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# BUILDING INFORMATION MODELING (BIM)

## 02 FURTHER EXPLORATION IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION

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Civil and Architectural Engineering  
Technical Report CAE-TR-4



Figure by Aliakbar Kamari



AARHUS  
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# DATA SHEET

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## **Abstract**

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I

# Building Information Modelling with Location-Based Scheduling for Construction Management

*Claus Sveigaard-Iversen*

## Abstract

With sustainability and BIM playing a major role in the AEC industry, previous initiatives have led to more efficient and well performing buildings. Yet until recently, improvement of on-site construction activities is being brought into focus by combining sequence and scheduling with BIM (4D BIM). The objective with the present report is to review the process of implementing and utilizing Location-Based Scheduling (LBS) for Vico Office software with Autodesk Revit 2018 as authoring BIM application. The report shows that by opting for LBS, a schedule is made more streamlined and uniform as interfering tasks or potential ineffective use of locations are revealed, enabling analysis and improvement of the schedule to generate more effective workflow, thus ultimately avoiding project delays. However, the discussed scheduling software application does lack better compatibility with the used BIM application, as information extraction between the two applications in some cases proved to be inadequate for scheduling purposes, hence not fully implementing the BIM methodology. The report also suggests future improvement of Location-Based Scheduling and introduced software by centralizing production rates to a cloud-based database. Furthermore, a digitalization of the production, for instance by introducing radio-frequency identification technology, would allow for easier monitoring of scheduled construction activities.

## Key words

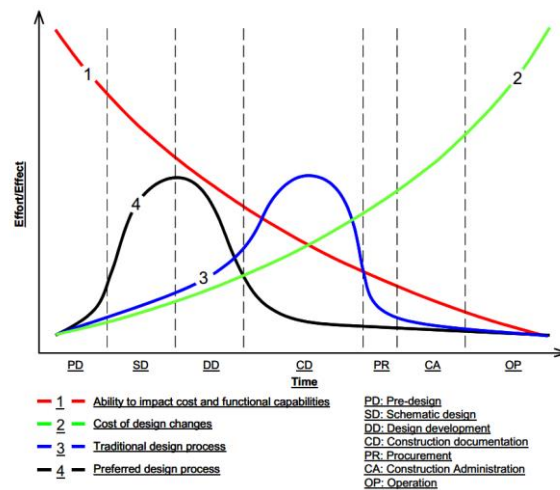
BIM, Sustainability, Construction Management, 4D, Location-Based Scheduling

## 1. Introduction

Environmental considerations have been an integrated part of a building process in many years (Marsh, Lauring, & Petersen, 2000). Today, not only the environmental aspects have to be considered but also social and economic aspects, hence defining the three main pillars of sustainability: *Environmental development, economical development and social development* (Khan, Dewan, & Chowdhury, 2016) (Chong, Lee, & Wang, 2017). As defined by the Brundtland report in 1987, sustainable development is about meeting present needs without compromising the future generations in meeting their own needs (Keeble, 1988). Hereby, sustainability is based on a more holistic approach (Butters, 2004) creating a balanced mindset regarding the human population's modern needs without neglecting our own environmental impacts.

Recently, sustainability plays an increasingly more important role within the Architecture, Engineering & Construction (AEC) industry, forcing project organizations to incorporate sustainable considerations and initiatives into the early design phases of a project. Due to increased sustainable knowledge and also more demanding restrictions from governments, for instance by the European Union's 2020 and 2030 energy policies (European Commission, 2014a; European Commission, 2014b), cause a rise of new buildings with very high energy performance during operation (European Commission, 2013). Consequently, the importance of reducing the environmental impacts of the construction phase is now being brought into focus, as on-site construction activities are being accounted for as a major source of environmental degradation (Jupp, 2017).

To help streamline a construction phase, proper management and planning of construction activities are crucial and need to be addressed even during the early design phases. By doing so, a better overall understanding of the project is generated amongst a project team's multiple-disciplinary stakeholders, thus maintaining the holistic approach of sustainability mentioned previously. The implementation of such managerial tasks necessitate a project organization that is heavily reliant on proper communication and information sharing between all stakeholders. This creates the need for a more centralized organization model where information is shared between all members of the organization (HOK Network, 2010a). This implies a project team to shift working effort to an earlier project phase, i.e. the design phases (HOK Network, 2010b). This can optimize the ability to make design changes while keeping associated project expenses at a minimum. Such shift in working effort has been proposed by Patrick MacLeamy. The concept is illustrated by figure 1.



**Figure 1:** Curve based on Patrick MacLeamy's effort-over-time curve (Roundtable, 2004)

### 1.1. Location-based scheduling

A study of several Swedish construction projects indicates that a maximum of 20% of a construction crew's working time is spent on actual effective work at a project site (Josephson, 2005). Roughly 45% of the time is spent on indirect work such as planning tasks or giving work-related instructions. Consequently, the work flow is interrupted causing a great deal of project delays which ultimately increases project expenses, thus having a negative impact considering the main pillars of sustainability as introduced earlier.

In the AEC industry, a schedule is typically designed to monitor production over a specific time duration, i.e. the completion of tasks or activities over time. Therefore, to create an effective production, it is important to properly coordinate tasks (activities) and resources (work-crew) to minimize ineffective work at a

construction site. Traditionally, activity-based scheduling methods, e.g. Critical Path Method (CPM), have been used in the AEC industry (Lu & Olofsson, 2009). Studies have however shown that for complex and large projects such traditional schedules often become too confusing and unmanageable due to the vast number of interlinked activities (Büchmann-Slorup & Andersson, 2010).

As an alternative, the linear scheduling method 'Location-Based Scheduling' (LBS) can be used to schedule repetitive activities, i.e. uniform repetition of work throughout a project (Alamdard, 2013; Lu & Olofsson, 2009), thus limiting the scheduling methodology to medium and large scale projects. Compared to CPM, LBS introduces space (locations) and the importance of the continuous resource flow through these designated locations. The space is structured hierarchically by breaking down a project into minor levels, e.g. storeys and sections.

Production rates for tasks are based on quantities, available resources, crew composition and consumption (Intelligent BIM Solutions, 2015). By using a somewhat constant production rate, work-flow can be scheduled (Akbaş, 2003). Typically, this is visualized by a flowline diagram which helps to keep track of resources as they move on through various locations of a project. Production rates are crucial to LBS as it supplies the underlying basis for task durations, hence rates should be imposed with caution.

LBS is based on flow-lines to graphically represent construction activities. This representation quickly reveals both ineffective use of locations and interfering tasks (Exigo, 2016). Flow-lines can be altered by assigning more resources to critical tasks.

## *1.2. LBS for Building Information Modelling*

A centralization of information, as discussed previously, can be attained through Building Information Modelling (BIM). BIM is a methodology, more specifically a body of methods used in a particular activity, e.g. design development (Kamari, 2018), which has gained a lot of attention in the AEC industry in recent years. BIM allows for an enhancement of communication and information sharing between project stakeholders by creating a collaborative database with different layers of information regarding design and construction (Kirkegaard, Zandieh, Kani, & Hessari, 2016). Hereby, BIM enables object-based parametric modelling (3D) used to design, document and analyze a building prior to its actual construction (Kirkegaard et al., 2016). Therefore, BIM is a set of technologies, processes and policies enabling several stakeholders to collaboratively design, construct and operate a facility (BIM Dictionary, 2015).

The AEC industry is under a constant pressure to increase quality and work efficiency because of mutual competition and growing demands from clients (Koo & Fischer, 2000). Due to recent development, 4D BIM (sequence and scheduling) is being used to further improve the building processes (Kirkegaard et al., 2016), and help coping with the increasing demands. 4D-modelling (3D + time) links time scheduling to BIM. By exploiting BIM and cloud-based sharing, all project stakeholders can communicate and cooperate within the same model to perform scheduling and planning related analyses. By doing so, unanticipated problems can be detected in the early design phase by reviewing the 4D model (Koo & Fischer, 2000). Unfortunately, LBS-supported software is sparse, as traditional scheduling approaches still are more widely recognized within the industry. Currently, LBS software is mainly being developed by Synchro Software ltd and Trimble Inc, offering both TILOS and Vico Office software.

A location-based approach for scheduling activities combined with BIM enhances the usability of work-flow analyses, allowing project planners to simulate work scenarios prior to construction (Jongeling & Olofsson, 2007). Such simulation of work scenarios can prevent clashing activities (Andersson & Christensen, 2007), hence avoiding potential project delays.

However, LBS in a BIM environment also has several major drawbacks. Firstly, LBS must be used as a scheduling method for repetitive work only, hence the method has its limitations for use during minor (non-linear) construction projects, e.g. single-family houses. Furthermore, scheduling combined with BIM requires a high Level of Development (LoD). Such development requires a lot of time and effort during early stages of the project from all stakeholders. Also, further aspects of construction activities are not directly related to components in BIM, for instance formwork for concrete pouring. For that reason, an accurate model for scheduling purposes can be complicated to compose (Jongeling & Olofsson, 2007). Another disadvantage to this is that while components in BIM often are modelled as a single object, such components are built in several sections. As an overall consequence, any 4D-modelling may end up as an abstract schedule if not sufficiently detailed.



### 1.3. Scope and aim

The purpose of the present study is to investigate the implementation process of Location-Based Scheduling (4D) in BIM based on selected software as described in section 2. A case is then introduced to review the software, and to highlight advantages or limitations regarding schedule analysis and visualization. Results from the case are being discussed in a separate chapter. Lastly, a conclusion is presented.

## 2. Materials and methods

Scientific papers regarding Building Information Modelling combined with time scheduling are included in this report. Location-based scheduling was chosen as main method. A case with a built model is used to investigate the implementation process and usage of location-based scheduling combined with BIM.

### 2.1. Scheduling

For scheduling, flow-line diagrams are chosen to visualize tasks throughout designated locations. Tasks are differentiated with different colors and titles. Task durations and connections are determined manually.

### 2.2. Building Information Modelling

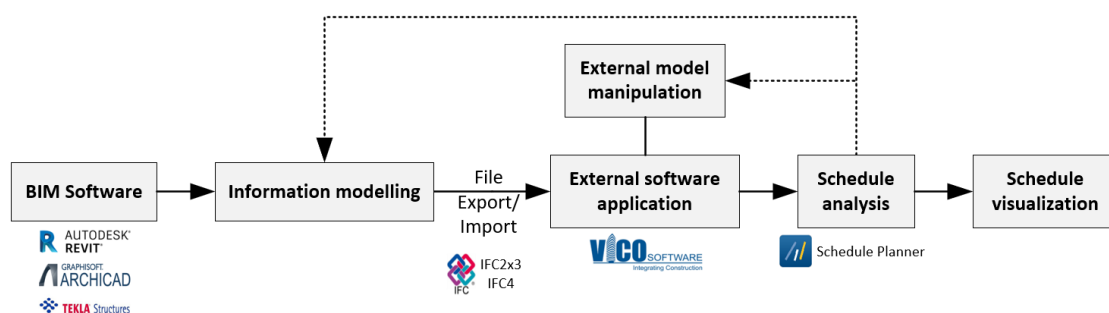
The built model in the presented case consists of architectural walls, columns, floors, curtain systems and roof. Used beams were modelled as structural components. All components are available in the Danish Revit content library.

### 2.3. Software

Building Information Modelling was conducted by using Autodesk Revit 2018 (version 2). Location and task management was carried out by using Vico Office (build R6.5 MR2) by Trimble. Scheduling was performed in Schedule Planner (service pack 4) software.

## 3. Results

By using adequate BIM software, a project can be scheduled with an external software application. Vico Office software is a set of tools accessible as modules (Pučko, Šuman, & Klanšek, 2014). The application process for LBS in BIM is conceptualized c.f. figure 2.



**Figure 2:** Concept of application process for LBS implementation in BIM by utilizing Vico Office as a scheduling tool, author's elaboration based on (Krawczyńska-Piechna, 2015)

A traditional 3D BIM model can be exported to Vico Office using an installed add-in to Autodesk Revit, or alternatively by importing supported file formats such as IFC2x3 or IFC4 (Intelligent BIM Solutions, 2014). Any files are accessible through Vico Office's dynamic 'Document Control' module. Upon transferring files to Vico Office, the software can be set to automatically divide the 3D model into floor plans as modelled in Autodesk Revit (Intelligent BIM Solutions, 2014). Thereafter, external manipulation of the model within the Vico Office software is needed. Further allocation of locations to each plan is done by using the 'Location Manager' module. Also, the software provides an instant quantity takeoff for each section and-or subsection based on the Revit model or manual input. Takeoff quantities can be used in the scheduling process to determine production rates as discussed in section 1.1.



After successfully creating the project work space, project tasks are defined and linked with the components of the 3D model in the provided 'Schedule Planner' program. Here, tasks can be loaded with quantities, resources and costs. Based on provided information in Vico Office, Schedule Planner utilize formulas for the calculation of task durations (Exigo, 2015; Intelligent BIM Solutions, 2015). After proper schedule analysis, a 4D visual review is possible through a simulation option.

### 3.1. Case

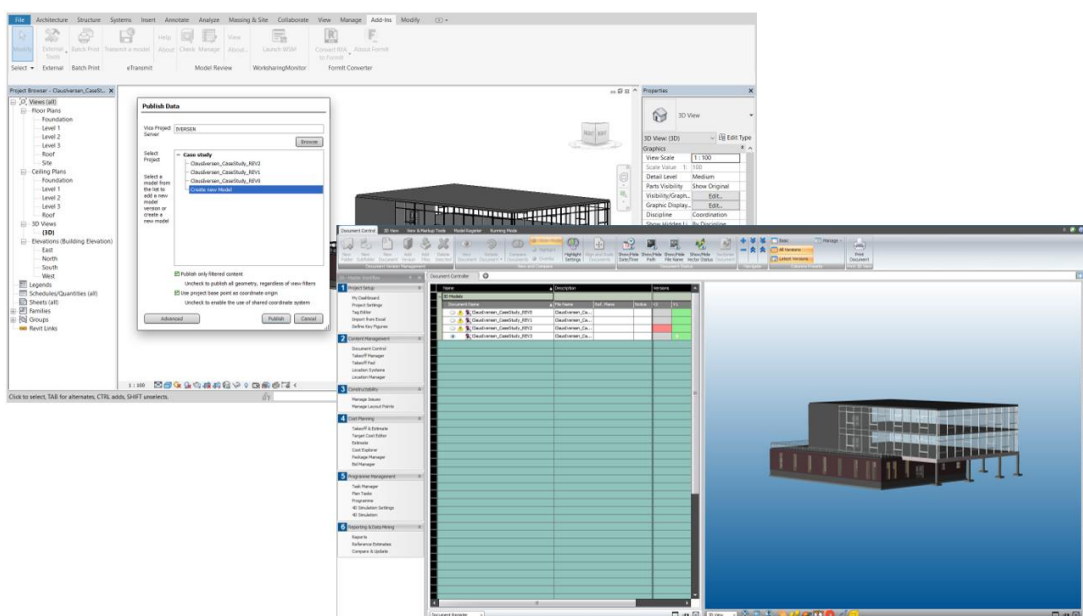
During this section, a brief example is presented to demonstrate the application process and utilization of 4D BIM. The considered example includes an approximately 1800 m<sup>2</sup>, 3 storey office building. The example is modelled purely for educational use. The model is composed of strip- and pad foundations, bearing columns and beams, slabs, internal and external walls and a large curtain wall construction at level 2 and 3. Furthermore, a concrete core is modelled for stability. A 3D view of the modelled is shown on **Figure 3**.



**Figure 3:** 3D view of example as modelled in Autodesk Revit 2018

The Revit model is exported to Vico Office by using an external tool command in the Revit interface. By default, all model elements and parameters in Revit are being exported.

When the model has been successfully exported, the model is visible in the 'Document Control' pane. In this module, all previous versions exported to Vico Office is displayed, allowing the user to either activate or deactivate older models. The current active version is displayed in a 3D view as illustrated on the lowermost picture c.f. **Figure 4**.

