally binding construction document. The cloud-based BIM is developed in terms of constructability, geometry, documentation, and information to provide a dynamic single source of construction information (see Fig. 3).

This study's findings primarily focus on the essential on-site dynamic processes required and implemented in the Total BIM case study projects. These processes include, dynamic views, sectioning, and measuring; filtering and quantity take-off; and communication through controls, checklists, scheduling, and issue management (see Fig. 3). Together, these processes enabled site workers to independently create and extract the construction information they needed on-site. The impacts of these on-site dynamic processes are discussed, addressing the issues commonly found in previous state-of-the-art BIM projects mentioned earlier in this paper (Aune, 2018, BIM Corner, 2022, Brooks et al, 2022, Bråthen and Moum, 2016, Budarina, 2017, Cousins, 2017, Disney et al, 2022a, Mershbock and Nordahl-Rolfsen, 2016, Rybus, 2022, Trafikverket, 2013, Ulvestad and Vieira, 2021).

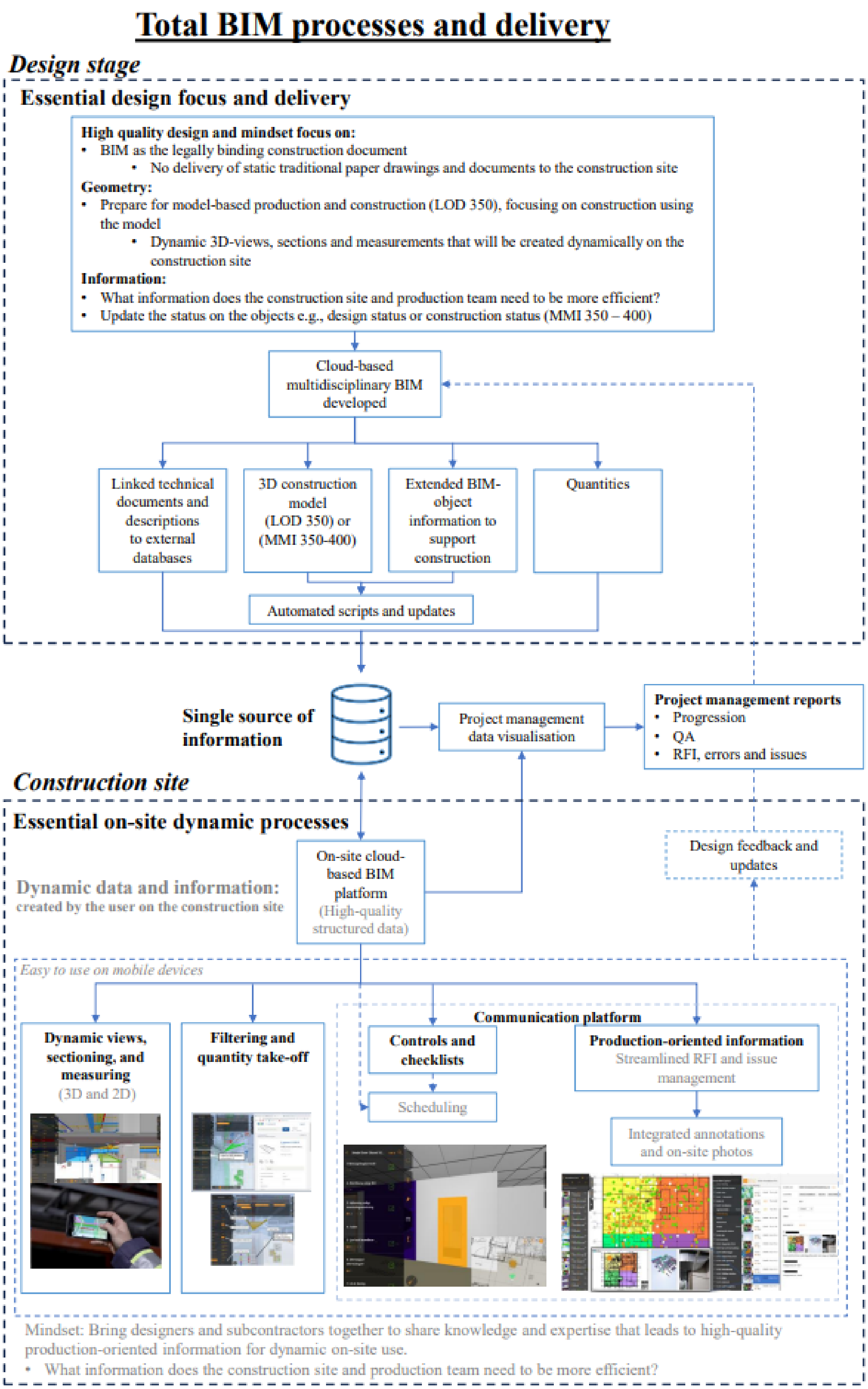

FIG. 3: The essential Total BIM processes for a dynamic single source of information on the construction site.

