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DRIVING CIRCULARITY WITH TOTAL BIM: AN INTEGRATED APPROACH TO DATA-DRIVEN DESIGN

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Despite the significant environmental impacts of the construction industry, the sector lacks practical decision-making tools to increase material reuse. Building Information Modelling (BIM) can address this by facilitating data-driven decision-making. Total BIM, a growing trend in the Nordic region, implements model-based design and construction with a single source of information. This research presents a case study of a Total BIM office renovation project, where innovative BIM and digitalisation processes were implemented to increase material reuse. These processes enabled proactive, data-driven decision-making, minimising CO2 emissions. The building's concrete structure was preserved, and various components such as plasterboards, radiators, ceiling panels, doors were all reused and evaluated for CO2 emissions. The Total BIM approach was enhanced by attaching material reuse data to objects to reduce waste. The data draws on interviews, workshops and a study visit from a unique case study project in Sweden. Findings highlight how tougher emissions regulations could be the tipping point for pushing BIM implementation in projects as we think about constructing for the future.

Keywords: digitalisation; BIM; model-based construction; circularity; drawingless

INTRODUCTION

According to the UN's Strategic Plan 2020-2023 climate change is one of the greatest challenges facing cities (United Nations Habitat 2019). Buildings in Europe account for 40 percent of energy use and 36 percent of greenhouse gas emissions (European Commission 2021). Renovation is an effective way of reducing the energy footprint of buildings since 85 percent of today's buildings will still be in use in 2050 (European Commission 2021). The construction sector in Europe is responsible for half of all resource extraction and a third of all waste (European Commission 2014). To address climate concerns, especially CO2 emissions from the construction industry, more attention needs to be given to material reuse and circularity in renovation projects.

In Sweden, emissions from the operating phase of a building are limited by energy management requirements (Boverket 2011). Until recently there have been no rules governing emissions during the construction phase. From 1st January 2022, a new act on climate declarations for buildings came into effect in Sweden, which aims "to reduce the climate impact from the construction stage" (Boverket 2021, Sadri *et al.,* 2022). However, this policy is limited. Contractors are required to report the climate

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impact during the construction phase but there are no limits, requirements, or maximum permitted values (Boverket 2021, Sadri *et al.,* 2022). The policy intends to make contractors more aware of climate impacts (Sadri *et al.,* 2022), but it does not include all building elements. Furthermore, there are currently no requirements to make climate declarations for building refurbishments, which according to Boverket (2020), "involve the removal and use of large amounts of material, causing relatively large climate impacts which would, of course, be beneficial to reduce."

As tougher rules and regulations are gradually being enforced to meet the EU's goal of net-zero emissions by 2050 (European Commission 2019), construction industry actors are beginning to implement strategies to tackle the challenge. Companies that are prepared to change their approach to use digitalisation as the driving factor can lower the climate impact from new build and renovation projects by up to 40 percent (Smart Built Environment 2020). Therefore, climate declarations may drive the industry to become more digitalised as we construct for the future.

Circularity and BIM

Even though greenhouse gas emissions are decreasing relative to production in the Swedish construction industry, the amount of waste generated is still increasing (Bovkerket. 2023). Waste has increased by 16 percent from 2018 to 2020, and 55 percent since 2014 (Bovkerket. 2023). Since, Boverket (2023) gathered this data, new regulations have begun to be applied to handle waste. Construction and demolition waste must be sorted by type and stored separately from other types of waste. However, these regulations are aimed at sorting waste, rather than directly reducing waste on the construction site.

The European Commission (2020), as part of their Circular Economy Action Plan promote the use of "digital technologies for tracking, tracing and mapping of resources." The European Commission regard digital tools and skills as drivers for promoting circularity in building projects. BIM has significant potential for efficient waste management in building projects (Jin *et al.,* 2019). Implementing BIM, with the support of other digital technologies can improve circularity assessments, increase material recycling and reuse, and more accurately track environmental data throughout a building's lifecycle (Charef and Emmitt 2021). Green building trends and tougher climate regulations are leading clients to consider the overall environmental impact of their buildings (Sacks *et al.,* 2018). By using BIM for environmental analyses, clients are provided with many advantages over traditional 2D methods (Sacks *et al.,* 2018) due to BIM's ability to contain more information than 2D drawings. Digital CO2 and life expectancy data can be included on BIM objects, which supports work with circularity (Charef and Lu 2022).