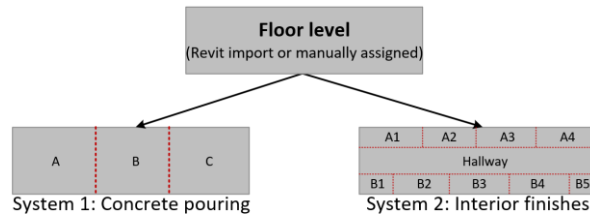


**Figure 4:** File export from Autodesk Revit 2018 (uppermost) to Vico Office (lowermost) via installed external tool command

The creation of locations is one of the most crucial parameters in Vico Office, as featured software modules are linked to these locations. For instance, scheduling is linked directly to assigned locations.

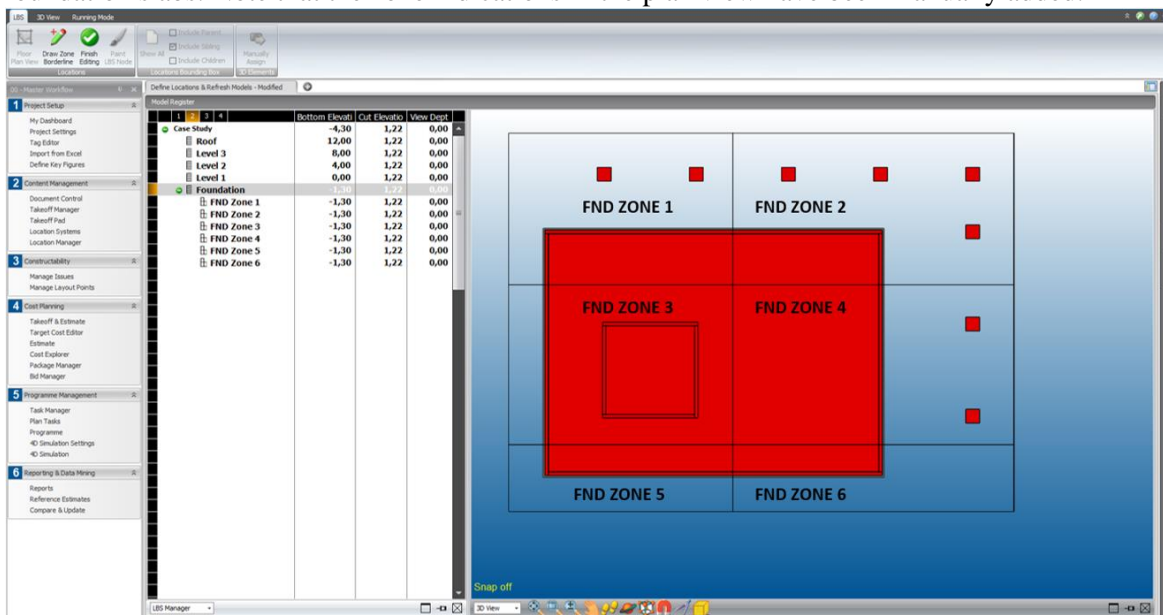
Moreover, quantity takeoffs are also location-based. Such takeoffs, along with cost estimation, can be used as an integrated part of the scheduling process to help generate an even more detailed schedule.

By using the 'Location Management' module, locations can be assigned to the active model version without having to go back to the original Revit model. Also, the software can automatically import Revit floor levels as locations, thereby automatically assigning all the 3D Revit elements modelled for each level. In addition to this feature, locations (and sublocations) can be combined with imported floor levels from Revit. Moreover, alternative location breakdowns can be introduced to create location systems based on the activity in the designated location as shown on **Figure 5**.



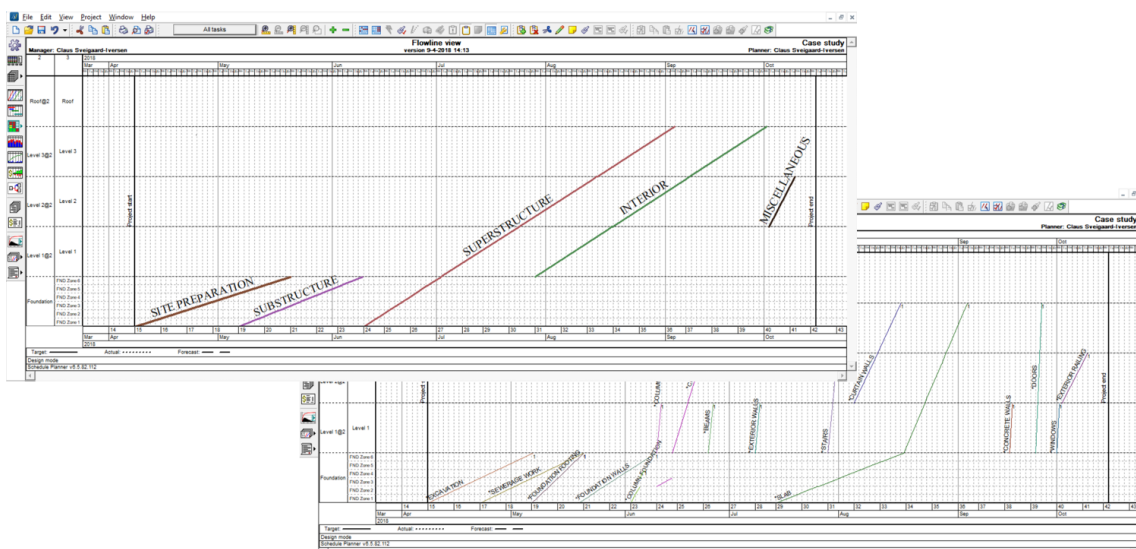
**Figure 5:** Concept of location systems in the 'Location Management' module

The concept of combining Revit floor levels with manual assigned zones is illustrated in **Figure 6**. The imported foundation level from the Revit model has been subdivided into six locations for concrete pouring of foundation slabs. Note that the zone indications in the plan view have been manually added.



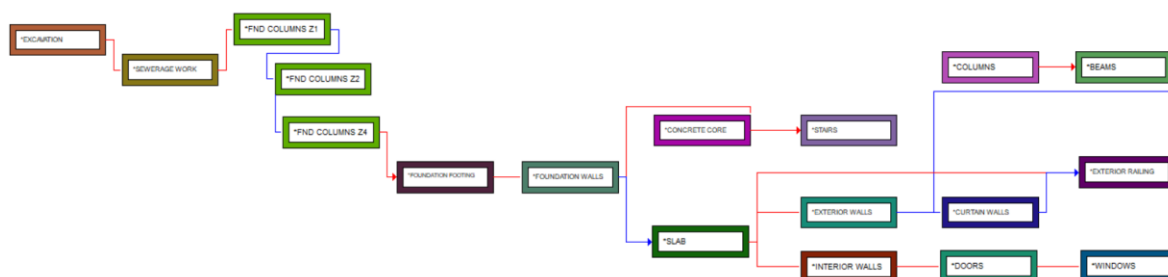
**Figure 6:** Location management in Vico Office

Under the 'Task Manager' module, tasks (activities) are created for later scheduling. This module can be used to establish a correlation between model-based quantities and user-defined production rates. The software uses 'Intelligent Task Durations' which calculates working hours required for completion of a specific task. If production rates are omitted, task durations can manually be modified in the 'Schedule Planner' software. An example of this is shown in **Figure 7**. Tasks without linked production rates are included in a location-based schedule by estimating the time consumption of each task. On the provided figure, locations are shown vertically and time horizontally. Workflow for the different tasks are then displayed throughout the locations. In **Figure 7**, higher task hierarchy levels (uppermost) are compared with lesser hierarchy levels (lowermost) allowing for a more simple or detailed view of the schedule.



**Figure 7:** Location-based flowline view of schedule in ‘Schedule Planner’ for different task hierarchy levels

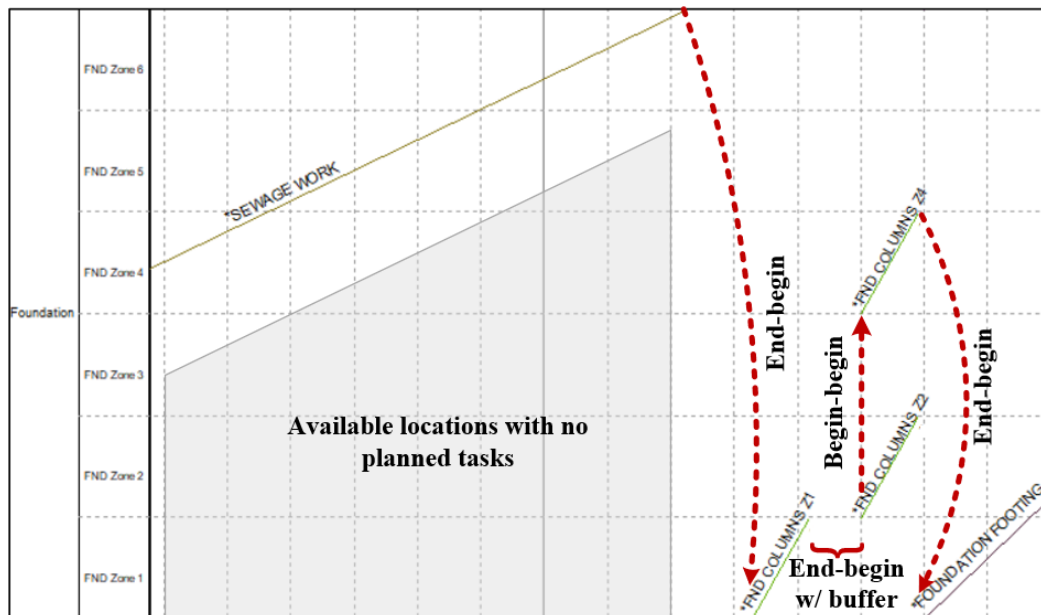
Defining scheduling logic and task dependencies, i.e. the work package connection, can be mapped by the ‘Network View’ of defined tasks in Schedule Planner. Within this view, tasks are represented as boxes. Work connections are created by dragging tasks on one another. The work connections can be edited between all tasks, thereby allowing for a mix between end-begin, begin-begin and end-end connections. The network mapping in Schedule Planner is shown in Figure 8.



**Figure 8:** Network view for mapping activity dependency

The influence of work connections is reflected directly in the schedule. An example of this is shown c.f. **Figure 9** for the foundation level, where ineffective use of locations is highlighted as well. Work connections can help avoid limitations throughout defined locations, as for instance an end-begin connection makes the successor task unable to begin before its predecessor is completed.

When the location-based schedule has been completed, 4D simulation is made possible via a 4D simulation tool in the Vico Office environment. Prior to simulation, similar tasks need to be assigned to 4D groups. Groups will be linked with a pre-defined behavior representation during simulation. Moreover, colors can be added to 4D groups which may help diversify simulated tasks. A color scheme legend can be activated during playback of the simulation to keep track of different tasks.



**Figure 9:** Location utilization and work connections in flowline view

#### 4. Discussion

The case in the following report reveals that LBS can prove to be a powerful tool to optimize and analyze task schedules. The flowline view provides an in-depth indication of tasks and workflow throughout defined locations. The schedule c.f. **Figure 7** clearly displays the different tasks undergoing at the assigned locations and location system (foundation level). By opting for this scheduling approach, task management is made easier since inefficient use of locations or potential interfering tasks, i.e. activities undergoing at the same location during the same time frame, can be easily spotted and improved upon.

However, the software does have several limitations in a scheduling perspective. Most significantly is the fact that it is running as an external application to the Autodesk Revit environment. As automated software interconnectivity between the BIM application and Vico Office is currently unavailable, any revised BIM models must be updated manually which, if not fulfilled carefully, can cause information sharing limitations and consequently confine multidisciplinary collaboration.

Takeoff-based schedules may become cumbersome due the vast number of parameters needed for scheduling. This way of scheduling is also relying heavily on precise production rates for assigned work crews, and if this part is not allotted a lot of attention then the scheduling outcome will become faulty. Determining production rates is difficult and often left as a personal assumption based on managerial experience, thus ultimately not reflecting the work crew's actual capabilities. To eliminate personal influence and refine the scheduling process, it would be beneficial to standardize production rates through a central database containing rates for different tasks. This concept has already been adopted in Finland, where production rates are based on numbers from national databases.

In addition to the potential downside of a quantity-based schedule is the built-in feature to extract takeoffs, as the software for some modelled families in Revit only counts the accumulating number of families, i.e. family units, within the project without calculating useful takeoffs such as surface area. In the case, this became clear as the modelled curtain wall construction was quantified as single families, e.g. mullions and panel glazing, thus the quantity takeoff mechanism was unable to deduce a total surface area for computation of work duration. This finding may indicate that the Vico Office software currently is restricted concerning quantity takeoffs for more complex modelled families, as the software is unable to detect any areas outlined by such elements. With increasing complexity in the AEC industry, the usage of such specialized families is expected to increase, thus it is crucial that the current software is improved in this field.

As also mentioned previously, the software is currently unable to automatically schedule all tasks related to modelled components in Revit. Therefore, initial tasks such as rebar and formwork prior to actual concrete casting of a slab component must be implemented manually in the schedule. As the LBS methodology is minded more for medium-large scale projects, such manual implementations and mapping of work connections can easily become extensive and time consuming.

A schedule is dynamic tool, thereby relying on constant managerial attention. If scheduled tasks are left unattended by not updating as-built information during the construction phase, task-dependencies (work connections) will cause project delays. Such as-built information could be digitalized and automated by integrating scanable radio-frequency identification technology into prefabricated construction components, allowing the schedule to be constantly updated regarding major project activities.

Vico Office introduces several scheduling tools that managers can take advantage of when creating a schedule, most noteworthy is the quantity takeoff feature. Though the overall work process and complexity of creating a schedule, for instance through mapping task connections, remains the same and is regardless of the scheduling software.

## 5. Conclusion

The aim of the present study was to review the possibilities and utilization of 4D BIM regarding location-based scheduling. Vico Office has been used as scheduling software with Autodesk Revit 2018 as the authoring BIM application. The review revealed that location-based scheduling provides great overview of multiple and complex scheduling information. This overview serves as a great tool to easily spot and optimize ineffective workflow, hereby avoiding interfering tasks. The possibility to create 4D visualization of a schedule can help different project stakeholders to better understand how different tasks at various locations may affect each other.

However, the review also showed that some of the current modules in the Vico Office software needs improvement to fully satisfy the BIM methodology. For instance, the quantity takeoff module should be modified so that special Revit families are included. Moreover, the implementation of 4D BIM requires a high level of model-based development to generate precise schedules.

Future improvement for Location-Based Scheduling would include a centralization or standardization of production rates to be incorporated in scheduling software. Also, real-time visibility of production, e.g. by utilizing Radio-frequency identification, would allow for a continuous visualization of the project during the construction-phase usable in comparison with the actual scheduled project.