4.1 Dynamic views, sections and measurements

In modern BIM-viewer software (i.e., StreamBIM), POVs and measurements no longer need to be pre-defined. In all four of the case study projects, users on-site interacted with BIM on mobile devices to navigate in either 2D or 3D to their current work area. Once they were positioned in the correct location, they made fine adjustments using a touchscreen interface to obtain the section or view that was most suitable. Simple and intuitive measuring tools made it possible to add single or multiple measurements in the same view. The measuring tools automatically snap to objects and can be extended, which allowed for quick and accurate measurements between objects or gridlines (see Fig. 4 and Fig. 5). Measuring tools also exist that enable users to measure between multiple objects at the same time. Objects can be highlighted, hidden or filtered so that only relevant information is shown.

FIG. 4: Site workers can use mobile devices to navigate in either 2D or 3D to their current work area and create unlimited sections and measurements (Image from case projects: Lumi and Celsius).

In the project, Celsius, the managers recognized the importance of creating additional measurement reference points that could be used by the construction workers during construction. Construction surveyors used BIM as a source to replicate structure gridlines and valid referenced BIM objects with physical painted reference points and lines on-site (see Fig. 5). In this context, the construction site can be recognized as dynamic as the construction develops towards the final product (i.e., building). While the design team delivers the design of the final building, the current state of the building depends on who has worked and what has been constructed. Construction workers need to adapt to the current situation and find known reference objects or points to measure from and to, as seen in Fig. 5. Therefore, it was important to identify valid referenced BIM objects and use structure gridlines for measuring references during construction.

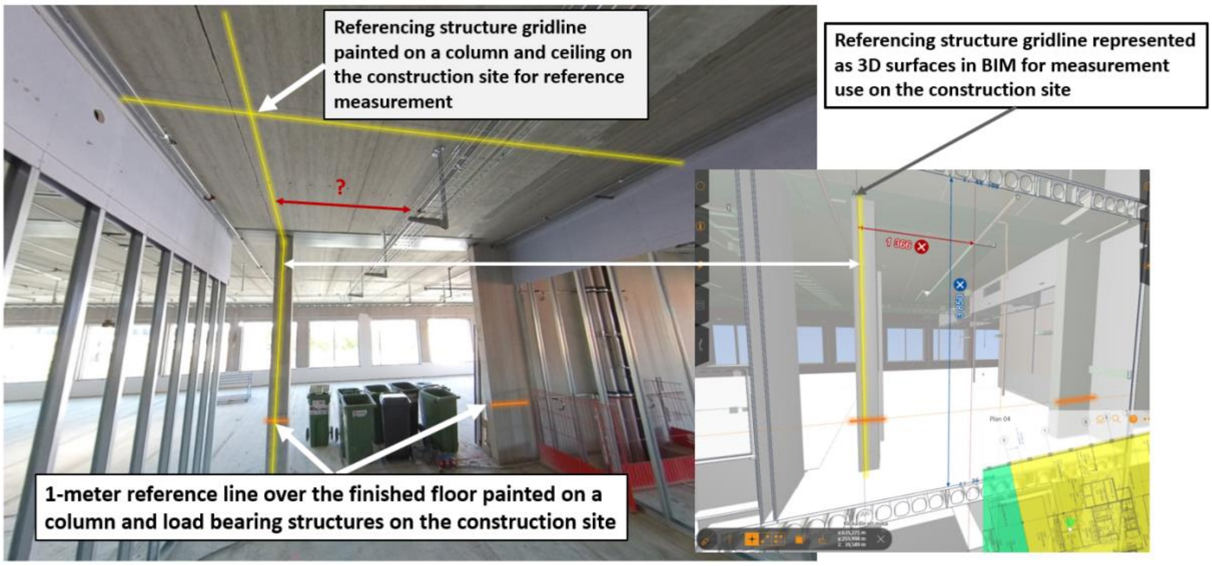

FIG. 5: BIM structure gridlines as measuring references on-site (Image from case project: Celsius).

Furthermore, a key feature of a Total BIM project is that site workers dynamically interact with BIM-viewer software to create their own views and measurements related to the current situation on-site (see Fig. 4 and Fig. 5). They are no longer limited by static digital, or paper-based drawings that have been created by design teams. Instead, site workers dynamically interact and navigate the 3D model on location to gain a better understanding of the space they are working in, without needing to switch to another drawing or document. Additionally, by using integrated BCF (BIM collaboration format) files, designers are still able to provide the pre-defined views and measurements (i.e., POVs) if they are required to do so.