To meet the net-zero emissions targets and reduce waste, the construction sector must rethink the cycle of "make, use and dispose" (Charef *et al.,* 2021) to include more circular activities e.g., "reduce, reuse and recycle" (Kirchherr *et al.,* 2017). Implementing circular activities requires industry actors to lead the change with practices, policies, and decision-making tools by exploring innovative concepts (Charef and Lu 2022). End users need to become more knowledgeable about reused and remanufactured products (Charef and Lu 2022). Suppliers also need to be incentivized to reprocess products rather than to always sell new ones.

Total BIM and Model-based Construction

Total BIM is a trend emerging in the Nordic region where model-based design and construction is implemented with a single source of information, notably even the construction phase (Brooks *et al.,* 2022; Disney *et al.,* 2022; Ulvestad and Vieira 2021). Since there are no paper drawings, the BIM is the contractual and legally binding construction document (Disney *et al.,* 2022). Without paper drawings, construction information must be derivable from the BIM. In Total BIM projects, the BIM must be significantly detailed during design to a level that is suitable for use in the construction phase (Disney *et al.,* 2022). Traditional construction projects do not usually create a high-quality and detailed BIM. A simplified model usually exists for purposes such as clash detection and coordination (Davies and Harty 2013), where a parallel process of creating BIM and detailed 2D drawings occurs (Disney *et al.,* 2022). Therefore, in traditional projects, it takes a significant amount of effort to extract environmental data. However, with model-based construction, objects are already accurately modelled, and including lifecycle data such as CO2 impact is less of a challenge. This digitalised data can be used at an early project stage to make accurate climate impact assessments as described by Jin *et al.,* (2019), Charef and Emmitt (2021), Sadri *et al.,* (2022) and Smart Built Environment (2020).

Research Gap and Motivation

Circularity is an important aspect of achieving the EU's net-zero emissions goals by 2050. Since, 85 percent of all buildings currently in use will still be in use by 2050 (European Commission 2021), renovation projects are a critical part of meeting these goals. Adopting digitalisation strategies in projects can lower the climate impact of the project by up to 40 percent (Smart Built Environment 2020). Moreover, implementing BIM can reduce waste (Jin *et al.,* 2019) and increase circularity (Charef and Emmitt 2021). Yet, there is a lack of research that explores BIM and emerging digital technology use to promote circularity in projects, especially renovation projects (Charef and Emmitt 2021; Charef 2022; Jin *et al.,* 2019). Therefore, this paper studies an innovative, renovation case study project in Sweden, where BIM and digitalisation processes have been used to work towards net-zero CO2 targets. By working this way, management teams were able to make real-time decisions based on the digitalised data, lowering the overall climate impact of the renovation project.

METHOD

Case Study Details

This research is based on a single case study of a leading, real-world, model-based construction project in Uppsala, Sweden. Our research draws on this specific case study as a "force of example" as supported by Flyvbjerg (2006) and a growing interest in experiences from implementing digital technologies in practice, advocated by Moum *et al.,* (2009). In the building renovation project, Lumi, Total BIM is implemented during design and construction as the single source of information (Disney *et al.,* 2022). Lumi, is centrally located in an old industrial area, which has been transformed, primarily into a residential area. Lumi is owned by a large client that have employed a small construction management (CM) company to manage the entire project. The client has aims to be climate neutral in their entire value chain by 2030. Previously, the site was several connected office buildings for large hire gusts. The renovation is split into three stages, new offices, a hotel, and 400 new apartments.

This study focuses on the processes implemented by the CM company to reduce waste and reuse materials during the renovation and creation of new offices.

Data Collection and Analysis

This research is part of an ongoing Ph.D. research project focusing on Total BIM (Disney *et al.,* 2022). The CM company responsible for the Lumi project has been recognized as an industry leader in digitalisation, having won the 2020 buildingSMART award for their previous project's digitalised construction process. Building on the success of their previous project, the CM company has further enhanced the level of digitalisation in their current project, Lumi, by implementing digital processes to address sustainability concerns. To understand and gather research data on these processes, the researchers of this paper organised a study trip to the Lumi project, accompanied by 22 industry experts in digitalisation. These industry experts are part of the Ph.D. project's study group. The visit commenced with a presentation by the CM company, during which they outlined their objective of preserving Lumi from demolition and explained the processes they have implemented to reduce waste and increase material reuse. A guided tour highlighted the reuse processes, including a demonstration of on-site test modules and ongoing challenges. Additionally, the tour underscored the interconnectedness between decision-making processes, CO2 impact and climate declarations. Further insights were provided by the CM company and architectural firm on the quality control processes necessary for working with Total BIM. The study visit to Lumi concluded with a workshop involving researchers, industry representatives and the CM company to engage in discussions on the project's material reuse process.