## 6. References

- Akbaş, R. (2003). *Geometry-Based Modeling and Simulation of Construction Processes*,  
 Alamdar, S. (2013). *Location Based Scheduling in the Form of Flow Line and its Comparison to CPM/Bar Chart Scheduling*,  
 Andersson, N., & Christensen, K. (2007). Practical implications of location-based scheduling. Paper presented at the CME 25 Conference Construction Management and Economics, 1367-1376.  
 BIM Dictionary. (2015). Building information modelling. Retrieved from [http://www.refworks.com/refworks2/default.aspx?r=references|MainLayout::init#Zt-pNci2Rcih\\_OQxMP44|start](http://www.refworks.com/refworks2/default.aspx?r=references|MainLayout::init#Zt-pNci2Rcih_OQxMP44|start)  
 Büchmann-Slorup, R., & Andersson, N. (2010). BIM-based scheduling of Construction—A comparative analysis of prevailing and BIM-based scheduling processes. Paper presented at the Proceedings of the CIB W78 2010: 27th International Conference, 16-18.  
 Butters, C. (2004). A holistic method of evaluating sustainability. *Building and Urban Development in Norway*, , 34-39.  
 Chong, H., Lee, C., & Wang, X. (2017). A mixed review of the adoption of building information modelling (BIM) for sustainability. *Journal of Cleaner Production*, 142, 4114-4126.  
 European Commission. (2013). Progress by member states towards nearly zero-energy buildings.  
 European Commission. (2014a). 2030 energy strategy. Retrieved from <https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy>  
 European Commission. (2014b). A policy framework for climate and energy in the period from 2020 to 2030.  
 Exigo. (2015). Vico schedule planner. afsnit 5: Tilføj mængder til schdule planner. Retrieved from [https://www.youtube.com/watch?v=WccmvEIQJjg&index=5&list=PLUPg\\_nFMXAYe3NVJ0PTNRvkq\\_i1MWMU](https://www.youtube.com/watch?v=WccmvEIQJjg&index=5&list=PLUPg_nFMXAYe3NVJ0PTNRvkq_i1MWMU)  
 Exigo. (2016). Location based scheduling in vico office. Retrieved from <https://www.youtube.com/watch?v=P9J0MZgbKwM&t=1s>



- HOK Network. (2010a). The future of the building industry: Team organization. Retrieved from <https://www.youtube.com/watch?v=tfb5nK97DdQ>
- HOK Network. (2010b). The future of the building industry: The effort curve. Retrieved from [https://www.youtube.com/watch?v=9bUIBYc\\_GI4](https://www.youtube.com/watch?v=9bUIBYc_GI4)
- Intelligent BIM Solutions. (2014). 4D BIM scheduling for dummies vico software. Retrieved from [https://www.youtube.com/watch?v=5I4F4Ioqk7s&index=4&list=PLYA8QJiZWWhbYVjpnHUASyjkpI4\\_VT4w1&t=438s](https://www.youtube.com/watch?v=5I4F4Ioqk7s&index=4&list=PLYA8QJiZWWhbYVjpnHUASyjkpI4_VT4w1&t=438s)
- Intelligent BIM Solutions. (2015). Construction planning, preparation, control by using location based methodology. Retrieved from [https://www.youtube.com/watch?v=xBcQMwLN10&t=0s&list=PLYA8QJiZWWhbYVjpnHUASyjkpI4\\_VT4w1&index=5](https://www.youtube.com/watch?v=xBcQMwLN10&t=0s&list=PLYA8QJiZWWhbYVjpnHUASyjkpI4_VT4w1&index=5)
- Jongeling, R., & Olofsson, T. (2007). A method for planning of work-flow by combined use of location-based scheduling and 4D CAD. *Automation in Construction*, 16(2), 189-198.
- Josephson, P. (2005). Byggfel och andra icke värdeadderande aktiviteter. Paper presented at the Byggkostnadsforum Seminar: Från no-Tech Till Hi-Tech, Stockholm, Sweden,
- Jupp, J. (2017). 4D BIM for environmental planning and management. *Procedia Engineering*, 180, 190-201.
- Kamari, A. (2018). Lecture notes in integrated engineering project, aarhus university, department of engineering. collaboration for revit C4R. Unpublished manuscript. Retrieved 03/16,
- Keeble, B. R. (1988). The brundtland report: 'Our common future'. *Medicine and War*, 4(1), 17-25.
- Khan, E. A., Dewan, M. N. A., & Chowdhury, M. M. H. (2016). Reflective or formative measurement model of sustainability factor? A three industry comparison. *Corporate Ownership and Control*, 13(2), 83-92.
- Kirkegaard, P. H., Zandieh, M., Kani, I. M., & Hessari, P. (2016). Adoption of BIM systems in the AEC industry. *Il Ponte (Florence)*, 72(9 Part 1)
- Koo, B., & Fischer, M. (2000). Feasibility study of 4D CAD in commercial construction. *Journal of Construction Engineering and Management*, 126(4), 251-260.
- Krawczyńska-Piechna, A. (2015). A concept of an integrated construction planning system involving location-based scheduling technique. *Czasopismo Techniczne*,
- Lu, W., & Olofsson, T. (2009). A continuous flow simulation model for probability repetitive projects. Paper presented at the Nordic Conference on Construction Economics and Organisation: 10/06/2009-12/06/2009, , 1
- Marsh, R., Lauring, M., & Petersen, E. H. (2000). Arkitektur og miljø. form konstruktion materialer-og miljøpåvirkning.
- Pučko, Z., Šuman, N., & Klanšek, U. (2014). Building information modeling based time and cost planning in construction projects. *Organization, Technology & Management in Construction: An International Journal*, 6(1), 0-0.
- Roundtable, C. U. (2004). Collaboration, integrated information and the project lifecycle in building design, construction and operation. *Construction Users Roundtable (CURT)*, Cincinnati, OH,

## II

# Five Dimensional Building Information Modeling -- 5D BIM

*Mateusz Błoniarczyk*

### **Abstract**

Quality, time and cost are the three most important elements in any construction project. This paper examines the global issues and challenges facing the project cost management profession. This relates to professionals in the fields of quantity surveying, cost engineering, project controls and project managers providing cost management services. Observations are focused on the major factors that could affect the practicability of 5D BIM, including the modelling effort, insufficiently trained staff, poor collaboration between parties involved in the project, information output and limitations. Although 5D BIM is an emerging trend in the construction industry that integrates all the most important information starting from the initial design to the final construction stage it still has some obstacles to overcome but it has a tremendous potential to be implemented on companies on a wide scale. This research concludes that by digitizing the traditional processes such as quantification or cost estimation we can derive real-time data from the project, increase the productivity of the teams. Moreover we are able to understand the scope of the project more clearly and achieve shorter project cycles.

### **Key words**

BIM 5D, Cost Estimation, Schedule, Cost Manager, Quantity Surveyors



## 1. INTRODUCTION

A success of the construction project is affected by the management of quality, time and cost. However, the information generated during a construction project is often huge and inconsistent. Therefore the level of difficulty of the project is increased and misinterpretations and misunderstandings of the project results may occur.

Building Information Modelling (BIM) provides both opportunities and challenges for the project cost management profession. As quantification increasingly becomes automated and BIM models develop the role of the project cost manager will need to adapt accordingly to provide more sophisticated cost management services that incorporate 4D time and 5D cost modelling and sharing cost information or data with the project team as part of the BIM integrated project delivery approach.

## 2. RESEARCH FINDINGS AND DISCUSSION

### 2.1. BIM

BIM is a set of technologies, processes and policies enabling multi-stakeholders to collaboratively design, construct and operate a facility.

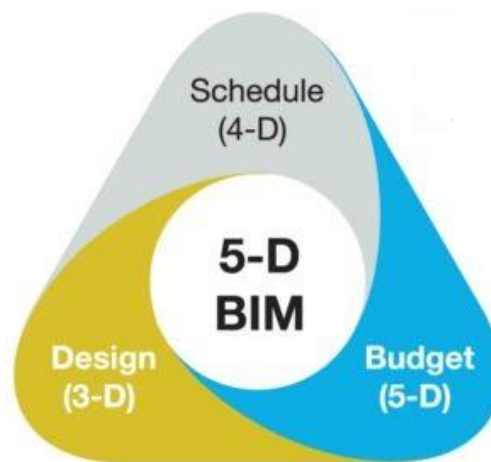


Figure 10 BIM 5D functionality

#### BIM 4D

The fourth dimension added to the traditional 3D-BIM model stands for ‘time’. This allows the 3D parts or assemblies inherent to a BIM model to be combined with a construction schedule. The resulting 4D model is capable of creating virtual simulations of building the BIM model. These simulations can be used to communicate the sequence of work to avoid rework in the construction industry as well identify, ahead of time any areas that may be congested due to too many trades being in one place at the same time.

#### BIM 5D

The fifth dimension added to the 4D-BIM model stands for ‘cost’. A 3D-BIM model has all the geometrical information needed to perform a take-off of material quantities. A 4D-BIM model has all the activities needed to complete the project. By attaching a cost database to the 4D-BIM model and by assigning actual costs to materials, equipment and personnel a 5D-BIM model can be created to provide the construction team with a useful tool. The implementation tools for applying BIM 5D model are relatively new and have only been available for about a decade.

The resulting 5D-BIM model can be used by construction professionals to give faster feedback about the cost of a project, allowing the designer to adjust the project design to fit the budget. The opposite scenario is often seen in the construction industry in that the project cost is estimated to be over what the owner can afford and consequently resulting in significant design changes and also perhaps losing the most attractive elements of the design. The 5D-BIM model can provide the owner and the design team with greater transparency in seeing the contractor's budget, building confidence within the various stakeholders of a project.

### 2.1.1. BIM technology development process

Development of information technology such as large data and cloud technology, then BIM technology allows us to integrate all the data of the construction project and realize the visualization management of the construction project life cycle management. Therefore, BIM technology is called the modern construction industry development of the second evolution.

BIM technology as the second revolution in the construction industry also indicates that the construction industry from design into the whole life cycle stage. The construction industry of the two technological revolution process shown in Fig. 2.

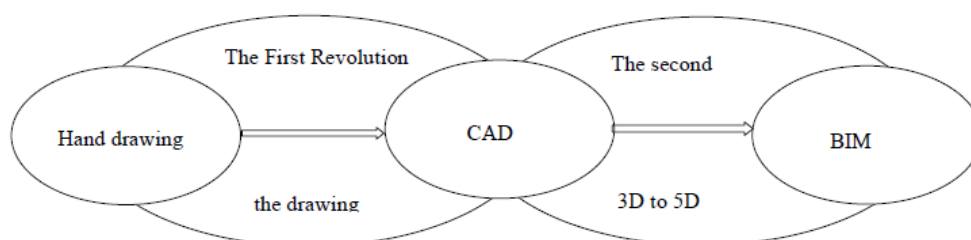


Figure 2 Information change in construction industry

### 2.1.2. Maturity Model

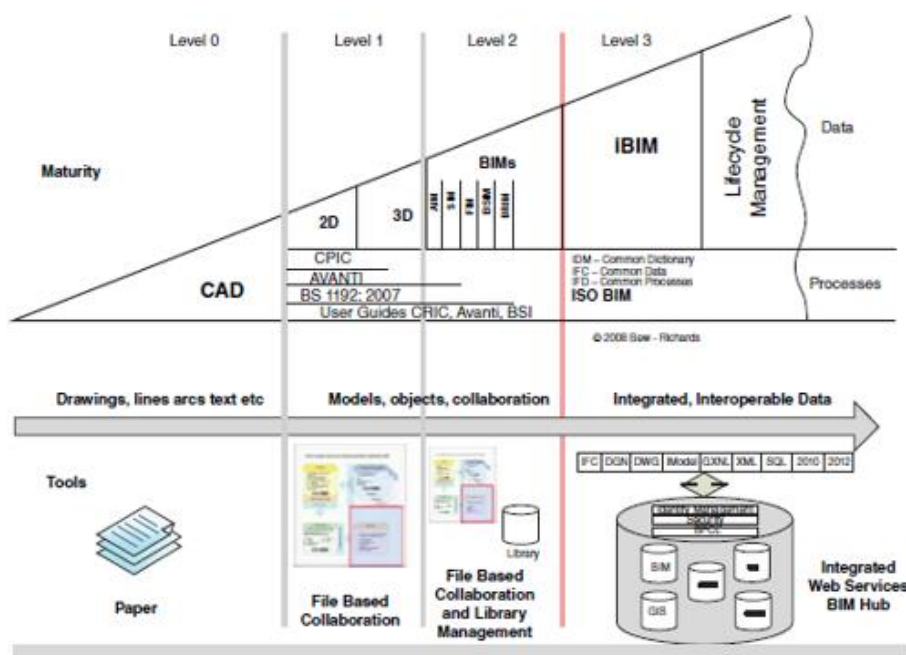
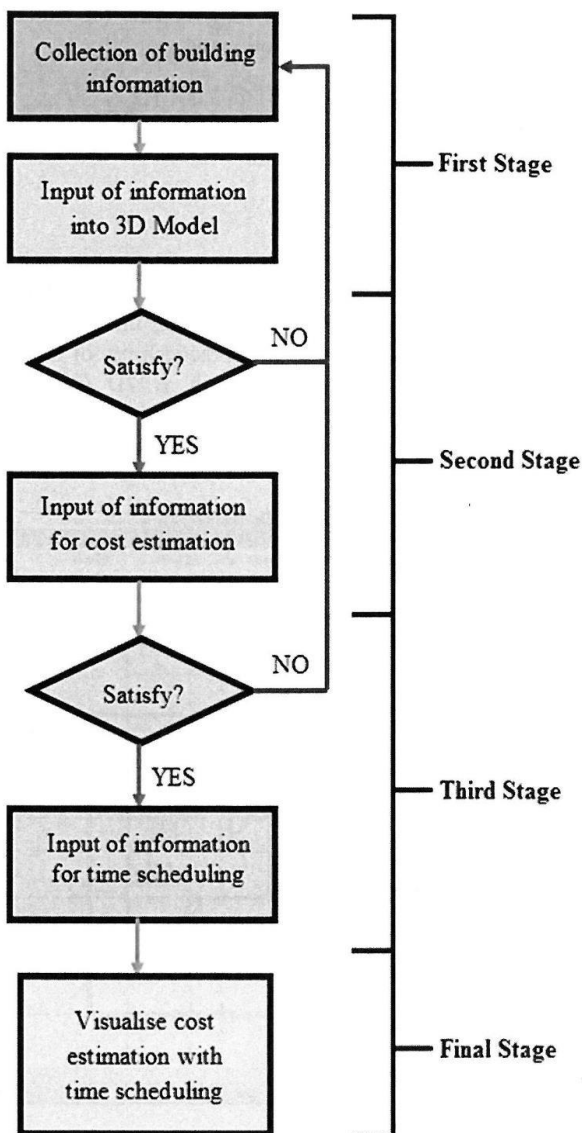


Figure 3 Bew-Richards maturity ramp

BIM 5D finds its place in the second level of maturity ramp of designing and project management. Well managed Level 2 programmes give credibility of the 20% savings we are seeing now on a repeated basis. Level 2 also has a significant benefit in that it has opened up the world of construction BIM data to many more people than ever before.



## 2.2. BIM 5D IMPLEMENTATION

### 2.2.1. Stages of practical 5D BIM approach

The first stage involves the collection and input of building information into 3D model. This process starts with clients briefing on their requirements that lead to an initial proposal. After creating architectural proposal the 3D model is made and other disciplines such as civil and structural engineering, mechanical and electrical engineering are incorporated. In 3D model the information specifying each component can be found.

After meeting the client's satisfaction about the initial design that comply to the specified requirements the second stage will take place. The information needed for cost estimation is added into the 3D model by quantity surveyors or cost engineers - which results in a cost estimation done by automatic quantification of building elements with unit price.

The third stage will proceed when the clients are happy with the previous stage. In this stage projects managers create Work Breakdown Structure for all types of construction activities. At this stage, all the necessary information is integrated as 5D BIM.

The final stage consists of visualizing and presenting 5D project components - project cost and time scheduling

Figure 4 5D BIM Process Flowchart

### 2.2.2. Two Main Aims to Implement 5D

- Firstly, it improves the productivity across a construction project by leveraging the value of accurate and complete information.
- Secondly, it can provide support to all the involved stakeholders so that all the issues across the life-cycle of a building can be managed well.

### 2.2.3. The main benefits of 5D BIM for owners and decision makers of a construction company are the following:

- 5D BIM helps build a database of cost and pricing, crew composition and labor productivity rates.

- 5D BIM helps get cost-loaded schedules, detailed analysis of project risks and accurate cash flow forecasts.
- It helps us understand how a change in the design of a project will influence the scheduling and budget of the project.
- With 5D BIM tools, the construction companies can compare multiple cost estimates with the target cost of project that helps take more informed decisions.
- It enables us to understand which areas of the construction work add to the total costs and how.

## **2.3. CHALLENGES OF BIM 5D IMPLEMENTATION**

### **2.3.1. Poor collaboration**

Collaboration between architects, engineers and design consultants can be a cumbersome process, because those different parties often don't provide full versions of their models to quantity surveyors, cost managers, contractors and so on. There are many reasons of doing that but the main one is that the designers don't want to take a potential responsibility of what will be done with their models, but also the firms don't want to give away their library of families. Due to providing the "information only" models to contractors and quantity surveyors the designers don't give them the possibility to work further with the model and implement BIM 5D. This lack of trust should be averted and show that collaboration can provide for all parties. For example, the more details quantity surveyor gets the more errors/clashes can be identified and the reported back to the designer for correction

### **2.3.2. Excessive cost for investors**

To derive the maximum benefit of BIM models, the models need to be rich in information with comprehensive and accurate data. This often requires modelers to have extensive knowledge on the part and spend a big amount of time on creating it. On many projects the BIM model has too little potential due to incomplete/inaccurate data. It usually happens because many clients do not see the value in paying the additional fees for comprehensive models or may not have sufficient knowledge to know whether this has been achieved or not.