Previous state-of-the-art BIM projects described in the background of this paper, have shown a situation where despite developing high-quality BIMs for production, the use of BIM as a dynamic source of construction information on-site is still limited (Aune, 2018, Budarina, 2017, Cousins, 2017, Mershbock and Nordahl-Rolfsen, 2016, Rybus, 2022, Ulvestad and Vieira, 2021). In these projects, the available hardware and software were not functional or optimized for site workers to dynamically interact with BIM and take on-demand measurements on-site (Aune, 2018, Budarina, 2017, Johansson and Roupé, Rybus, 2022, Ulvestad and Vieira, 2021). Instead, what often occurred was that static images were created from BIM, measurements were manually added, and then they were printed on paper. The information on these printouts was static, which is comparable with traditional ways of working where 2D drawings with measurements are produced by design teams. The parallel processes of creating high-quality BIM and printouts repeat many of the issues commonly found in traditional projects, where the information is no longer dynamic, and it is difficult to maintain and update outdated drawings (Davies and Harty, 2013). Despite the problems associated with maintaining static information sources in traditional projects, BIM is often not trusted due to its inconsistent updating and lack of reliability (Perera et al, 2023, Påsse et al, 2022). However, in a Total BIM project all stakeholders focus on BIM as the dynamic single source of information. Recent advances in hardware and software have led to the development of easy to use software on-site. The intuitive and easy to use features of this software on mobile touchscreen devices, has made it possible to work digitally with Total BIM in all project stages. Site workers can be quickly trained to use the software so that a dynamic work environment can be maintained, and users do not fall back on traditional methods.

The previous issues of measuring directly from BIM (Aune, 2018, Budarina, 2017, Cousins, 2017, Mershbock and Nordahl-Rolfsen, 2016, Rybus, 2022, Ulvestad and Vieira, 2021) are superseded by the improved functionality and optimization of new software packages. The four case studies show that site workers were able to choose the views, sections and points of reference that they found most appropriate. Within these views, users can add measurements, dimensions and extract information to dynamically display what they needed to perform their work, where the benefits of BIM as a live, dynamic platform can be realized (Eastman, 1999). Structure gridlines were replicated from BIM on the construction site to create additional reference points and enable construction to occur more accurately than what has previously been possible (Fig. 5). Additionally, by directly utilizing BIM-viewer software, construction workers can seamlessly switch between 2D and 3D views, depending on the task at hand, resulting in a more efficient and precise construction process. The model-based construction approach enabled benefits relating to higher levels of quality, accuracy and efficiency (Brooks et al, 2022) in the four case study projects.

The new possibilities for site workers to be the creators of information on the construction site also leads to many benefits. Traditionally, designers create the section drawings that they decide are most appropriate. However, in situations where they are paid per drawing rather than producing production-oriented BIM, they may sometimes choose sections that are easy to represent. By empowering site workers to create construction information using Total BIM, the information is more suitable for on-site use. Total BIM is not simply a replacement for 2D drawings (Lu et al, 2018), it is a dynamic environment where site workers can produce the sections they want and need, so BIM becomes a digital virtual copy of what they are building, rather than a static document they are building from. They may also be able to plan their work better by exploring the model in advance. In the Norwegian hospital project (Glasblokkene Trinn 2), a plumbing subcontractor even took the initiative to develop the BIM they received to a higher level of detail (i.e., production and manufacturing model), ensuring that when they arrived on-site, they could just focus on assembly.

Working with a dynamic BIM environment sets new demands on project stakeholders. Designers are tasked with developing BIM to a high level and no longer produce 2D drawings. In the Swedish office and laboratory case, Celsius, design costs increased by 18 percent compared with a similar traditional project (Disney et al, 2022a). However, it should be noted that the project was still delivered under budget (Disney et al, 2022a), which reflects the benefits described by Gaunt (2017), where the potential for cost savings during construction is significant. Site workers adopt a new role and become the creators of information on-site as they extract information from BIM. Management teams must also oversee the new digital processes and monitor communication through the software. One of the benefits of working from BIM is that precise measurements can be extracted. By using custom reference planes and replicating structure gridlines on-site to create known reference points (the Swedish projects), site workers never had to measure to objects further away than the length of a "carpenter's ruler" (the Norwegian project). However, standard regulations still allow tolerances during design that are suited to non-digital, traditional work methods where 2D paper drawings are measured and scaled. Currently, in Sweden, tolerances are allowed up to 25mm. These current tolerance regulations pose significant challenges during the design and construction phases that must be effectively managed. In the future, it is important for regulators to address these challenges in order to achieve greater levels of accuracy and quality in the final built object.

4.2 Filtering and quantity take-off

There are many ways to display and filter information in BIM-viewer software, (i.e., StreamBIM). Object information can be pre-sorted by design and construction teams into a simple tab that displays only relevant information for construction rather than the typical overwhelming amount of information usually associated with a BIM object. In the Swedish case study projects, custom tailored property sets on objects were created for site workers to gain easy access to information. This information was displayed under a tab simply called "PRESS here." The property sets contained the information that the site workers needed to perform their work, which was decided during discussions between BIM managers and site workers. The custom property sets also contained links to WEB-databases and PDF datasheets on objects for use during both construction and facility management (see Fig. 6A).