After the study visit, two online interviews were conducted with the CM company's VDC on-site engineer, who was mainly responsible for the development of the reuse processes. The interviews were semi-structured, aiming to delve into the digitalisation and decision-making processes that were implemented to increase material reuse. The interviewee was given the freedom to express their experiences and challenges with current practices. The online interviews were recorded and later transcribed.

A second workshop was held with the CM company and 12 industry digitalisation and sustainability experts from a large Swedish construction company. The workshop focused on discussing the intricacies of the waste minimisation and material reuse processes, and exploring how they were implemented.

The empirical data was analysed by adopting a thematic analysis, in accordance with relevant literature and current regulations. After the case analysis, an online discussion took place with the CM company's VDC on-site engineer and project manager. The paper's themes were presented to initiate a discussion, where the CM company were asked to provide specific case examples from the ongoing project, Lumi.

FINDINGS

The CM company implemented Total BIM processes to improve the data management and accuracy of construction information in their projects (Disney *et al.,* 2022). By adopting Total BIM and achieving better data management, the CM company has been able to improve work processes and implement improved circularity practices, such as material reuse and waste reduction, through data-driven decision-making.

Case Study Concept

Total BIM was successfully implemented in the CM company's previous project, improving data management, and helping to minimise design problems that frequently led to delays (Disney *et al.,* 2022). Building on this success, the CM company and the same client reached an agreement to expand and enhance their Total BIM approach to incorporate and address circularity concepts. In the Lumi renovation project, the CM company attempt to dismantle as many components on-site as possible for reuse in the finished building. This includes items such as plasterboard, joists, carpets, radiators, brick, suspended ceiling tiles, kitchenettes, sheet metal, windows, doors, glass partitions etc. The concept is not to force office hire guests to have reused materials, but to offer them an informed choice. They can choose to have the reused materials or pay extra for new materials. They are shown data to help them understand the CO2 implications of their decisions. Test modules were created on-site to showcase the material reuse. The CM company identified that they had an approximately 55,000 square meter traditional empty office building with cell offices. Within the building, there were approximately 800 doors and 800 glass partitions that were in good condition. The CM company therefore felt they had the opportunity and responsibility to change the existing practices of demolish and dispose.

Circularity Process

To commence the implementation of circularity processes, the CM company collaborated with architects to develop a BIM for the office renovation building. In this model, all objects were modelled as new (windows, doors, glass partitions etc.). By adopting this approach, they established a baseline that could effectively demonstrate the climate impact resulting from the exclusive use of new materials. Using this model, object properties were gradually changed to use recycled materials instead of new ones. They began with suspended ceiling tiles that they had identified as a typically problematic item that cannot be recycled and usually end up in landfill. By implementing this process, the CM company could efficiently compare the CO2 impact of using recycled materials with the ones modelled in the baseline.

The CM company also worked with a Swedish company that provides a service to calculate a construction project's climate impact. At the beginning of the Lumi project, the software company did not offer a service for model-based calculations. During the collaboration process a digital solution that automatically reads object properties from the BIM was created. The software differentiates between objects with recycled properties and those without. As a starting point, new materials were calculated using their full CO2 impact and reused objects had zero CO2 impact. Adjustments were made later if materials needed to be transported off-site or repainted etc.

Materials that could be reused needed to be dismantled, managed, stored, and tracked. The CM company used a cloud-based database and application for this process. Materials that had been selected for reuse were dismantled. After dismantling, information was entered into the database containing information such as a unique identifier, object name, description dimensions, material type, colour, location, sound rating, fire rating and photos (Figure 1). Materials were marked with RFID tags and sticky notes so that they could be tracked and located later for reuse (Figure 1).

Office hire guests are informed of potential reuse options, or the climate impact and additional cost if they decided to use new materials, which helped to raise awareness about sustainability issues. The BIM is regularly updated to reflect design decisions and the material choices by hire guests.

Figure 1: Left: Material database, Right: Generated product ID tag with EPC code

The cloud-based materials database and BIM are linked to a central database. Using this central database an algorithm attempts to find best matches between the designed objects in BIM and the available materials for reuse. Object properties are automatically updated in the BIM with the unique material identifier (EPC code) that was generated when the object was dismantled and inventoried. Using model-based construction techniques, site workers can access the cloud-based BIM on-site, on mobile devices. When an object is selected the properties are displayed, including the unique identifier (EPC code). This can be matched with the physical labels and RFID tags on stored materials to install the right reused item in the right location. Figure 2 shows the digital process for increased material reuse implemented by the CM company in the Lumi project.