### **2.3.3. Outsourced subcontractors**

Usually a big part of the work on construction projects is outsourced to subcontractors. Therefore the scheduling of construction activities depends on having the information about the productivity rates of subcontractor's crews. Since some subcontractors not always are willing to share this information with the construction team, there are no assurance that the necessary number of workers would be sent on site on a given day especially since subcontractors themselves sometimes try to simultaneously meet obligations on multiple projects. For this reason the schedule update and coordination with various trades is complicated. However, it should be remembered that such things happen regardless of whether 5D-BIM is implemented or not.

## **2.4. COST ESTIMATION**

The accuracy and precision of cost estimation at the early stages of construction projects is very important, because cost estimations are usually significant for making decisions. Errors in estimation may lead to huge cost overrun and project delay. Estimates in early phase of the project are the key factors in business decisions and usually they are the foundation for a project's ultimate funding. Although the cost estimation is a really important player in the business, due to deficiency of information at the beginning of the construction process, it is neither simple nor straightforward. That information gap can be reduced by applying 5D BIM for controlling project financing and cash flow more effectively. Furthermore using traditional 2D solutions take much more time to obtain cost planning advice and it constraints comparative analysis within allocated time frame for the design development process. By implementing BIM 5D the cost manager can do all the above quickly, as

many times as it is needed and in a complex combination. It is also much easier to re-estimate the developing project every time it is needed and provide a feedback about estimate variances and corrective suggestions.

The traditional way of estimating and cost trending is for the contractor to get PDFs or printed drawings of each deliverable in order to manually take off (estimate) the work and reach out to the subcontractor community for numbers. The main issue with this type of data transfer strategy is that as soon as the architect or engineer clicks ‘print’, you are already looking at old information, because the changes in the design will be constantly implemented, no matter if the general contractor has already reviewed the documents or not. The only thing that is current is the model, because it is producing the documents. To truly understand how the design is trending, estimators must leverage the model information.

## **2.5. SOFTWARE**

There is a various BIM software available in the market. The Autodesk Revit 2018 was used to create a 3D model of the. To create BIM project estimate or schedule there are many kinds of software that could be used and combined together, such as ArchiCAD, Bentley Architecture, Digital Project Microsoft Project, Primavera, CostX, Autodesk Navisworks, Sigma Estimates, VICO and so on.

The Autodesk Revit is a good choice as a modelling tool because it is able to multidisciplinary integration and configurable automation, which is very important for 5D workflow.

## **2.6. Expert intervention still required while estimating cost in 5D BIM.**

As we know fifth dimension BIM is an emerging technology helps for cost estimation in construction industry. Certainly, No BIM tool can be self-reliant or self-sufficient – it is only as good as the experts who use it.

Expert engineers or cost estimators (i.e. 3D modeler, project planners, project scheduling experts, etc.) can understand the challenges and problems that are beyond technology. Hence, with efficient use of BIM can accurately track the cost changes as the project progresses. In addition, 5D BIM makes it easy to estimate the changes in expenditure, as the design or project schedules are altered. Vico Office product manager Duane Gleason said that on average you can extract about 65 percent of the estimate from an architect or engineer’s model. To reduce the 35 percent risk, some companies create their own parallel model as they receive information from the architect and engineer to ensure the model is accurate for estimating – this approach an additional spends though.

### **2.6.1. The quality of quantity documentation**

The quality of the documentation is critical to the development of correct quantities. This issue has existed long before the introduction of electronic documentation. In the traditional paper based documentation (2D) the days were spent on studying of the drawings and queries to correct design information errors and inconsistencies. Although in 3D environment the time spent on measuring is much smaller which is a big advantage, there are also some drawbacks. The understanding of the documentation details might be dramatically smaller.

Another drawback is that there is also a new generation of young quantity surveyors who don’t have solid fundamental training in 2D paper-based measurement and due to lack of expertise and experience there may be difficulties with identifying problems in CAD/BIM models as they might have done in the 2D environment. For this reason there is a major problem of not trusting the automatic quantities produced due to quality issues with the model. Moreover, if quantity surveyors are not completely familiar with the software such problems may also occur.



### 2.6.2. Education and training

A young staff may be proficient in the use of BIM models and various software associated but its fundamental knowledge of basics of the profession (construction/services technology knowledge, measurement principles etc.) is often poor. Education and training in BIM environment is still required and that's why universities has started conducting courses in this area to help the graduates enter the industry with at least foundation knowledge of BIM and show how to use associated software and digital tools. On the other hand, experienced older staff often struggles with this new technology. The best solution to overcome the gap between these two generations of workers is to team them up wherever possible so that they can work together and help one another to balance their deficiencies in knowledge/expertise and eventually lead to long term continual growth amongst themselves.

## 3. CONCLUSION

The research paper shows that making a processes such as quantification more automated we can significantly lower the time spent on technical processes thus we can provide more sophisticated management services. Although in electronic environment it can be done much faster than in standard (2D) approach, the documentation still needs to be checked by experts for errors and inconsistencies. However To identify problems of produced quantities, the experience, expertise and intuition is required. Nowadays the cost manager should be a 5D cost manager using electronic models and software to provide detailed 5D estimates and living cost plans in real time. The cost managers provide a tremendous value by their cost planning role at the conceptual phase of a project by providing cost advice and estimates plenty design proposal and the refining those estimates throughout the evolving of the design.

Digitizing the process has brought a clear methodology based on traditional techniques, which in itself brings benefits. We now have the opportunity to build the building twice, first in a virtual shared model and then as a physical artefact which leads us to have a possibility to plan the process of construction within the virtual model before getting onto the site. There should not be any surprises any more. We are now able to reduce the number of clashes; finalize design information and get it signed off by all stakeholders prior to starting production; run through the effective delivery of the building before any physical work starts; agree timescales and costs with a high degree of certainty; and be certain of the intended design quality.

In the current market not many companies use 5D-BIM because of a limited number of staff knowledgeable enough in this area nevertheless it is hoped more construction professionals will be trained and implementing it on future projects.

## REFERENCES

- Anoop Sattineni, J. A. (2014). 5D-BIM: A CASE STUDY OF AN IMPLEMENTATION STRATEGY IN THE CONSTRUCTION INDUSTRY.
- Brad Hardin, D. M. (2015). *BIM and Construction Management. Proven Tools, Methods and Workflows* . Canada: Wiley.
- Darius Migilinskasa, V. P. (2013). The Benefits, Obstacles and Problems of Practical Bim Implementation. *Elsevier*, (pages 767-774).
- Eynon, J. (2016). *Construction Manager's BIM Handbook* . WILEY Blackwell .
- Holzer, D. (2015). *The BIM Manager's Handbook: Guidance For Professionals in Architecture, Engineering and Construction. Best Practice BIM* . John Wiley & Sons Ltd .

- Rafael Sacks, S. K. (2018). *Building Lean, Building BIM*. New York: Routledge.
- Smith, D. P. (2014). BIM & the 5D Project Cost Manager. *Elsevier*, (pages 475-484).
- Smith, D. P. (2014). Project Cost Management – Global Issues and Challenges. *Elsevier*, (pages 485-494).
- Smith, P. (2015). Project cost management with 5D BIM. (pagee 193-200). Westin Playa Bonita, Panama: Elsevier.
- Xia Shen Lee, C. W. (2016). 5D Building Information Modeling - A Practicability Review . *MATEC Web of Conferences*.
- Xu, J. (2016). Research on Application of BIM 5D Technology in Central Gran Project. *13th Global Congress on Manufacturing and management, GCM* (pages 600-610). Elsevier.
- <https://geniebelt.com/blog/5d-bim-in-construction>.
- <https://sigmaestimates.com/news/aarsleff-guarantees-accurate-price-calculations-with-5d-bim-vdc/>.
- <https://sigmaestimates.com/news/bim-makes-a-massive-impact-at-schmidt-hammer-lassen-architects/>.
- <https://sigmaestimates.com/news/ramboll-in-bim-vdc-offensive-signs-global-agreement-with-sigma-estimates/>.
- <https://www.truecadd.com/bim-cost-estimation.php>.
- <https://www.truecadd.com/news/benefits-of-4d-5d-bim-to-general-contractors-across-construction-projects>.
- <https://www.truecadd.com/news/bim-5d-to-fabrication-building-smart-construction-capabilities>.
- <https://www.truecadd.com/news/construction-design-engineers-should-adopt-autodesk-revit-to-meet-stringent-project-deadlines-market-demands>.
- <https://www.truecadd.com/news/how-5d-bim-fuels-the-growth-of-construction-industry>.



### III

## Using BIM as a tool to decrease variation in quantity and optimize the workflow of generating a cost estimation

*Jonas Kjems Christensen*

### Abstract

The focus of this research is to study the use of Building information modelling (BIM) for decreasing variation in quantities and creating more precise cost estimations. A cost estimation and the bill of quantity forms the basis for the cost of each construction project, so the precision of this from an early stage is important. The research includes a literature review to briefly find the state of the art of BIM in this construction management area and an interview with a Danish construction management firm will further explain the position in Denmark. Two different software applications were examined in regard to enhancing the process of generating a precise and quick cost estimation, which showed promising from many perspectives. The main focus is the ability to instantly update any cost estimation or bill of quantity with any change made in the 3D-model, which greatly reduces tedious tasks from traditional methods. The research showed many benefits of using BIM for estimation and generating lists of quantities and costs. However, some challenges were spotted in the form of actors in AEC industry being unwilling to adapt to BIM and see the benefits. It is a conservative industry where change happens slowly, but there is proof that the BIM users can see the positive effects and is eager to continue using BIM.

### Key words

Construction management, BIM, Bill of quantities, Dynamo, Vico Office

## 1. Introduction

When considering changes in a construction project, the effect on the economy is a huge factor and is often the dispute subject between the owner and a contractor. One of the many reasons how changes affect the economy, is in the bill of quantities and the unit prices that is agreed upon in the procurement process. Long, R. J. (2013) states that owners often seek to change the design and change quantities in an effort to realize cost savings. On the other side contractors take risks with unit pricing contracts. Often the unit prices are tactically applied to increase the potential profit when expecting expensive quantities to increase and the cheaper quantities to decrease as the project matures.

The benefits of BIM have been discovered by many and Azhar, Khalfan & Maqsood (2012) explains how (BIM) can improve the collaboration between all actors of a construction project, compared to traditional methods. This increased collaboration can improve the relationship between the owner and the contractors, which will make tackling dispute easier. Another benefit of BIM according to Azhar et al. (2012) is the contractors ability to perform more accurate quantity surveys and prepare more detailed estimates. The more detailed cost estimations will in return help the owner take a quick and well-informed decision in the procurement process.

In order to achieve this purpose, the study starts by reviewing literature regarding the use of BIM for cost estimation and quantity validation. An interview will be performed with a consulting firm in Denmark, that specializes in using BIM for multiple purposes throughout the construction project phases. In addition, Vico Office and Dynamo, which is tools used to enhance the use of the BIM-model, will be investigated to see if this improves the process.

## 2. Methods

The research is a combined literature review and a field research, as the objective is to answer the research questions formulated based on preliminary research. The research explores the use of BIM tools in relation to the bill of quantities and the cost estimation between the owner and the contractor of a construction project. The literature review seeks to understand the state of the art to understand the benefits and challenges with using BIM tools in the relation to the creation and when maintaining a bill of quantity. Furthermore, the current practical use and possible future steps will be discovered by interviews with employees at Exigo, which is a construction management firm in Denmark, that specializes in project management software application.

By finding the state of the art requires a quantitative analysis of the literature found in the field of study, which can give a good generalized output. Because this field is quickly evolving a lot of information can be outdated very quickly and therefore, a qualitative analysis is performed in the form of the interview. This can verify or reject the information gathered from the quantitative analysis and give a professional opinion on the benefits of using BIM-models and BIM related software.

Subjects around the cost estimation will be discussed to achieve a higher degree of understanding of how BIM has an effect on different processes of the construction phases, and that every aspect influences the precision and cost of a construction project. A small reflection to the greater picture of BIM is required to explain the difficult situation the use of BIM for quantities and cost estimation is in.

To find the most optimal way to generate a cost estimation Dynamo and Vico Office will be examined in this research. These are two different tools to assist in handling a 3D-model. Dynamo is a free open source application for Revit, and Vico Office is a product of Trimble with a requirement of a paid license. A small comparison of the two methods will be discussed to see if any of these tools can decrease the time taken to generate a cost estimation and improve the accuracy.

## 3. Results

### 3.1. BIM

Building information modelling (BIM) is not the actual 3D-model, but the process of the development of the 3D-model and the use of it. The BIM processes include the planning, design, construction and operation of the facility which is represented in the 3D-model. (Azhar, Michael & Blake, 2018)

#### 3.1.1. BIM in general

Azhar et al. (2018) argues that the 3D-model can be used in many aspects and for many purposes, which requires it to be data-rich, object-oriented and intelligently representing the facility. This model can then

provide users with different views and data which can be used for analysing to generate information that can be used to make decisions and improve processes.

The difference when using a 3D computer generated model compared to the older 2D computer generated model, is the quantity of data that the model can contain, apart from the more visual aspect. The model can now contain information about the materials, sizes quantities needed of individual items and much more. In short, the 3D model can be used to demonstrate the entire building life cycle and as a result the quantities and shared properties of materials and elements can be extracted for analysis and other use. (Azhar et al. 2018).

The BIM has many applications in the Architecture, Engineering and Construction (AEC) industry. Azhar, S. (2011) outlines the many applications as follows:

- Visualisation: 3D renderings can be generated with little effort from the best angles to showcase the project for many different purposes.
- Fabrication drawings: All the different work drawings can be generated with very little effort and updates when the project changes.
- Code reviews: Officials can use the model to quickly approve the building before completion.
- Cost estimation: BIM software has the possibility to generate detailed cost estimates and updates with any change in the project.
- Conflict, Interference and collision detection: A 3D-model is a way to spot and prevent future conflicts by having a model to scale. An example could be pipes clashing in the line with ventilation ducts, which is an expensive challenge to handle on-site.

Azhar, S. (2011) mentions other great benefits that the BIM can bring to the AEC industry, and in this research the cost estimation and the use of BIM for its data will be the main focus. The detailed cost estimation that is referred to are estimations containing information of every element in a building. Whereas the traditional method could be pricing by square meter.

### 3.1.1. BIM data extraction for properties of elements

There are several ways to extract data from a 3D-model generated in the BIM process, which depends on the software used. The most commonly used CAD program in Denmark is Revit which is the program this research will take outset in. Revit has built in schedules to extract data from different categories, as illustrated by figure (1). This kind of schedule can provide all the data properties that has been entered in the model about the element, in this case a door schedule has been created. Figure (1) shows the name, numbers, height, width, thickness and the level of the doors, but this can be manipulated to the individual's needs. This schedule can then further be exported to other a program which can handle large data quantities such as excel, which is a common software for cost estimation and bill of quantities.