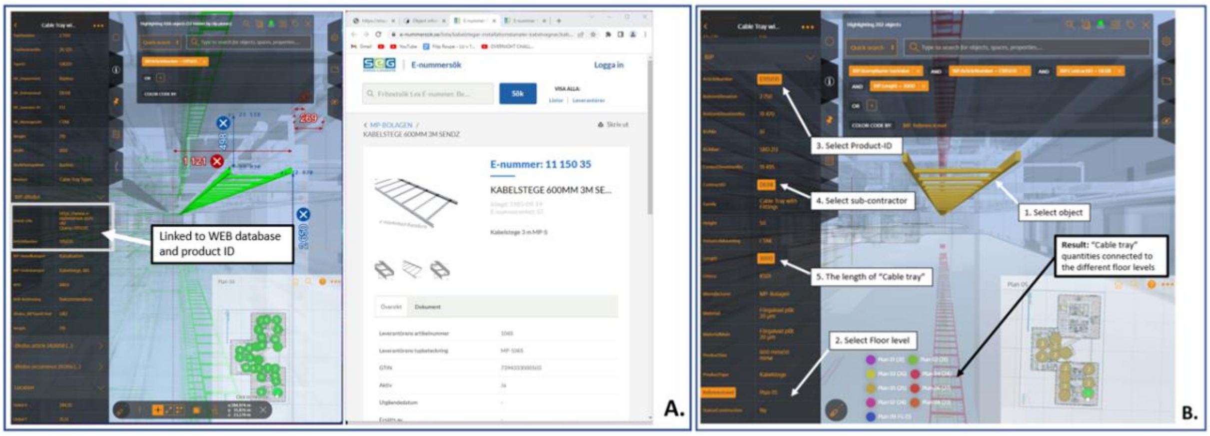

FIG. 6: (FIG. 6A): In the BIM-viewer (i.e., StreamBIM), BIM-objects had custom property sets that contained information such as product ID, WEB-database links and PDF datasheets, supporting a single source of information both during construction and facility management. (FIG. 6B): By clicking on a BIM-object and then different object properties an information filter automatically builds up a query of filters (Image from case project: Lumi).

Within StreamBIM, any user can view all the "layers" of the BIM. Site workers were therefore able to view the entire model and gain a deeper understanding of how their work is meant to occur. If they wish to only see their part of the model, such as sprinkler systems, they can toggle all other "layers" to hidden. It was also possible to highlight a system, whilst making all others partially transparent to maintain an overall view (Fig. 6). Furthermore, it was possible to filter all objects of a certain type from which any object property or multiple properties can be chosen. Multiple properties can be selected by clicking on different object properties which automatically builds up a query to filter the information (see Fig. 6B). For example, in Fig. 6B, information can be filtered to create a quantity take-off for different floor levels using floor level, product ID, subcontractor and length of the product.

Filtering features in modern BIM-viewer software enable new levels of interactivity with BIM. Filtering has existed in software previously but has not been as intuitive or accessible as it is now. In combination with the navigation and measuring tools, users dynamically interact with BIM to gain a more thorough understanding of the space in which they are working. The tools also enable them to gain insight into how BIM objects interact with each other, and the current situation on-site, as different construction disciplines work in series and parallel.

FIG. 7: Filtering BIM objects during a renovation project to understand which should be demolished and which should be kept (Case project: SB47).

In the Norwegian hospital project and the ongoing Swedish renovation projects, checklists were linked to an object's status to monitor an object's progress on-site. This information was used in filters to highlight the overall construction progress, or that of systems and zones on-site. The checklist information was also utilized to determine which parts of the project had been sufficiently developed to commence construction, as well as to identify which objects to keep and which to demolish during renovation projects (see Fig. 7). This approach helped streamline the construction process as design and construction occurred in parallel and provided users with an easy way to filter the information. As BIM becomes more complex and objects have increasing amounts of data it is not surprising that novice users may find the information overwhelming. Therefore, powerful filtering tools are vital (Fig. 6 and Fig. 7). In the Swedish projects, important data was sorted into a single, easy to access tab (see Fig. 6A). In the BIM-viewer software there was also an easy to use, user-interface to filter objects by their properties, displaying only those objects that matched the query criteria (see Fig. 6B). These filtering features are not possible in static drawings, where a lot of time is lost to manually measuring or quantifying objects. Instead, the dynamic BIM environment makes it possible for the user to filter the view and information according to their needs. For example, this might be used for quantity take-offs, logistics planning, or renovation projects to determine which parts should be demolished and which should be kept. When compared to drawings, which have been criticized for being inefficient, inconsistent, wasteful, error prone and limited (Brooks et al, 2022, Davies and Harty, 2013, Jahn et al, 2018, Sacks et al, 2018), filtering processes in a Total BIM environment are more efficient, simpler and consistent. Furthermore, the options to hide, show and highlight layers or objects in modern BIM applications make it easier for subcontractors to understand the space they are working in, which can lead to fewer errors and changes on-site.