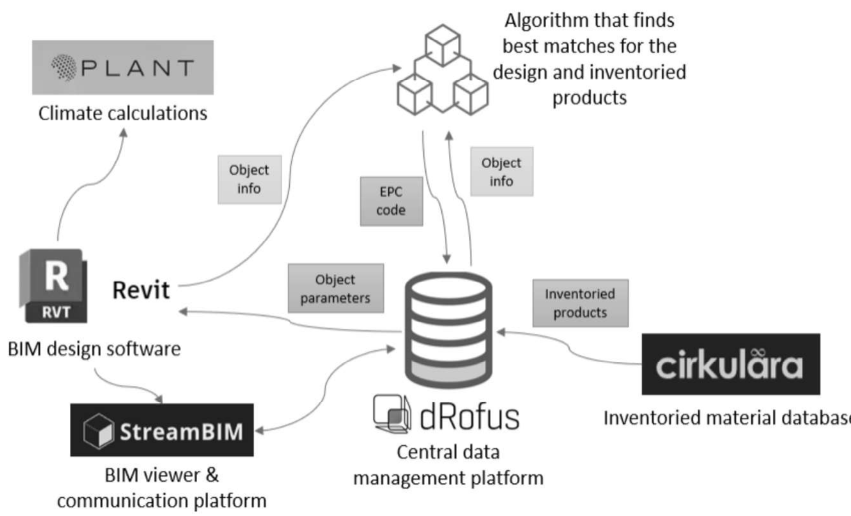

Figure 2: Digital process for increased material reuse in project Lumi.

This approach to addressing material reuse in the renovation project relies heavily on BIM. The processes developed during this project allow for the automatic generation of climate impact assessments from the BIM. Without implementing Total BIM, it is questionable if this approach would be feasible. Total BIM requires creating a high-quality, information rich BIM and the necessary investment to achieve this. While it may be possible to calculate climate impact from drawings, the accuracy and speed are challenging, which usually results in only having a climate pre-study and a declaration after construction is complete. By calculating the CO2 emissions directly from BIM, it is possible to have ongoing decision-making processes to reduce emissions throughout the project. This more flexible approach enables new opportunities to have discussions with clients and end users.

A digitalised approach to construction has been reported to lower the climate impact of projects (Charef and Emmitt 2021; Jin *et al.,* 2019; Smart Built Environment 2020). As environmental product declarations (EPDs), Life Cycle Assessments (LCAs) and climate declarations are being enforced across the EU, BIM may become necessary to handle this data in an effective way. Moreover, these climate impact tools may even be the incentive for promoting greater BIM use in projects. Cost has been a limiting factor related to developing a high-quality BIM (Brooks *et al.,* 2022; Disney *et al.,* 2022). However, if an information rich, accurate BIM is a necessity for climate impact studies, then one of the major barriers to model-based construction may be overcome. Currently model-based construction might not be possible in some countries due to regulations, but the benefits shown in this study of a data driven, model-based approach to material reuse in projects may highlight the need for reconsideration of existing regulations.

Decision-Making

Climate impact reports that show the CO2 contribution of building components are sent every six weeks to the CM company. The reports show the impact over time of the decisions made during the project and help to guide future decisions. These reports also show which components are most impactful for a project's CO2 emissions. In the Lumi project, beams, installations, and windows were overall the most impactful.

In the Lumi project a decision was made to reuse as much plasterboard as possible. It was noted that plasterboard is quite cheap to purchase, so normally it is not considered worth reusing. However, what they found in the project was that the time to dismantle plasterboard in traditional projects, separate and recycle materials was equal to the time it took them to prepare to reuse it. In the words of the VDC on-site engineer:

> You cannot compare the cost of recycling with blowing up a building, it does not work like that…it is clear that demolition will be chosen because it is cheaper and faster, but if you include the environmental aspect, which I think is becoming more and more important in the mindset of property owners and projects nowadays, you value the time and cost in the right way. That way you compare apples and apples and not apples and pears.

As Charef *et al.,* (2021) states, the construction sector must rethink material use cycles to become more circular. Innovative concepts and policies should be explored to lead the change towards more circularity in construction (Charef and Lu 2022). The VDC on-site engineer gave his opinion about how this could be implemented:

> There should be legal requirements and the industry should be taxed according to the remaining lifespan of the product they are disposing of.