<Door Schedule>							
A	B	C	D	E	F	G	H
Level	Family	Type	Keynote	Mark	Height	Width	Thickness
<b>Level 1</b>							
Level 1	M_Door-Exterior-Dou	311001_Exterior Double Door_Wood_2000x2500mm	311001	1	2.48 m	1.95 m	0.04 m
Level 1	M_Door-Exterior-Dou	311001_Exterior Double Door_Wood_2000x2500mm	311001	2	2.48 m	1.95 m	0.04 m
Level 1	M_Door-Exterior-Dou	311001_Exterior Double Door_Wood_2000x2500mm	311001	3	2.48 m	1.95 m	0.04 m
Level 1	M_Door-Exterior-Dou	311001_Exterior Double Door_Wood_2000x2500mm	311001	4	2.48 m	1.95 m	0.04 m
<b>Level 3</b>							
Level 3	M_Door-Interior-Doubl	321001_Interior Double Door_Wood_2000x2000mm	321001	5	2.00 m	2.00 m	0.04 m
Level 3	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	6	2.30 m	0.90 m	0.05 m
Level 3	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	7	2.30 m	0.90 m	0.05 m
Level 3	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	8	2.30 m	0.90 m	0.05 m
Level 3	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	9	2.30 m	0.90 m	0.05 m
Level 3	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	10	2.30 m	0.90 m	0.05 m
<b>Level 4</b>							
Level 4	M_Door-Interior-Doubl	321001_Interior Double Door_Wood_2000x2000mm	321001	11	2.00 m	2.00 m	0.04 m
Level 4	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	12	2.30 m	0.90 m	0.05 m
Level 4	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	13	2.30 m	0.90 m	0.05 m
Level 4	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	14	2.30 m	0.90 m	0.05 m
Level 4	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	15	2.30 m	0.90 m	0.05 m
Level 4	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	16	2.30 m	0.90 m	0.05 m
<b>Level 5</b>							
Level 5	M_Door-Interior-Doubl	321001_Interior Double Door_Wood_2000x2000mm	321001	17	2.00 m	2.00 m	0.04 m
Level 5	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	18	2.30 m	0.90 m	0.05 m
Level 5	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	19	2.30 m	0.90 m	0.05 m
Level 5	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	20	2.30 m	0.90 m	0.05 m
Level 5	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	21	2.30 m	0.90 m	0.05 m
Level 5	M_Single-Flush	321002_Interior Single Door_Wood_900x2300mm	321002	22	2.30 m	0.90 m	0.05 m

**Figure 11.** Example of Revit door schedule

The schedules from Revit update with every change that is made in the 3D-model, which means that there is no need to create a new schedule each time a change is made. However, if anything was exported to excel, a new extraction is required. These tasks can be tedious as there many different categories of elements which

must have a schedule each. This leads to the use of more specialised software for construction management use.

Another way to manipulate 3D-models can be with programs like ‘Dynamo BIM’. Dynamo allows the user to use programming to design and change the model. The primary use is parametric design of 3D-models. However, for construction management it can also find use, as it can use the underlying database of the model to import and export data. As Dynamo is based on visual programming, it is easy for non-programmers to use and create ‘scripts’ that can be reused. Figure (2) shows a Dynamo script that can export all elements and the given properties onto an excel sheet. This compared to Revit schedules is a lot faster and more automated as it only requires one press of a button to re-export the data when changes have been made to the model.

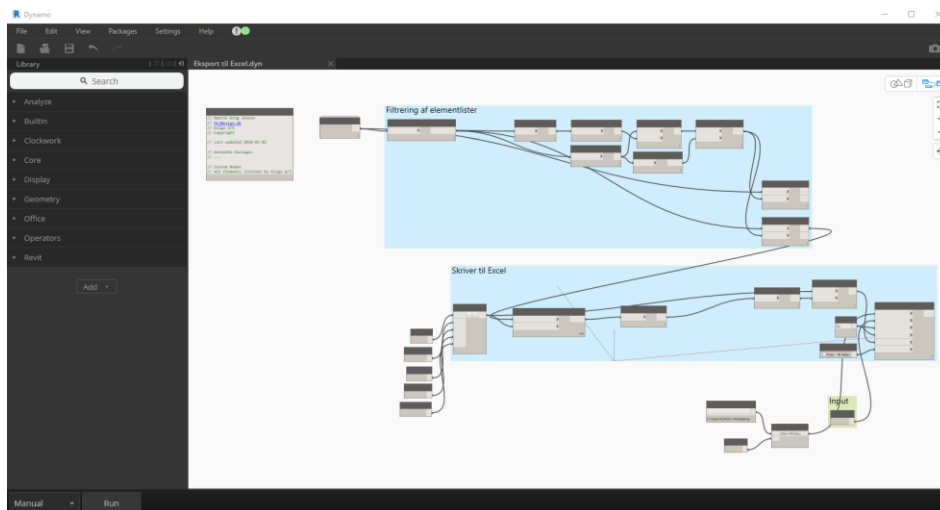
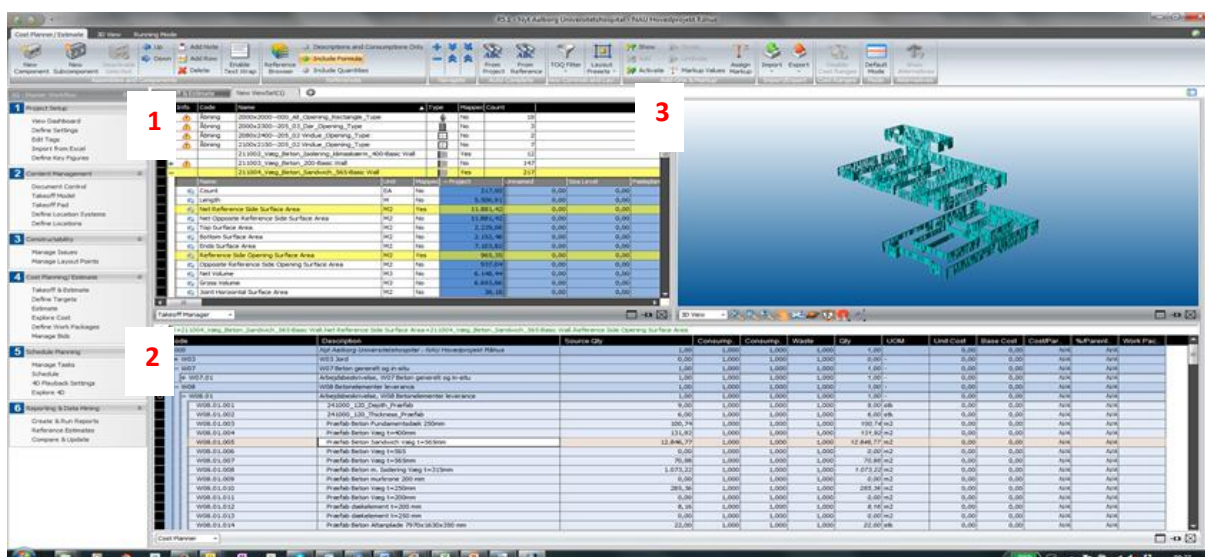


Figure 12. Dynamo script to export elements and all the wanted properties to excel

Exigo is a Danish construction management firm which specialises in the use of BIM. Exigo utilises a software called Vico Office (VO), which is a package solution for model checking, cost estimation, quantity estimation and much more. This program can import several Revit files into the same project file, which is a good tool for larger projects. Often a 3D-model is split into smaller files because of different architects and engineers having a contract on different parts of the project. This can mean that there is a model for architecture, structural, plumbing, electric and more. By combining these models in VO, it allows for a larger perspective of the model’s buildability and element properties. Figure (3) shows an example of a quantity take-off list from VO. This allows the user to locate the elements directly in the 3D-model and the properties of these. These lists update every time a Revit file is updated into the VO database.



Item	Description	Quantity	Unit	Cost
1	2000x2000-2000_A1_Opening_Overhang_Type	6	m	30
2	2000x2000-2000_21_2m_Opening_Type	6	m	30
3	2100x2100-2000_22_Vindue_Opening_Type	1	m	10
4	2100x2100-2000_23_Vindue_Opening_Type	1	m	10
5	2100x2100-2000_24_Vindue_Opening_Type	1	m	10
6	2100x2100-2000_25_Vindue_Opening_Type	1	m	10
7	2100x2100-2000_26_Vindue_Opening_Type	1	m	10
8	2100x2100-2000_27_Vindue_Opening_Type	1	m	10
9	2100x2100-2000_28_Vindue_Opening_Type	1	m	10
10	2100x2100-2000_29_Vindue_Opening_Type	1	m	10
11	2100x2100-2000_30_Vindue_Opening_Type	1	m	10
12	2100x2100-2000_31_Vindue_Opening_Type	1	m	10
13	2100x2100-2000_32_Vindue_Opening_Type	1	m	10
14	2100x2100-2000_33_Vindue_Opening_Type	1	m	10
15	2100x2100-2000_34_Vindue_Opening_Type	1	m	10
16	2100x2100-2000_35_Vindue_Opening_Type	1	m	10
17	2100x2100-2000_36_Vindue_Opening_Type	1	m	10
18	2100x2100-2000_37_Vindue_Opening_Type	1	m	10
19	2100x2100-2000_38_Vindue_Opening_Type	1	m	10
20	2100x2100-2000_39_Vindue_Opening_Type	1	m	10
21	2100x2100-2000_40_Vindue_Opening_Type	1	m	10
22	2100x2100-2000_41_Vindue_Opening_Type	1	m	10
23	2100x2100-2000_42_Vindue_Opening_Type	1	m	10
24	2100x2100-2000_43_Vindue_Opening_Type	1	m	10
25	2100x2100-2000_44_Vindue_Opening_Type	1	m	10
26	2100x2100-2000_45_Vindue_Opening_Type	1	m	10
27	2100x2100-2000_46_Vindue_Opening_Type	1	m	10
28	2100x2100-2000_47_Vindue_Opening_Type	1	m	10
29	2100x2100-2000_48_Vindue_Opening_Type	1	m	10
30	2100x2100-2000_49_Vindue_Opening_Type	1	m	10
31	2100x2100-2000_50_Vindue_Opening_Type	1	m	10
32	2100x2100-2000_51_Vindue_Opening_Type	1	m	10
33	2100x2100-2000_52_Vindue_Opening_Type	1	m	10
34	2100x2100-2000_53_Vindue_Opening_Type	1	m	10
35	2100x2100-2000_54_Vindue_Opening_Type	1	m	10
36	2100x2100-2000_55_Vindue_Opening_Type	1	m	10
37	2100x2100-2000_56_Vindue_Opening_Type	1	m	10
38	2100x2100-2000_57_Vindue_Opening_Type	1	m	10
39	2100x2100-2000_58_Vindue_Opening_Type	1	m	10
40	2100x2100-2000_59_Vindue_Opening_Type	1	m	10
41	2100x2100-2000_60_Vindue_Opening_Type	1	m	10
42	2100x2100-2000_61_Vindue_Opening_Type	1	m	10
43	2100x2100-2000_62_Vindue_Opening_Type	1	m	10
44	2100x2100-2000_63_Vindue_Opening_Type	1	m	10
45	2100x2100-2000_64_Vindue_Opening_Type	1	m	10
46	2100x2100-2000_65_Vindue_Opening_Type	1	m	10
47	2100x2100-2000_66_Vindue_Opening_Type	1	m	10
48	2100x2100-2000_67_Vindue_Opening_Type	1	m	10
49	2100x2100-2000_68_Vindue_Opening_Type	1	m	10
50	2100x2100-2000_69_Vindue_Opening_Type	1	m	10
51	2100x2100-2000_70_Vindue_Opening_Type	1	m	10
52	2100x2100-2000_71_Vindue_Opening_Type	1	m	10
53	2100x2100-2000_72_Vindue_Opening_Type	1	m	10
54	2100x2100-2000_73_Vindue_Opening_Type	1	m	10
55	2100x2100-2000_74_Vindue_Opening_Type	1	m	10
56	2100x2100-2000_75_Vindue_Opening_Type	1	m	10
57	2100x2100-2000_76_Vindue_Opening_Type	1	m	10
58	2100x2100-2000_77_Vindue_Opening_Type	1	m	10
59	2100x2100-2000_78_Vindue_Opening_Type	1	m	10
60	2100x2100-2000_79_Vindue_Opening_Type	1	m	10
61	2100x2100-2000_80_Vindue_Opening_Type	1	m	10
62	2100x2100-2000_81_Vindue_Opening_Type	1	m	10
63	2100x2100-2000_82_Vindue_Opening_Type	1	m	10
64	2100x2100-2000_83_Vindue_Opening_Type	1	m	10
65	2100x2100-2000_84_Vindue_Opening_Type	1	m	10
66	2100x2100-2000_85_Vindue_Opening_Type	1	m	10
67	2100x2100-2000_86_Vindue_Opening_Type	1	m	10
68	2100x2100-2000_87_Vindue_Opening_Type	1	m	10
69	2100x2100-2000_88_Vindue_Opening_Type	1	m	10
70	2100x2100-2000_89_Vindue_Opening_Type	1	m	10
71	2100x2100-2000_90_Vindue_Opening_Type	1	m	10
72	2100x2100-2000_91_Vindue_Opening_Type	1	m	10
73	2100x2100-2000_92_Vindue_Opening_Type	1	m	10
74	2100x2100-2000_93_Vindue_Opening_Type	1	m	10
75	2100x2100-2000_94_Vindue_Opening_Type	1	m	10
76	2100x2100-2000_95_Vindue_Opening_Type	1	m	10
77	2100x2100-2000_96_Vindue_Opening_Type	1	m	10
78	2100x2100-2000_97_Vindue_Opening_Type	1	m	10
79	2100x2100-2000_98_Vindue_Opening_Type	1	m	10
80	2100x2100-2000_99_Vindue_Opening_Type	1	m	10
81	2100x2100-2000_100_Vindue_Opening_Type	1	m	10

Figure 13. Vico Office workspace (1) Quantity take-off list (2) Cost planner (3) 3D-visualisation

Figure (3) showcases at 1. the quantity take-off list which contains all the different element types and the quantities related to this element type. 2. shows a cost estimator, where elements can be added once or several types depending on the purpose of the estimation, the prices calculated in this estimator is updated with every change made in Vico Office or when an updated Revit Model is uploaded into Vico Office. 3. Shows the 3D-visualisation of the activated models.

Vico Office allows the user to select an element type on any list and the elements locations will be highlighted on the other lists or 3D-visualisation. This allows the user a quick overview of the different elements in a very large model.

To summarise and compare the two softwares, Dynamo is a very good free option for the user that can experiment and write scripts for every project and every demand. Vico Office is a whole package product that delivers many aspects to construction management, also more than quantities and cost estimation. So if only looking at efficiency for creating a cost estimation it is presumed that Dynamo is a good option for the user who is not afraid to research and develop and learn the program. Where as Vico Office is a very user-friendly program compared to Dynamo and can be expanded to help with even more aspects of the projects.

### 3.2. Actors in the construction projects

In a construction project there are a few different actors who share the same goal, but often have different mind set of how to get there. The owner wants to have the best possible building standing the fastest possible for the lowest budget, which is often an impossible feat and some sacrifices must be made to achieve the best desired result. To help achieve this goal the owner hires an architect and engineering team which designs, plans and makes the 3D-model, but these actors also have to earn their pay for the work that they complete, so any changes or tedious tasks, costs money. On the otherside an contractor will try to get as much money as possible to erect the building.

When dealing with many different actors in a construction project, there is in the AEC in Denmark according to Exigo still a need to mature with the task of using BIM. Not all actors on both sides can see the benefits that technology and BIM in general can bring to construction projects, and many see these as hinderances for their old traditional methods. Henrik, who is a project manager at exigo and a part of the research and development projects from Exigo, states that the AEC is a very conservative industry and is on the technology area a lot behind other industries. Henrik compares the 3D-model details with the detail level of factories and their machine components, where screws and bolts are illustrated and counted as an element.

Henrik emphasizes that the different actors in the industry most have a common understanding and agreement upon starting a project with their expectations of the use and implementation of BIM, for the project to succeed.

#### 3.1.1. The Danish regulations

In the Danish agreement regulations (AB92) §14 states that the owner can demand change in the work, when it is categorised as a 'natural' change. §14 pcs. 3 states that changes made after contracting to unit prices can only affect the contracting price by +/- 15 % and within +/- 100 % of the individual posts on the bill of quantities used for cost estimation signed upon contracting.

Long, R. J. (2013) includes a court statement about a bid where the contractor changed the unit prices strategically to earn more money in the end. "Such a bid, it is explained, is one in which the contractor allocates a disproportionate share of indirect costs and anticipated profit to the unit prices bid for those items on which he anticipates an overrun; the object being to reap over generous profits should the anticipated overruns materialize." (Long, R. J., 2013). Such a practice can backfire and end up reducing the contractor's profit.

The danish regulations are written to prevent a large scale of this practice and reduce the consequences if this was to be the case.