The filtering tools in modern BIM-viewer software (StreamBIM) address some of the limitations found in previous state-of-the-art BIM projects. In these previous projects software such as Solibri or Autodesk Navisworks was used on-site. It was found that these software packages were mainly aimed towards skilled users, not suitable for on-site use, not optimized to present pre-defined views and difficult for users to filter information (Aune, 2018, Budarina, 2017, Rybus 2022, Trafikverket, 2013, Ulvestad and Vieira, 2021). Additionally, competencies and skills are lacking for using these digital tools (Brooks et al, 2022, Budarina, 2017, Mershbock and Nordahl-Rolfsen, 2016, Rybus, 2022). If companies adopt model-based construction or Total BIM, then the choice of software is crucial to the project's success. Previous projects have attempted to use advanced software for novice users on-site, where information is difficult to extract. The four case study projects in this study recognized these issues and implemented modern BIM-viewer software that was tailored for on-site use. This meant that after a brief initial training session (Disney et al, 2022a), even novice users could filter information to meet their requirements. However, as with previous state-of-the-art BIM projects, users require some training, which would be unlikely if drawings were used. In the Swedish cases, the costs for training were absorbed by the projects. Since model-based construction is still in its infancy, skills need time to develop across the industry. Once these skills develop, the industry could realize further cost savings. Furthermore, model-based construction applications, such as StreamBIM, are relatively new, and features are being quickly developed. They have also significantly developed since Celsius (2018-2020) and the ongoing projects in this study. A concern might be that, in the future, as more features are added, these too will become expert packages where novice users cannot perform simple tasks. A current strength of these applications is their focus on how end-users dynamically interact with information on-site. To avoid losing the benefits of a simple-to-use package, it is suggested that both simple and advanced software modes are considered so that new users can quickly engage with the concept. This may also help address the current lack of BIM competencies on-site.

4.3 Communication platform

In all four case study projects, controls, issues, discussions and RFIs (requests for information) were all captured and communicated within the modern BIM-viewer application (Fig. 8). These are not new ideas and already exist in construction software applications. However, the difference is in how they are implemented. Modern BIM-viewer applications are designed for use on mobile devices, on the construction site. Site workers interacted with both hardware and software at the location where they are performing their work. The integration between hardware and software facilitates easy capturing of images by using a device's in-built camera. When issues arose on the construction site, new topics were created within the application. These topics shared information such as location (both in 2D and BIM), messages and photos from on-site (see Fig. 8). Workflow categories and user access rights were established early in the projects to ensure that RFIs were quickly resolved. Communication occurred between site workers, design teams, managers and the different disciplines on-site. Site workers were notified directly of responses by receiving mobile push notifications and notifications within the application, which reduced handling times.

Working dynamically with BIM on mobile devices, rather than relying on static information sources, leads to more integrated communication processes. Having a single source of information connected to BIM also contributed to this integration. The different construction disciplines working in series and parallel on-site can communicate digitally with each other and share the current state of the construction site. This allows the next construction discipline on-site to understand the current state and plan and prepare for their work before arriving at the construction location. The dynamic BIM-viewer application tools, such as views, sections, measuring, and filtering, were combined with photos taken by users, detailing the current state on the construction site. Connecting these processes within a single digital platform contributed to making the BIM-viewer a single source of information. This was evident in the construction project of the new office and laboratory building in Sweden i.e., Celsius (see Fig. 8) (Disney et al, 2022a).

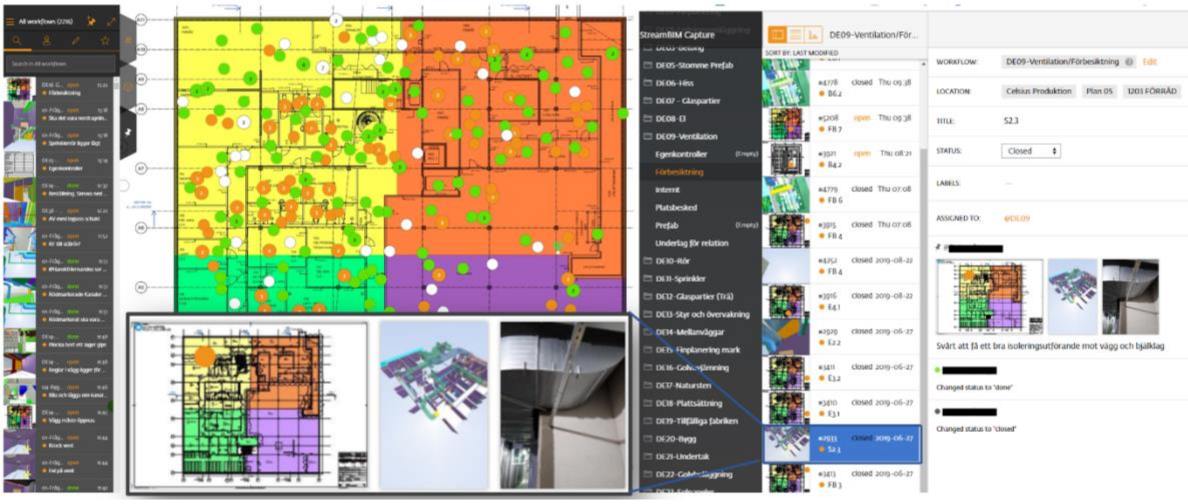

FIG. 8: During the projects StreamBIM was used as a communication platform where requests for information (RFIs) were created and answered. Users received push notifications on their mobile devices when their RFI was updated (Image from case project: Celsius).