If the industry was to be taxed in the way the interviewee describes, then the additional costs relating to recycling and reuse could be offset. A circular approach may even become the most economical. End users must become more knowledgeable about reused and remanufactured products (Charef and Lu 2022), so they can actively participate in these discussions. Responsibility for circularity also needs to be defined, is the client responsible, the contractor, the end user, or regulators? Would high-end clients be content with reused materials that perhaps in some cases show minor wear and tear? If a circular approach is to be adopted, which seems necessary to meet climate goals, then the CM's company's digital processes may help to guide future decision-making in projects.

Challenges

The project has also encountered several challenges. Not all products have pre-defined values for their environmental impact. Instead, standard values are usually calculated based on the size of the contract or net area, but the CM company found that these were inaccurate. As the VDC on-site engineer said:

> We got rid of all standard values for climate ratings in our calculations…standard climate ratings that exist, for example, for installations are completely useless. It presented a much worse image of the project…We couldn't go out to newspapers and say this is a good (sustainability) project, but we said that at least we know what we are working with and we can see the effect of our decisions.

The CM company invested time and effort into making their own, more accurate calculations based on material weight. This enabled them to gain an improved understanding on the climate impact of the decisions they made during the design and construction process.

It is not possible to reuse all materials. For example, some of the pipes in the project were not in a suitable state to be reused and replacement parts are no longer sold. The CM company worked with consultants to determine what was possible to reuse. In other cases, materials were suitable to reused but no longer comply with modern regulations. One relevant example from the project of this is doors that were too narrow to meet modern standards. Special hinges were purchased that extend the width of the doors when fully open, but even these resulted in a shortcoming of approximately 5 mm. The CM company decided to reuse the doors anyway as they found the climate impact of disposing of doors that were in good condition too impactful. There were also problems working with suppliers. Suppliers are usually incentivised to sell new products, and some had no support for refurbishment of existing ones. Storage of materials for reuse also became an issue. The VDC on-site engineer said that ideally materials would be sorted by zones and delivered to the construction zone just before construction begins.

As outlined previously there are currently many challenges implementing circularity in renovation projects. Boverket (2020), have recognised the importance of reducing material use in renovation projects, but lack regulations to enforce it and even lack requirements to declare resource use (Sadri *et al.,* 2022). The CM company implemented many strategies that may prove not to be beneficial to themselves, such as calculating a realistic environmental impact rather than using standard values and reusing doors that fail modern accessibility standards. They also reused items such as radiators that may have marginally worse performance than modern equivalents. These factors again raise the issue of who is responsible for reducing construction material use in projects. It is unreasonable to expect most clients to adopt a similar approach if it requires more resources and provides them with worse financial returns. Sustainability issues need to be addressed over a building's life cycle and current climate declarations need to be further developed from goals to requirements (Sadri *et al.,* 2022). The CM company have taken many steps towards digitalising resource reuse and decision-making processes for circularity in renovation projects. However, many challenges remain and the implementation of circular practices at a project level still needs support from external actors.

CONCLUSIONS

In the Lumi project, a new digital approach was implemented with the aim of increasing material reuse and circularity in renovation projects. This approach enabled the client, CM company, and tenants to make informed data-driven decisions that reduce waste and lower the overall climate impact of the project. Tougher regulations are being enforced to meet net-zero objectives, including climate declarations for new constructions. The requirement for climate declarations for renovation projects is also currently being investigated, with the aim of promoting efficient use and extending the life of existing building materials. These tougher regulations may be the tipping point for pushing greater BIM implementation in projects because climate calculations can be automatically and quickly calculated based on object properties in BIM. Using BIM in this way enables data-driven decisions throughout a project, assisting with meeting climate objectives and end users' needs as we think about constructing for the future. Furthermore, if the tipping point is reached and a high-quality BIM is created, the parallel processes of creating 2D drawings may not be necessary, promoting the use of the Total BIM approach with a single source of information.

Many challenges remain to maximize material reuse in renovation projects, such as, lack of support from suppliers, lack of replacement parts, reduced performance, and older materials not meeting new standards. However, if we are to achieve net-zero climate objectives, actors in construction projects should rethink how they value sustainability. This research contributes to regulators, researchers, and practitioners by investigating a digital approach that facilitates decision-making processes for reducing resource use in renovation projects.

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