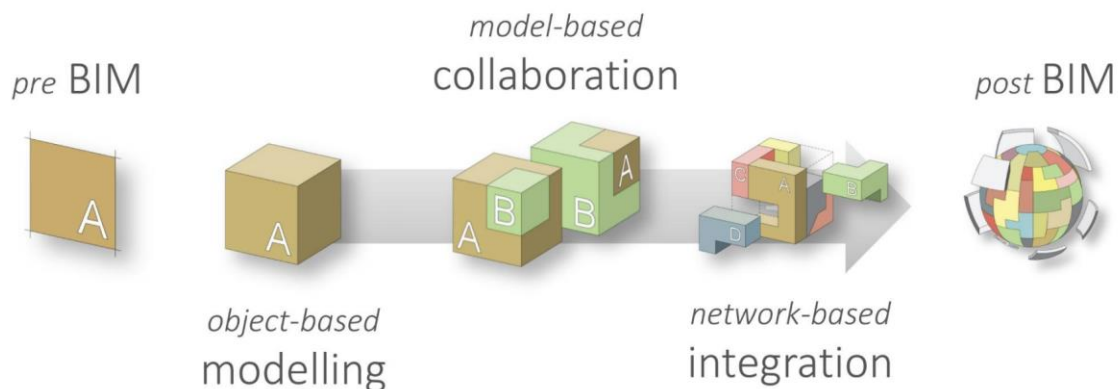
## 4. Discussion

### 4.1. What project teams can benefit from BIM?

When considering BIM there are a lot of different aspects in the processes and which each impact different areas of the AEC industry. Therefore, as discussed in the results section, an understanding of the level of BIM implementation and the general expectations must be shared and uniform for all actors on the construction projects. Figure (4) shows the different BIM stages, from pre-BIM (2D cad and hand drawings)



to the end-goal of post-BIM (Everything the software can accomplish is used, which can for example be the cost of elements or geographic information systems). For many the post-BIM is too advanced, and Exigo states that there is a learning curve for BIM and in the Danish AEC industry we are only in the beginning.



**Figure 14.** The BIM stages

Henrik from Exigo explains that there are benefits to climbing higher on the BIM stages for a project, if all actors in the process has agreed upon this and are willing to allocate more resources. He further clarifies that BIM is way to plan ahead, and therefore it requires the project managers to change the resource distribution. This is the part where many of the current project managers do not see the benefits and Henrik explains that this is a result of not fully committing.

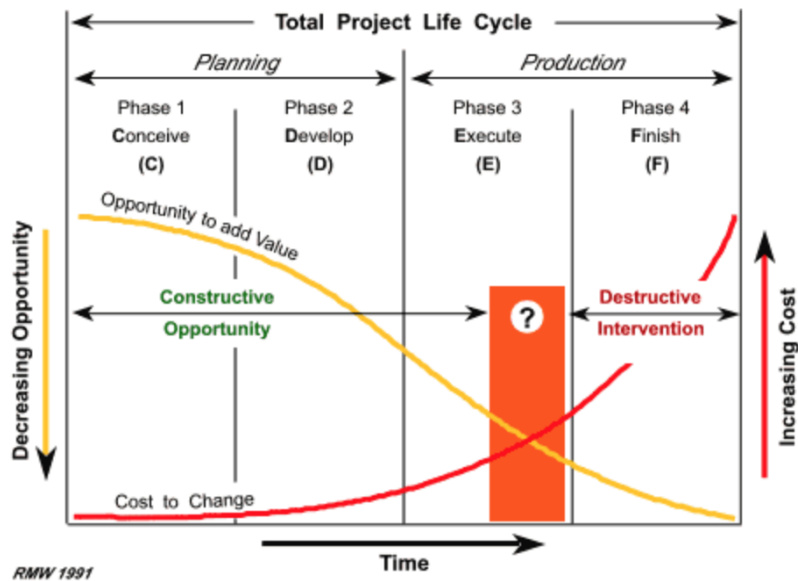
In Denmark an Information and Communications Technology (ICT) specification is used to establish the expectations of the 3D-model to be developed. This specification is drafted by the owner and is on larger projects a contract between the owner and the contracting advisors. It includes among many other things the required data points to be filled out during the different phases of the construction process. Henrik argues that the better and more precise a specification the better the results tend to be.

Henrik explains that he has seen larger projects benefit more from using the BIM-processes, as they are often more capable and willing to allocate the correct resources to handle it.

#### 4.2. Application and benefit of BIM

BIM has many uses when considering construction management, one of these can be the task of planning. Planning is in many projects tied up with the cost of the building, as good timing and planning can result in fewer delays and therefore a cheaper project. One of the issues with planning by using the traditional methods is that it can be extensive and very time consuming. Kim, Anderson, Lee & Hildreth (2013).

Kim et al. (2013) writes that there is a need to automate tedious tasks in regard to planning and many attempts has been made to accomplish this, but the processes are insufficiently supported by the software applications in many cases. However, the software has continued to improve since this statement was written. The opinion of Exigo is that are great benefits to harvest from using BIM if you are ready to allocate resources to doing it right. Figure (5) shows the time line of a construction process from planning to finishing. It illustrates that in the first phases (planning) there is a great opportunity to add value and very little cost attached to the change in the project. However, when the production has started, the opportunity to add value decreases and if any change is made the cost of this increases tremendously. This gives an incentive to assign more resources to a create a better plan and drawings for the model. BIM is a great tool to take illustrate this scenario, as it costs only very limit time to change the type of columns on a whole floor in a building if a mistake has been made. However, if this mistake was to make it to the contractor in the execution or finishing phase, these columns are already ordered, made, delivering and installed, where all steps include costs. So visualising and planning a building before executing it can in many cases save a lot of money on errors.



**Figure 15.** The opportunity to add value compared to the cost to change (Maxwideman.com)

Azhar, S. (2011) concludes the following benefits of BIM on projects from a larger data gathering:

- 40% elimination of unbudgeted change
- Up to 80% reduction in time taken to generate a cost estimate
- Saving up to 10% of the contract value from clash detections
- 7% reduction in project time

This supports Exigo's vision that by allocating resources to the early processes of the construction phases will grant you a shorter, cheaper and better end product.

#### 4.3. Generating a cost estimation

In the previous section it was shown that the time taken to generate a cost estimate can be drastically reduced by using BIM. Exigo adds a few other arguments and benefits to the cost estimation, by stating that BIM gives a more accurate quantity and thereby price, and it is more consistent if updated. A benefit for the owner is that it makes scenario based decision a possibility as it allows the user to change the model and see the consequences on the price estimation, almost immediately, making it a very powerful decision making tool. In the next section it will be discussed how the future of cost estimations can be and what is required to get there. However, this is closely related to the acceptance for the whole industry that BIM is here to stay, and requires attention.

#### 4.3. Future of BIM in general

As stated there is also a possibility for cost estimation to become even more precise and faster updating with the different methods discussed in this report, which Dynamo and Vico Office is only a few examples of. If the industry is changing to accept and allocate resources to using BIM and all its aspects, there are a lot of benefits to be gained. But what is needed to get there? Henrik from Exigo describes it as the burning platform, where you need to make the comfortable platform that project managers and bosses are standing on now burn (meaning they need to start seeing they cannot survive or make money in position they are in now) for them to accept that it is time to move on. Exigo will continue to push the industry in Denmark towards using BIM for the correct purposes and set a standard to work against.

Azhar, S. (2011) illustrates how 82% of BIM users of a large group of architects, engineers, contractors and owners think that BIM has a very positive impact on their companies productivity. Furthermore 66% thinks that BIM increases their chances of winning project bids, which directly relates to the precision and optimisation of the cost estimation.



## 5. Conclusion

The aim of this research was to find the benefits and challenges of using BIM for reducing variation in quantity and generating a cost estimation. A criteria that was found to achieve any benefits was that all actors have the same expectations of the project, which means that the owner, architect, engineers and contractor must all be willing to allocate resource to BIM if it is to succeed. Exigo stated that they meet a reluctance to use BIM on some larger construction projects because they do not see the benefits and are not willing to change. So, it seems that the largest challenge for developing BIM in Denmark is still convincing the conservative AEC industry to change.

The use of BIM for cost estimation allows it to be more extensive and contain all elements of a building instead of just pricing by square meter building. This can be seen from different perspectives, it can be seen as a very good way to optimise buildings and gain precise estimations. However, there is a worry for contractors as their pricing strategy can result in a loss of profit as the owner has access to the unit prices. For many companies the use of BIM can be necessary to optimise processes and win bids, and therefore strategies for pricing and winning bids must adopt.

BIM has the potential to change many projects fate, by reducing the risk of having unbudgeted change and reducing project time.

## References

Long, R. J. (Ed.). (2013). *Construction claims for variation in Quantity* (Rep.). Littleton: Long International.

Azhar S., Khalfan M., & Maqsood T. (2012). Building Information Modeling (BIM): Now and Beyond. *Australasian Journal of Construction Economics and Building*, 12(4), 15-28. Retrieved from <http://learning-analytics.info/journals/index.php/AJCEB/article/view/3032>

Azhar S. Michael H. & Blake S. (2018). Building Information Modeling (BIM): Benefits, Risks and Challenges.

Kim, H., Anderson, K., Lee, S., & Hildreth, J. (2013). Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology. *Automation in Construction*, 35, 285-295. doi:10.1016/j.autcon.2013.05.020

Azhar, Salman. (2011). Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering*. 11. 241-252. 10.1061/(ASCE)LM.1943-5630.0000127.

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<http://www.maxwideman.com/papers/framework/variables.htm>

## IV

### **BIM and State-of-the-art Acoustic Virtual Reality – does it work?**

*Vojtěch Dědek*

#### **Abstract**

Possibilities and limitations of Acoustic Virtual Reality and its connection to BIM are discussed in this paper. First we discuss what the possibilities of creating this connected environment are, then we define what the terms of acoustic, virtual reality and BIM. Finally we start connecting the disciplines together and present what is currently possible in the separate fields I case of case studies, what connections exist and which should be created. All this aims to present possibilities of cooperation between different technical environments in order to increase workflow and cross disciplinary cooperation not only between professional but also into general public area.

#### **Key words**

BIM, acoustics, virtual reality, VR, auralisation

## 1. Introduction

In last years, increased awareness of energy consumption, environmental impacts and indoor environment means that architects, designers, engineers require and are required to consider all these factors and incorporate them into building design.

These days, Building Information modeling (BIM) is considered as the most appropriate tool for representation of building design & elements. BIM models are used for many different purposes from drawings, performance analysis to building demolitions and can follow the entire building lifetime. All kinds of analyses can be performed and building optimized for energy efficiency, lighting conditions or indoor climate. This will improve the design efficiency, cost and errors because the whole process can be located at a single BIM model for all participants (cloud based BIM). This opens up a huge possibilities for future improvements. (Brodoschi, Pilosof, & Kalay, 2015)

Immersive Virtual Reality (iVR) is a field in rapid progress that offers representation and simultaneous perception of reality and realities' physical attributes in interactive virtual environment generated by computers. It does not only offer a visual experience of the non-existing world but also supports other senses for us to believe in it even more. One of those senses is our acoustic perception of the space and we can call it Acoustic Virtual Reality (AVR). Combination of seeing the space and hearing it as well offers great opportunities for building design and improvement of acoustic qualities and their early integration to building design. (Frederiksen, 2018) Usually, acoustic performance of the building is presented in charts or plans with many parameters present that only trained acoustician can fully understand. If a "normal" person could experience the space before it was build and give designer their "gut" feeling about it, the user response could be quickly integrated and building elements quickly changed. This future user involvement can play a big part of the design in the future. (Musca, 2018)

In order to build Virtual Reality environments, we need a geometry and material properties (sound absorption coefficients, etc.). BIM models are very rich in information providing geometry and many other parameters of building materials and processes. The question stands, how much connections is between BIM and VR today and where real-time acoustic simulation and auralisation stands in all this?

## 2. Definitions

### 2.1 BIM

There is many definitions of what BIM is or represents, all vary based on who talks about them. Architects, from my experience often mean a software such as Revit or ArchiCAD but in fact it is much more. It is more of an idea overlapping all parts of building industry with technology and policy all going for one goal. Making the project simpler with all possible informations at one place, following definition sums it up nicely that BIM is:

*"a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a facility in virtual space"* (BIMdictionary, 2018)

Ideally, the whole process of the design – build – operate - demolition would be run on single 3D model that would contain all information. Because BIM was not always around, the current state is that every profession has their own programs and uses their own models so this have to be disrupted and integrated within one model. This is the main reason why it is taking a lot of time because changes always do. There are 2 main incentives for everyone to start using BIM. *First* is monetary, as always.

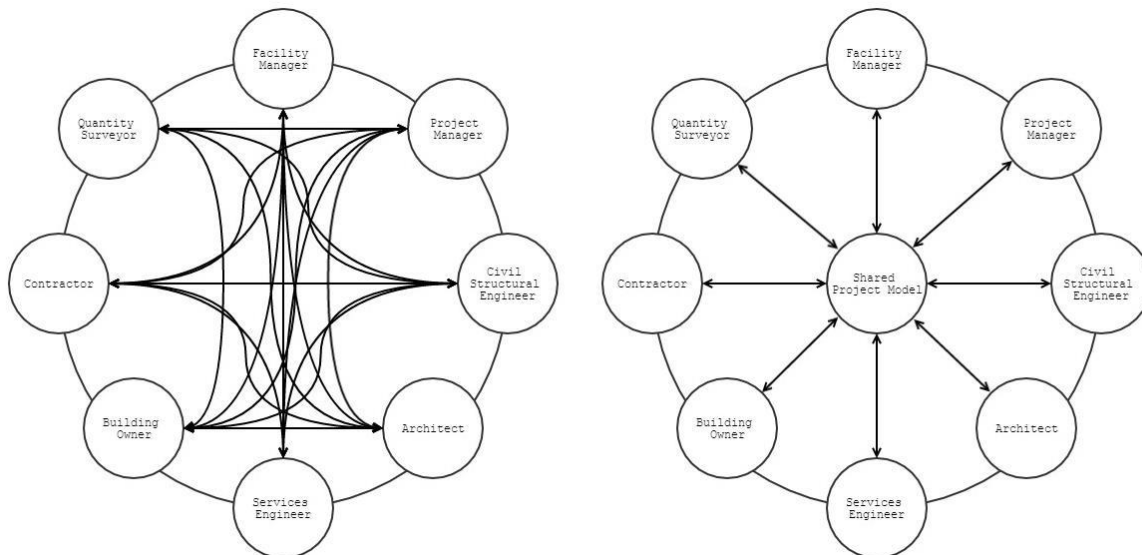


Fig.1: BIM potential = connections of professions

Figure 1 clearly shows potential than BIM has to save time, improve communication, decrease error making and clearly state responsibilities. By taking down risks and saving time on constant model changes (now 1 model instead of 1 for each profession), we save money. *Second* incentive is government actions. If you want to work for public sector, BIM models need to be submitted in some countries and this goes hand in hand with standards. Combination of these 2 factors is making the building industry slowly change to BIM environment even though training in new softwares is needed.

The true potential of BIM in the design phase is the possibility of cooperation between all the professions taking part in the design. With one model, there can be done preliminary acoustic calculations as well as structural or energy calculations early in the process by professionals and thus the impact on architectural design can be great. Architects can get almost instant response to the mass changes and truly improve building design to fully integrated level. This was never easy to do because transfer of data between professions was never instant and loss-less. Before results came in, some more changes to the design were done, thus it was always just catching up. If calculations can be done within the same model, no changes could have happened, so full use of them can be utilized. This of course depends on the level of BIM integration within the design process.

Because we don't have a full integration of BIM to all stages of building life cycle now, we differentiate several levels of integration to make things clear. Level 0 means no integration, Level 1 is typically mixture of 3D CAD for concepts and 2D construction drawings, Level 2 is distinguished by collaborative work and should be based on a file format such as IFC to export all data (not only geometry), with Level 3 being still in the future because new frameworks and sets of international open data standards have to be achieved as well as change in cultural environment as co-operation (NBS, 2018). These Levels an indication of integration of BIM, sometimes also fully defined in a standards. For example Level 2 have to be achieved in all public UK projects since 2016.