In the Celsius project, StreamBIM was primarily chosen to be used for site workers to access construction information, but it unexpectedly became a platform for communication (Fig. 8) (Disney et al, 2022b). The project received high ratings in worker surveys for communication (Disney et al, 2022b). Initially, the management teams thought that they were communicating in the same way as in previous projects. However, they later realized that the BIM-viewer software, which enabled a single source of information, connected commonly unconnected information sources and facilitated open communication, rather than relying on closed e-mail chains or phone calls

(Disney et al, 2022b). Brooks et al. (2022) assert that model-based construction benefits from a single source of information, leading to more streamlined and efficient communication. These benefits are evidenced by the improved communication reported in worker surveys from the Celsius project (Disney et al, 2022b), which implemented the Total BIM concept. The reported findings of improved communication by site workers suggest that the software was easy to use, which addresses concerns expressed in previous state-of-the-art projects that software is often too complex for novice users (Budarina, 2017, Rybus 2022, Trafikverket, 2013, Ulvestad and Vieira, 2021). Therefore, it is important to choose appropriate software for site workers, rather than relying on overly complex software that may hinder productivity and efficiency.

4.4 Checklists, scheduling and production-oriented information

All four of the case study projects used checklists and controls within the StreamBIM application. Using checklists and controls in construction projects is not a novel concept. However, what are commonly found as static or unconnected information sources can instead be found integrated with the other interactive tools in one application, creating a dynamic work environment. In the SB47 and Lumi projects, BIM objects were linked to checklists that tracked their status and sub-activities performed by various subcontractors (see Fig. 9).

FIG. 9: Checklist for different sub-activities for door assembly (Image from case project: SB47).

As site work was performed on an object, workers updated the object's status. By assigning objects to individuals, subcontractors or project teams, progress was able to be monitored remotely by management teams. Checklists in Lumi and SB47 were also linked to scheduling tools in StreamBIM to control takt planning (Lehtovaara, 2023) and coordination. Controls were associated with zones in which workers marked their presence at the start of work and signaled completion with another control once the area was ready for handover. These checklists and controls were also used to visually highlight construction teams that were behind schedule.

In the Norwegian hospital project and the two Swedish renovation projects, StreamBIM data was integrated with Power BI software to create real-time data visualizations. To accomplish this, RFIs and checklists completed by site workers in StreamBIM were linked to Power BI. This allowed management teams to analyze data in new ways and monitor various aspects of the projects, including communication, quality controls, safety checks, and object completion states. The availability of a single source of information and the ability to visually track construction tasks in real-time greatly contributed to the efficient management of the projects. This allowed management teams to quickly identify and address the most urgent issues.

The Total BIM concept and the new way of working set new demands on the process of systematically ensuring the quality of BIM and its information. BIM serves as the legally and contractually binding construction document for designers, management teams and subcontractors. It becomes the single source of information. However, on its own this is probably not enough. To ensure the right quality levels are achieved when it comes to constructability, e.g., how well things "fit together on-site," simply being legally binding is insufficient. The design team, i.e., architects and engineers, faces the challenge of maintaining quality control through new Total BIM processes, as they are accustomed to traditional quality practices of delivering 2D-drawings as a legally binding document. In the traditional design process, the BIM design does not need to be fully thought through, detailed, and finalized, and the focus at the end of the design process is on delivering construction drawings to the site. The design team also has limited knowledge of constructability, assembly and production. In this context, knowledge from construction site workers should be considered and new quality assurance processes must be created where the designers and construction site workers collaborate to finalize the constructability quality and production design. In the Norwegian hospital project, they recognized this and implemented a 17-week, 7-step process. The quality control and constructability process of the BIM design started 17 weeks before construction began at the specific construction location or area. This process ensured that 7-step milestones were achieved in a timely manner and the maturity and quality of BIM was developed in time to required levels of development (LOD) or more specifically as used in the hospital project, Model Maturity Index (MMI) (Hansen et al, 2022). The 7-step process for each zone in the model begins when designers coordinate to develop the control area to MMI350, and interdisciplinary controls have been conducted. The model is then semi-automatically checked by rulesets (i.e., in Solibri), and BCF reports are generated. 17 weeks before construction work starts in the control area, the model is checked by site workers for collisions, errors, ambiguities and constructability. During week 17 to week 8 the designers and site workers collaborate to finalize the design for construction. 8 weeks before production, designers update the final model to MMI400 (a level that can be trusted on-site), and the control area is locked. In the following stage, a lockout meeting is held to discuss difficult elements, scheduling and sequencing, and allow subcontractors to submit comments and plan their work. Before the site work begins in the planned zone, another coordination meeting is conducted with site management teams and subcontractors. Shortly after this work commences on-site. Although concerns have been raised about site workers resorting to workarounds if their expectations are not met (Brooks et al, 2022), Total BIM focuses solely on BIM as the single source of information. The 17-week, 7-step process ensures high-quality BIM production and eliminates the need for hybrid solutions.