Until now, we lack a fully defined standard format of BIM files that could transfer all the information between various programs. It is mostly on the software developers to include the possibility to transfer the data and its amount. Lately, energy demands have driven the developers such as Autodesk to include energy performance data to their softwares and thus they enable data transfers to specialized energy analysis tools, this uses the one model, we can be all working on. But ways of building analyses are many and their full integration still awaits further development. (Bernstein, 2015)

## 2.2 Acoustic Auralisation

The goal of Acoustic Auralisation is to make room acoustics audible. We try to represent acoustic properties of a space by several metrics (reverberation time, sound clarity, sound pressures etc.) that should represent how the sound behaves within the space. But there is the problem that all we can do is more or less educated guesses of how the space will feel after construction ends. Acoustic engineers are good at it but for normal people, it is hard to understand any of it and they have to take engineers word that “it will be all right”. The best way for all is to hear the sound and not read plots and graphs because only then, we can hear it and get emotions and feeling of the space perfectly. The result of an auralisation is our hearing experience of a source playing in a real or virtual environment. Kleiner et al. presented a definition of the term auralisation as follows:

*“process of rendering audible, by physical or mathematical modeling, the sound field of a source in a space, in such a way as to simulate the binaural listening experience at a given position in the modeled space” (Kleiner, Dalenback, & Stevansson, 1993)*

Scale models were used to predict and assess the sound performance of the room, but not today anymore. The frequencies of the source were scaled down to fit the model. Before coming with microphones accurate enough to enable scale models based techniques, we used to use a very different methods like a use of light beams to simulate reflections behavior (Knudsen, 1932). Today, due to increase in computational power, computer-based predictions are the case these days. There has been many methods developed since 1960s like Ray Tracing models, Wave Equation models, Particle Tracing models and many more. Acoustic software of today like CATT, Odeon, EASE and others can perform precision analysis of room acoustics, some also with acoustic auralisation. For example, once you place and define source, receiver and medium (room geometry and its acoustic qualities), CATT can generate a sound file that you can listen to like you were the receiver. This has some limitations like no possible movement of the receiver or source without re-calculations, calculations taking long time and no visual connection to space itself. The good news is that we can listen to it.

## 2.3 Real-time Auralisation

Acoustic auralisation can be adopted in virtual reality environment for as long as the quality of auralisation framework are above the quality restrains of human perception. There is more factors that need to be fulfilled such as latency (up to 50ms) of input-output of auralisation, for example between head movement and change of the auralisation signal. There is several methods for computing accurate acoustic models, but they are generally not fast enough for real-time auralisation of sound for simultaneously moving sources and receivers. Therefore new methods are being developed for simplification of the calculations and prioritization of sources/responses in order to decrease calculation time and power needed. The task of producing a realistic acoustic perception is a hard task for off-line auralisation and real-time processing is possible only due to reductions of complexity. (Sunyoung, Coffeen, & Sanguinetti, 2013)

One way of increasing computational speed is various level of details for every major frequency, because the lower frequency, the less details in geometry are needed for precise calculations. Moreover, the level of details is also decreased as the time propagation goes on because accurate reflection patterns are not so important for late part of the reverberation. These and many more optimizations are performed in RAVEN software being specifically developed for real-time auralisation. But still, lack of computational power leads to approximations, even though the use of GPUs with many cores is being used these days in order to move the computations from CPU with not enough power. But still, development in acoustics algorithms that could unleash the full power of graphic GPUs is necessary. (Schroder, 2011)

## 2.4 Immersive Virtual Reality

Virtual Reality is usually understood as a virtual space that we can see using an artificial tools. For us to be part of the virtual environment, our vision is the start but we will not believe to be part of it if our senses besides visual tell us that we are not there. For us to truly believe to be in virtual reality, preferably all the

senses should be engaged. We are not there yet, but experiments are being done to include more senses at the same time from climate chamber experiments bringing air/heat control to realistic sound simulations. We should ideally be able to physically interact and also get a feedback. A general definition of the term from Rouse is as follows:

*“...presentation of an artificial environment that replaces users’ real-world surroundings convincingly enough that they are able to suspend disbelief and fully engage with created environment.” (Rouse, 2018)*

### 3. Combinations of fields

#### 3.1 BIM + Acoustics

With acoustic being a part of building design, lots of acoustic prediction software have been developed. It is mostly supported by CAD based geometry and the rest of the procedures are happening within the specialized acoustic software. BIM based software like Revit is a tool that also creates geometry, thus exporting it to acoustic software like Odeon is a possibility but due to lack of acoustic data in BIM, there is no option to bring it in as well. Besides lack of acoustic data a live link between BIM model and exported geometry is missing, thus any updates within BIM will not affect geometrical data in acoustic software. Providing a live link between BIM and acoustics software is a step that should happen.

A review of software capable of using the rich environment of BIM showed, that prior to March 20 2015 (acoustic properties discontinued), Autodesk Ecotect software had enabled to import gbXML files and used the data in acoustic simulation. After importing geometry from BIM, due to lack of acoustic data in gbXML file, acoustic properties had to be assigned in Ecotect software. In addition, Ecotect did not account for frequency composition of sound source. (Autodesk, 2015) (Habidi, 2017)

An American PhD student did a Revit API plug-in to Revit software that is able to perform an acoustic analysis or acoustic auralisation in a very simple rooms. Because Revit does not enable acoustic properties of materials, a custom absorption coefficients are added for the 6 major frequencies. All that can be done is a simple reverberation time of a room using Sabine equation and sound intensity level map for only a direct sound source. Calculations run in background and should take only couple seconds. This was supposed to prove the concept that connecting BIM and acoustic simulation can highly decrease time needed for calculations and significantly improves workflow within Revit environment, which the prototype proved so. Any update made in Revit file was able to re-simulate immediately, therefore designer can conduct “what-if” scenarios very quickly. Further prototype development, also creating connection with virtual reality, was promised but I did not find any more publications about it from the duo. [14]

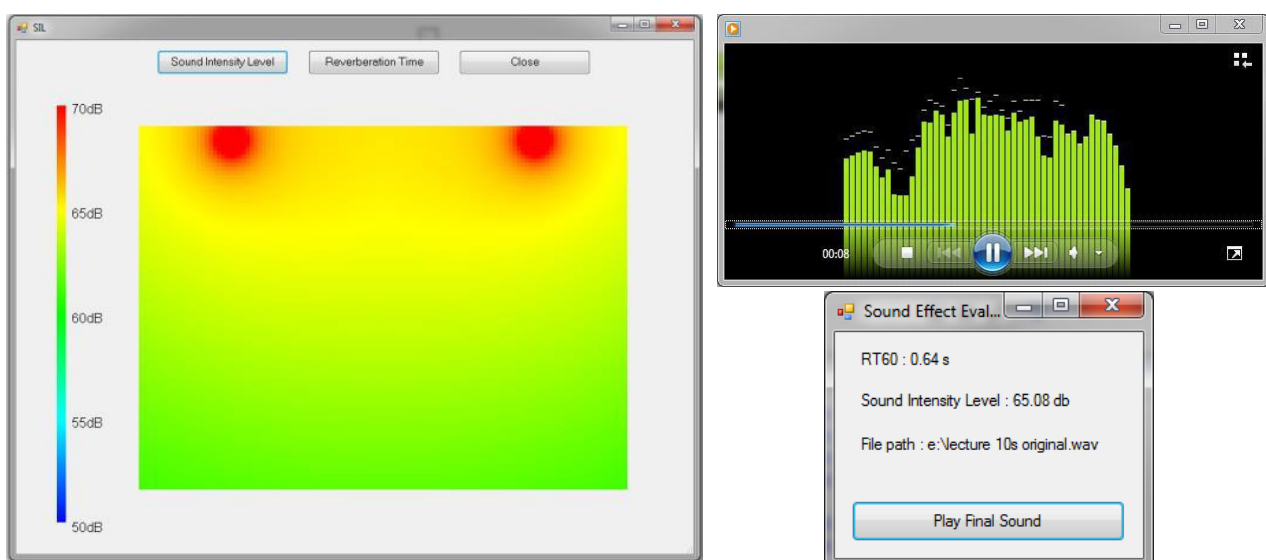


Fig.2: Outputs of acoustic simulation pop up in Revit and you can play the sound file as well

Some manufactures provide acoustic data to BIM software such as Revit as of now only for informational purposes. They include acoustic data in their models in a form of text, but the actual data is there! Due to lack



of gbXML compatibility, this data will not be transferred in a relevant format if the file is exported, it will be only a text without additional properties. In this way, it looks like a quick transition can happen if acoustics will be implemented in BIM software because acoustic data is already present, only not as material property. As an example, Rockfon provides acoustic data in their BIM objects as following Figure 3 indicates. **(Rockfon, 2018)**

Data	
WidthMaximum	1200.000000
VOCEmissions	Depends on application, please contact CMS Danskin
ThermalConductivityInformation	n/a
ThermalConductivity	Depends on application, please contact CMS Danskin
SurfacePattern	Solid
SoundAbsorptionCoefficient	0.18 (125 Hz), 0.55 (250 Hz), 1.13 (500 Hz), 1.10 (1000 Hz), 1.05 (2000 Hz) 1.02 (4000

Fig 3. Example of Sound Absorption Coefficients already present in BIM objects, but only as additional text information

### 3.2 BIM + VR

The main question is simple, why? BIM already includes all the data possible for VR visualization. To be honest, it is only more complicate rendering software for which we had to figure out a way of showing it well enough. With hardware tools such as Ocul Rift or HTC Vive that let us comfortably get into VR, we can use this much more easily than ever before. This will let us walk with the client through the real model of an ongoing architectural project. Not all people can imagine a building from couple drawings or renders so this tool can let people get in, see and explore. Several architectural companies started to use this not as a design tool, but as a presentational tool for the client and we can see a trend of getting faster approvals of the projects **(BIMcommunity, 2018)**. There is several softwares that enable import of BIM files to their dedicated VR rendering software such as Fuzor or Autodesk Live. After import, the render goes through and you can explore.

The future of this can be best seen at Enscape software that is a plug-in to Revit and enables real-time changes. No export is needed, all changes to the model can be instantly seen in VR which means real-time workflow possible. This shows the path the BIM connection to VR can poses. No export means no lost data, no lost time. This can further improve the engagement of clients by offering them a bigger choice and influence over projects and decrease decision and approval time.

Besides Enscape, there is many other softwares that offer export from Revit or other BIM softwares into VR environment and why they are different from the others:

Autodesk LIVE – need to re-render the files for VR, so not exactly “live” or real-time connection just yet

IrisVR – offers bi-directional synchronization between softwares (changes done in Fuzor will also change Revit file and the other way around) so we can work and design inside VR environment doing basic changes in materials/ furniture and other

Fuzor – similar to Iris VR, it offers bi-directional synchronization between softwares (changes done in Fuzor will also change Revit file and the other way around)

SketchFab – interesting software/webware (software needing only internet browser to work in) making any computer and phone capable of showing 3D models or VR because all it needs is a web browser. Direct plug-in for Revit for file export was added in April 2018. They are also starting to implement acoustic possibilities but so far only on game-engine base calculations, no “real” acoustic behavior of sound. **(Sketchfab, 2018)**

And several more...



### 3.3 VR + Acoustic

Currently, there is no VR software capable of handling real-time auralisation simulation based on proper simulation techniques. There are several software offering some level sound within the VR environment but all of it is game-engine based, thus not realistic acoustic simulation and cannot be used to design or asses architecture. People realize this thus try to come with a mixed solutions of combining independent acoustic software with VR simulation.

For acoustics, due to lack of software capable of producing real-time 3D auralisation (processing power for now) for more complicated spaces (not a shoebox), there is a method of pre-calculating the sound affects being used. If we have a fixed position of a listener and a source (dry sound - sound that is not affected by room acoustics), we can calculate the sound effect prior to experience, how the sound will behave. In this case, we skip the heavy real-time computational calculations. After that, we track listeners movement (head rotations only) and calculate rotations of ambisonic channels (full-sphere sound technique), than do binaural encoding if we are using headphones. This method gives us very good listening results with relatively low computational power needed but is limited to pre-fixed places and calculations, listener can only move his head (sound will change with head positioning) but he can't move. Combined with visual environment, overall experience is more immersive than sound or visual rendering only. This method was used in a paper by **(Poirier-Quinot, Postma, & Katz, 2016)**. They use a mix of 2 independent softwares, one for real sound simulation, CATT-Acoustics, the second for creating a VR environment, BlenderVR.

In another study, they are using very similar technique of pre-calculating sound in several points in the space. The difference here is use of a many point in a grid for which the calculation will be done. After assigning every point in the grid with a sound file and providing with area of influence, we can perform motion to our avatar. He will hear the sound as calculated for a given point and the differences will occur only as he moves from point to point. To prevent sudden changes in intensity or other properties, an overlap area is

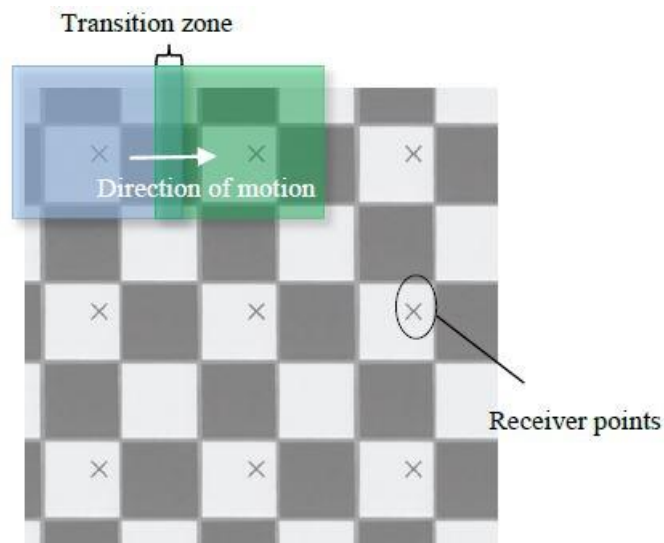


Fig 4: Receiver grid points used for auralisation. Overlap zone is for prevention of “sound clicks” during motion.

created, where 2 various sound files are mixed together based on their algorithm. This should provide smooth transfer over the whole area and not limit us to the points calculated. They do not offer any guidelines of how the grid for sound calculations should be constructed. Visual part was offered by TyrEngine, acoustic simulation by common CAD acoustic simulation software (not specified), new version of TyrEngine offers this mix of with acoustic input now. **(Lindebrink & Nätterlund, 2015)**

Technological problems are still present and mostly come by lack of computational power of computers. In a paper by **(Poirier-Quinot, David; Postma, Barteld NJ; Katz, Brian FG, 2016)**, they tried to render sound via real-time convolution of the 3<sup>rd</sup> order (higher accuracy than 1<sup>st</sup> or 2<sup>bd</sup> order) Ambisonic RIRs (room

impulse response) with the recordings. Trying to prevent audible artifacts in sound (“cracks”) due to buffering and time-lag, they needed to do real-time convolution of over 3 000 channels, which proved not possible for their PCs. Thus they needed to perform convolutions offline. Due to need of pre-calculation of all points, huge sound files were needed (12GB/min). If there was not a lack of computational power, they created a software combination capable of handling real-time auralisation within VR. But for now, if we pre-calculate sound in a grid they advise to plan the grid properly with making it not dense only in areas with suspected changes in sound properties and less dense in areas with not many changes happening. This will decrease pre-calculations and file size needed (**Poirier-Quinot, David; Postma, Barteld NJ; Katz, Brian FG, 2016**).

### 3.4 BIM + VR+ Acoustics

As of today, I did not manage to find any paper or software capable of connecting all three disciplines together in a simple and unified way. As stated in VR + Acoustic part, simulation were done when geometry was based on BIM software and then transformed to separate acoustic program to run the acoustic simulation there. The goal here, I see as a fluid connection between them all.