In the Lumi project, the construction management team also attempted to implement the 17-week, 7-step process to ensure that a high-quality BIM would be ready for construction. However, the prevailing culture of subcontractors posed challenges, as they initially failed to grasp their potential to influence the design process or on-site BIM quality. Creating engagement and changing the project culture and mindset is an ongoing process in Lumi, with managers striving to bridge the gap between designers and subcontractors. In previous projects by the Swedish company, the exact placement of electrical installations was primarily resolved on-site due to limitations in what 2D drawings can represent (Davies and Harty, 2013). In Lumi and SB47, the objective is to accurately model electrical installations, but designers lack the necessary skills to do so. To address these challenges and foster inclusion while transforming the existing culture of separate design and construction processes, the Swedish company is bringing designers and subcontractors together to share knowledge. By facilitating collaboration between designers and subcontractors, expertise can be shared to produce high-quality production-oriented information for dynamic on-site use. In the SB47 project, a cultural shift occurred whereby structural engineers had open discussions with site workers. The goal was to create custom property sets that contained important information needed on-site to perform work efficiently, as shown in Fig. 10. This approach can overcome issues identified in other projects, such as a scenario where codes entered by designers in the BIM were too abstract for site workers to understand and required translation using data dictionaries (Tallgren, 2021).

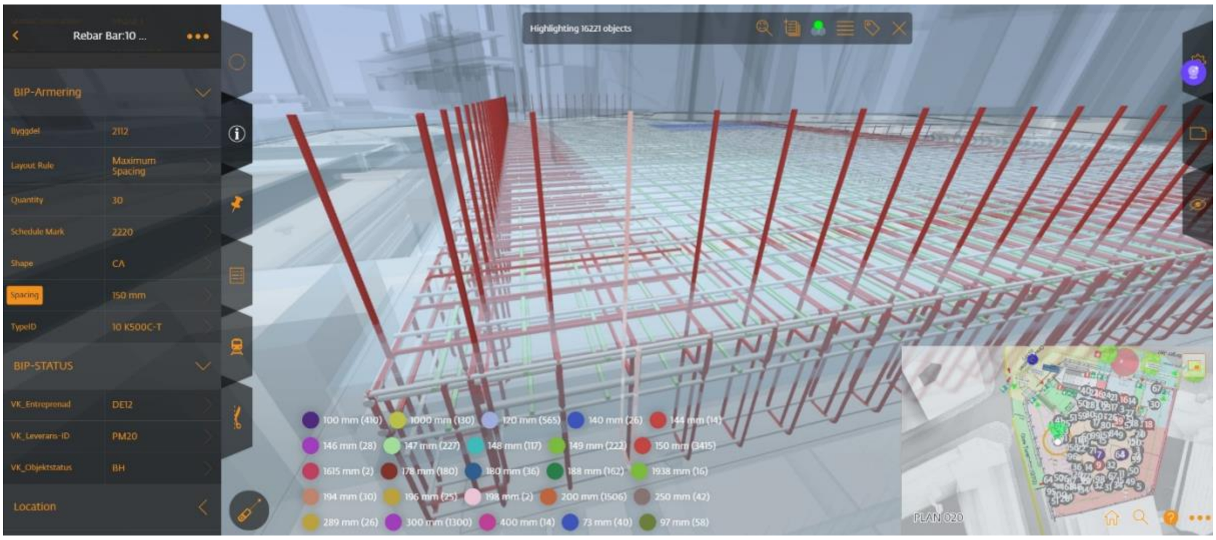

FIG. 10: Production-oriented information for concrete reinforcement (Image from case project: SB47).

The early involvement from subcontractors sets new demands on them. The construction document is no longer a static document from which they work, but rather, they are part of a dynamic process in producing BIM. As a result, standard contracts may need to be revised to include these new roles, which is one of the challenges the industry faces when adopting Total BIM (Brooks et al, 2022, Mershbock and Nordahl-Rolfsen, 2016). Early involvement ensures that site workers have access to the most suitable construction document from which work occurs on-site. Site workers are no longer passive recipients of static 2D unconnected information sources, but they actively participate in the dynamic creation of information during both design and construction. Working this way, detailed, important production and assembly information could be integrated into BIM, which may create a more efficient construction site. By being involved in the design process, site workers can gain trust in BIM, and the design solutions, which addresses the concerns raised in previous studies (Perera et al, 2023, Påsse et al, 2022). Moreover, in Total BIM, BIM becomes the virtual copy of the construction site, which could serve as a foundation for digital twins in the future. For example, by linking wireless sensors to BIM objects, such as wireless moisture sensors of concrete, management teams could receive real-time data feeds for construction planning and site monitoring.

A challenge is that design and construction often occur in parallel, which complicates the process of setting states on objects. As mentioned, the Norwegian hospital project, used a 17-week, 7-step process where MMI status was added to BIM objects. In the Swedish office building projects, design changes often occur very late in the process as new rental tenants enter the project. This sets strict requirements for controlling design and change orders on the construction site. Decisions must be anchored and negotiated between the various actors before construction begins. Any design changes are automatically sent to the cloud (every night in the Swedish projects), and while this is beneficial in some regards, the BIM-viewer automatically shows the most up-to-date version, which can be challenging and places new demands on trust and management. At present it is possible to track these updates digitally, but what often happens is that many objects change state, and information overflows occur. Instead, the changes are manually tracked in static documents and then communicated to site workers and subcontractors through change orders. These updates occur so frequently and dynamically that tracking them can be difficult and places new demands on leadership and management. In a Total BIM project, all information is linked to BIM. However, controlling the status of objects in BIM is still in its infancy. There may be many future opportunities in terms of how object states are handled and linked to scheduling. Currently, this information is mostly used for controls and monitoring but perhaps in the future, it can be more dynamic and used to feedback into other processes, for example, automatic scheduling adjustments. For now, the main advantage of object controls in BIM over traditional methods is that the information is more integrated, and the other benefits can be leveraged to a greater extent.

Total BIM is understood as a model-based approach to construction where BIM is the single source of information (Cousins, 2017, Disney et al, 2022a). This information is used dynamically by site workers to extract the information they need. The current international standard for information management using BIM, ISO 19650, closely follows the requirements outlined by BIM Level 2 and UK PAS1192 standards. While these standards provide standard methods and protocols for the organization and management of information, they do not sufficiently address BIM use in the construction phase or model-based construction processes. As noted in previous studies, research on BIM implementation in the construction phase is scant (Davies and Harty, 2013, Tu et al, 2021). This paper contributes concrete examples of how Total BIM was implemented in the construction phase as a dynamic single source of information. The findings may assist in determining the necessary considerations for future standards and BIM Levels, which could support model-based construction processes and a dynamic single source of information towards the construction site's digital twin. By linking BIM objects to checklists or controls that correspond to the object's status, (see Fig. 9), management teams are provided with new opportunities for monitoring the construction site more effectively. In this context, Total BIM connected to the progression monitoring of the construction site using operation feeds through checklist and sensor data, could be a promising key. It could empower project managers, site managers, and construction workers with an advanced scheduling, planning and decision-making tool, highlighting the progression and inconsistencies effectively.

5. CONCLUSIONS

The parallel processes of delivering 2D drawings and BIM hinder traditional construction projects. In these projects, 2D drawings as an information source have been criticized. Additionally, trust is lost in BIM as it ceases to be consistently updated. The previous state-of-the-art BIM projects have been limited by several factors such as software and hardware limitations, challenges measuring on-site using the available software, lack of competencies, interoperability issues, and legal issues. Therefore, until recently, construction has mostly occurred using static and unconnected information sources. However, the Total BIM concept applies a new dynamic way of working where there is a single source of connected information for an integrated approach. This paper addresses a gap in research of model-based construction projects. The Total BIM on-site processes from the four case studies are not new ideas. What is new and shown in this study is the way that these processes are dynamically implemented, which changes how on-site construction occurs.

A key aspect of Total BIM is that site workers can dynamically extract and create construction information on-site. Previous attempts to achieve this have been limited by software tailored for expert users, difficulty adding information to objects such as measurements and lack of trust in BIM. The four projects in this study have demonstrated that modern BIM-viewer software enables construction workers to dynamically filter, create and extract information from BIM. Simple to use measuring features, pre-defined property sets, and query filtering tools enabled users to work in a dynamic BIM environment rather than with static information sources. Site workers adopt a new role as creators of information and independently extract the most suitable information they need for their tasks. However, due to the new work methods, new demands are set on project stakeholders and challenges remain regarding allowed tolerances, which may need to be addressed by regulators.

Although it was initially unexpected the BIM-viewer application became much more than a tool for interacting with BIM. In all four projects, it became a communication and management platform where commonly found unconnected information sources were integrated. By using mobile devices, photos from on-site were linked with information from BIM and short descriptions to accurately document RFIs. This approach reduced handling times and enabled management teams to better observe the on-site status, as all the information was connected.

Total BIM sets new demands on the process of the systematic quality assurance of BIM and its information since BIM is the legally and contractually binding document for all stakeholders. A 17-week, 7-step process was implemented where subcontractors and site workers were involved during the design stage to assure constructability and a high-quality BIM. This changes the role of site workers from recipients of static information sources to assisting in the creation of dynamic information, both during design and construction.

This research addresses and answers the question, "how could BIM be used throughout a construction project as the dynamic single source of information on the construction site, i.e., Total BIM?" Until now the main challenges have been implementing BIM effectively on-site. The case studies show that static 2D drawings are no longer necessary for the construction site, and it is possible to use BIM throughout all project phases as a dynamic single source of information. Total BIM may even be the preferred method of the future, saving money due to fewer errors and re-work. This research highlights key dynamic processes that are required to implement the Total BIM concept on-site. These findings can be used to support the on-site implementation and strategy work of Total BIM. They also provide practical, concrete examples where there is a lack of empirical studies about on-site BIM implementation and may be useful in the development of future standards. The Total BIM concept could support model-based construction processes and a dynamic single source of information towards the construction site's digital twin. Progression monitoring of the construction site using operation feeds through checklist and sensor data, could be a promising approach, empowering project managers, site managers, and construction workers in their daily work.

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