The only program that was ever close to this was Enscape which could connect generating sound in VR environment with Revit. But as of today, this connection is severed because acoustic data was taken away from Revit software even though Enscape is still trying to read them but can’t anymore. This feature was lately disabled also from the Enscape (2018) because of it was “too complex to use and to maintain”. (**Enscape forum, 2018**)

### 3.5 Literature overview

After extensive readings of literature, I found a couple case studies that managed to generate immersive VR experience with auralisation as Table 1 shows:

	<i>Title</i>	<i>Framework</i>	<i>Pros/cons</i>
1	<b>Augmented auralisation: Complementing auralisations with immersive virtual reality technologies.</b>	Catt-Acoustics - acoustics BlenderVR extension – combines all 3ds Max - graphics Kinect 2 - motion Cave environment - presentation	-complicated framework +good acoustic quality and presentation
2	<b>An engine for Real-time audiovisuar rendering in building desin process</b>	TyrEngine – combines all BIM software – geometry CAD based acoustic software Unreal Engine 4 - graphics	-combination of programs needed
3	<b>Virtual Reality Performance Auralization in a Calibrated Model of Notre Dame Cathedral</b>	Catt-Acoustics – acoustics Blender Game engine - rendering BlenderVR – combines 3ds Max - graphics Max/MSP – audio combination engine Oculus Rift – presentation	-heavy calculations needed -many programs combined +high quality auralisation simulations done
4	<b>Sound simulation in Revit Enscape</b>	Revit – geometry, acoustical data Enscape – rendering, sound calculations	-not possible anymore + big possibilities for building industry
5	<b>Physically Based Real-Time Auralization of Interactive Virtual Enviroments</b>	Cad-based program - geometry Raven - acoustics Cave environment - presentation	- non commercial - no BIM + less steps for real-time auralisation / acoustic simulation

Table1. Case study overview

## 4. Conclusion

Direct connection between BIM + Acoustics + VR is not here just yet. All the solutions possible, as of today, are a mix of various softwares for smaller or bigger parts in the process with one software that connects the separate result together into a coherent form for presentation. This is being done on a research basis only because for normal work environment, these methods are too complicated to do on a daily basis. They also require high level of programming and complex modelling. Link between BIM + VR is here. Real time Auralisation is still quite new and demanding, but possible due to use of GPUs that can offer powerful engine to run the calculations.

The main problem lies within connecting BIM + Acoustics. If the link will be done, the rest should be able to follow quite quickly. If this will be solved, the possible outcome is great with increase in workflow, faster project approvals or presenting building designs to non-professionals in a way more understandable to them.

## 5. References

- (2018, 05). Retrieved from BIMdictionary: <https://bimdictionary.com/en/building-information-modelling/1/>
- (2018, 05). Retrieved from NBS: <https://www.thenbs.com/knowledge/bim-levels-explained>
- (2018, 05). Retrieved from BIMcommunity: <https://www.bimcommunity.com/news/load/354/is-bim-taking-advantage-of-all-the-resources-from-the-vr>
- Autodesk. (2015, 05). *Ecotect Analysis Discontinuation FAQ*. Retrieved from Autodesk: <https://knowledge.autodesk.com/support/ecotect-analysis/learn-explore/caas/sfdcarticles/sfdcarticles/Ecotect-Analysis-Discontinuation-FAQ.html>
- Bernstein, P. (Performer). (2015). *The Future of Making Buildings*. TEDxYale.
- Brodeschi, M., Pulosof, N. P., & Kalay, Y. E. (2015). The definition of semantic of spaces in virtual built environments oriented to BIM implementation. *The Next City: 16th International conference CAAD Futures* (pp. 331-346). Israel Institute of Technology.
- Enscape forum. (2018, 06). Retrieved from <https://forum.enscape3d.com/index.php?thread/1545-sound-virtualisation>
- Frederiksen, A. K. (2018, 05). *Hear the sound in your new building*. Retrieved from DTU.dk: <http://www.dtu.dk/english/news/2017/05/hear-the-sound-in-your-new-building?id=ec7b101b-c19d-4745-9718-abab73f51927>
- Habidi, S. (2017). The promise of BIM for improving building performance. *Energy and Buildings* 153, 525-548.
- Kleiner, M., Dalenback, B., & Svensson, P. (1993). Auralisation - an overview. *J. Audio Engineering Society*, 861-875.
- Knudsen, V. (1932). *Architectural Acoustics*. Wiley.
- Lindebrink, J., & Nätterlund, J. (2015). AN ENGINE FOR REAL-TIME AUDIOVISUAL RENDERING IN THE BUILDING DESIGN PROCESS. *Acoustics 2015 Hunter Valley*. Hunter Valley.
- Musca, T. (2018, 05). *Why Henning Larsen Architects Believe that VR Is "a Gift for the Future of Architecture"*. Retrieved from ArchDaily: [https://www.archdaily.com/876881/why-henning-larsen-architects-believe-that-vr-is-a-gift-for-the-future-of-architecture?utm\\_source=dlvr.it&utm\\_medium=twitter](https://www.archdaily.com/876881/why-henning-larsen-architects-believe-that-vr-is-a-gift-for-the-future-of-architecture?utm_source=dlvr.it&utm_medium=twitter)
- Poirier-Quinot, D., Postma, B. N., & Katz, B. F. (2016). Augmented auralisation: Complementing auralisations with immersive virtual reality technologies. *Simulation and Auralisation of Concert Halls / Opera Houses*. Buenos Aires: International Symposium on Musical and Room Acoustics.

- Poirier-Quinot, David; Postma, Barteld NJ; Katz, Brian FG. (2016). *Virtual Reality Performance Auralization in a Calibrated Model of Notre Dame Cathedral*. Porto: European Acoustic Association.
- Rockfon. (2018, 05). *BIM library*. Retrieved from Rockfon: <https://www.rockfon.co.uk/resources/bim-library>
- Rouse, M. (2018, 05). *Definition of immersive virtual reality*. Retrieved from TechTarget: <https://whatis.techtarget.com/definition/immersive-virtual-reality-immersive-VR>
- Schroder, D. (2011). *Physically Based Real-Time Auralization of Interactive Virtual Environments*. Aachen: Faculty of Elektrotechnik at Aachen University.
- Sketchfab. (2018, 07). Retrieved from Sketchfab: <http://blog.sketchfab.com/sketchfab-adds-sound/>
- Sunyoung, K., Coffeen, R. C., & Sanguinetti, P. (2013). Interoperability Building Information Modeling and acoustical analysis. *Proceedings of Meetings on Acoustics*. Montreal: Acoustical Society of America through the American Institute of Physics.
- Wu, C., & Clayton, M. J. (2013). BIM-Based acoustic simulation framework. *30th CIB W78 International Conference*, (pp. 99-108). Beijing.

## V

# **Life cycle assessment of a building information model made in Revit**

*Eskild Mo Rognes*

### **Abstract**

This paper describes the LCA as a method and as a decision making tool. The purpose is to investigate the power of a life cycle assessment. The LCA is implemented on a simple BIM model design in collaboration with the course Integrated engineering Project at Aarhus University. The design part is done in Revit and the life cycle assessment done in the application Tally. The results show how a simple comparison of two design options can be used in the decision making. It is also argued how when the LCA process should be implemented in the whole construction phase.

### **Key words**

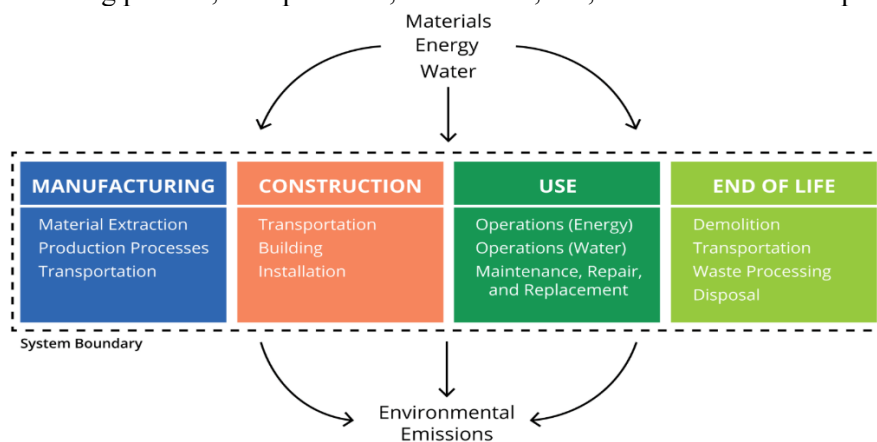
Life cycle assessment, BIM, Decision making

## 1. Introduction

Due to a better social and economical development world wide the construction industry is experiencing a rapid growth. As a consequence, the construction industry demands more and more energy (Ortizab, Castellsa, & Sonnemann, 2009). Not just for the operation stage, but also during manufacturing and construction face. Energy is the essential input during the whole life cycle of a building. In China, nearly 25% of the total energy consumption goes to the the construction industry and its estimated that this will increase to 35% by 2030 (Geng & Mao, 2017). The building construction industry consumes 40% of the materials entering the global economy and generates 40-50% of the global output of greenhouse gases and the means of acid rain (Kofoworola & Gheewala, 2008). Extraction of materials is an activity that consumes energy, generates waste and contributes to environmental damage with negative impact such as depletion, biological diversity losses, global warming and smog. Buildings are one of the areas in urban development that needs to be assessed in terms of the environmental impact. They provide necessary infrastructure for many productive activities such as industry, services, commerce and satisfies the very basic human needs (Kofoworola & Gheewala, 2008). Even though, this very basic nature of buildings, stakeholders on development do not consider the environmental impact of buildings. Life cycle assessment is e very helpful tool in this context as it not inly provides an account of materials and energy involved in a product or system, but it also measures the associated environmental impacts. Therefore, the building construction industry needs to move towards a more sustainable development. This has been a raising concern throughout the last decades and this is where life cycle assessments of buildings are essential. The aim of this study is to describe the LCA importance and examine the environmental impact of a building information model created with the use of Revit® and which areas of the building process contributes most to the global warming and energy consumption.

### 1.1. Life cycle assesment

Life cycle assessment is an in depth analysis tool that conducts environmental impact assessment on whole buildings, manufactured building products and material assemblies. This analysis calculates the direct and indirect inputs (such as water and energy) and outputs (such as carbon dioxide) that results from a material or assembly's manufacturing process, transportation, installation, use, maintenance and disposal, see figure 1.



**Figure 1: LCA circle**

The increased awareness of the importance of environmental protection and the possible impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts. ISO 14040:2006 “Environmental management – Life cycle assessment – principals and framework” (ISO, 2006), lists the following where LCA can assist:

- Identifying opportunities to improve the environmental performance of products at various points in their life cycle.
- Informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign).
- The selection of relevant indicators of environmental performance, including measurement techniques.
- Marketing (e.g. implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration).



LCA has been used to develop an eco-label criteria for hard floor coverings, to compare building insulation products, assessing the potential environmental impacts that might result from meeting energy demands in buildings and to assess the CO<sub>2</sub> emission reduction in the construction field through the selection of materials in houses with passive house standards. LCA is also used for analyzing the energy consumption of processing building components (Kofoworola & Gheewala, 2008). As an example, H. R. Lu conducted a life cycle assessment of a laminated veneer lumber (LVL) beam. The LVL product was compared to steel and concrete. The global warming potential (GWP) and embedded energy were assessed and the result indicated the LVL product presented the lowest GWP. However, due to the significant energy requirements for wood drying, the embedded energy in LVL was only marginally less than steel, but significantly less than concrete (Lu, El Hanandeh, Gilbert, & Bailleres, 2017).

The task of this paper is to quantify the embodied environmental impact of the building materials by performing a life cycle assessment. The result of such an assessment is typically not available to designer, as most are conducted on whole buildings and building components after construction. The LCA can be used as a decision making tool for creating a more sustainable manufacturing, construction and operation process of a building and is a relatively new practice for many engineers and architects.

### 1.2. Building information model

In this paper a building information model will be assessed with the use of the application Tally in Revit®. A building information model characterizes the geometry of the building, spatial relationships, geographical relationships, quantities and properties of elements, cost estimation and project schedule. As a result, the model can be used to retrieve quantities and shared properties of materials. The amount of work can easily be defined and systems and sequences can be shown relatively within the entire facility. Drawings procurement details and other specifications can easily be retrieved. BIM can be described as a virtual process for collaboration between all the disciplines within the AEC-industry, engineers, architects, owners, contractors, subcontractors and suppliers to collaborate even more accurately and efficiently than using traditionally processes. This allows team members to continuously refine and adjust parameters to the best solution of a model before the project physically breaks ground (Azhar, 2011).

## 2. Materials and Methods

The process starts with making a BIM model. The model is a 5 storage building situated in Aarhus with some simple furniture, curtain walls, brick cladding and a simple concrete structure. It is created in collaboration with the course Integrated Engineering Project at Aarhus University. The Tally software extrudes the building information from the Revit® model and creates a report. The Tally application allows architects and engineers working with Revit® to quantify the environmental impact of the building materials for whole building analysis as well comparative analyses of design options. While working in the Revit® model, it created a relationship between the BIM elements and the Tally database. The following parameters in table 1 were examined in the report excluding the windows, doors, stairs, curtain walls and plants.

**Table 1: Components with specification included in the Tully report**

<b>Building parameters</b>	<b>Specification</b>
Floors	5
Ceiling height	3,75m, acoustic ceiling tiles
Building life	100 years
Structure	Concrete columns
Walls	Brick and curtain wall combination
Floors	Wood plank, concrete 150mm
Roof	Flat roof, concrete 400mm

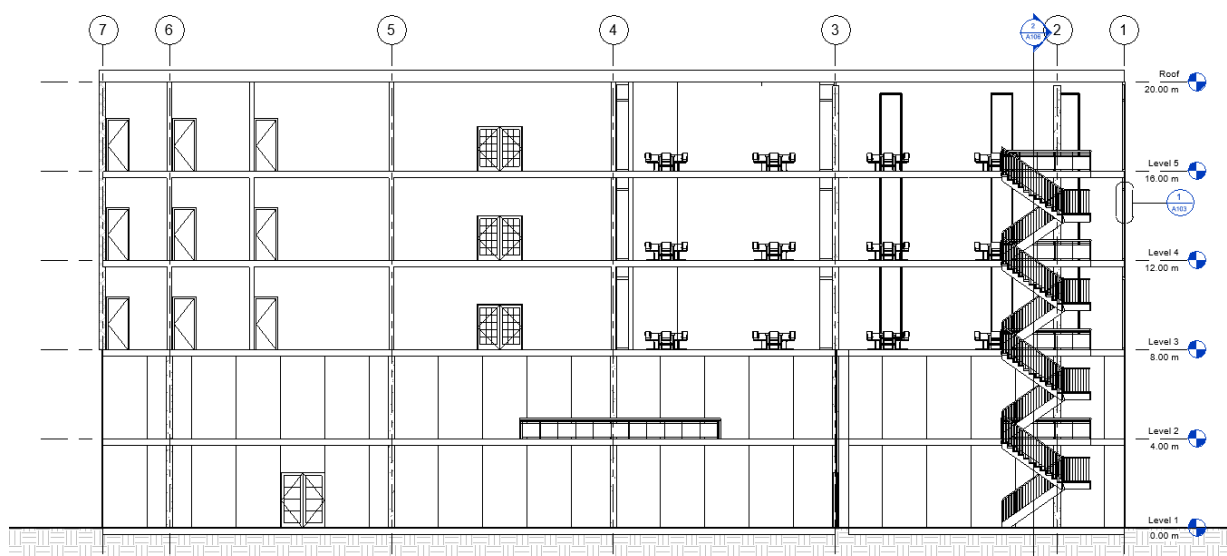


Figure 2: Cross section of the BIM model

The system studied includes the entire life cycle of the building, including manufacturing of the building material, transportation, operation, maintenance and demolition (see figure 4).

PRODUCT	CONSTRUCTION	USE	END OF LIFE
<b>A1. Raw material supply</b> <b>A2. Transport</b> <b>A3. Manufacturing</b>	<b>A4. Transport</b> <b>A5. Construction installation process</b>	B1. Use <b>B2. Maintenance</b> <b>B3. Repair</b> <b>B4. Replacement</b> B5. Refurbishment  <b>B6. Operational energy</b> B7. Operational water	C1. Demolition <b>C2. Transport</b> <b>C3. Waste processing</b> <b>C4. Disposal</b>  <b>D. Reuse, recovery, and recycling potential</b>

Figure 3: Building life cycle stages. Process included in Tally modeling scope are shown in bold, except the construction part.

The manufacturing process, or product process, includes raw material supply (e.g. harvesting wood), transport of raw material and manufacturing of this product. The construction process includes the transportation and the assembly of the materials as well as the installation of electrical work, plumbing etc. This part however, is not considered in the Tally report. The use includes maintenance, repair and replacement of materials as well as the operational energy consumption of the building. The last part is end of life or demolition. This part includes the transportation and the processing of the waste, disposal and the reuse, recovery and recycle potential of the materials after demolition.

The analysis accounts for the full cradle-to-grave life cycle of the design in Revit®. To examine the power of a LCA, the concrete structure in the roof was changed from 400mm to 225mm and the concrete in the floor from 150mm to 100mm. See attachment B. The report gives the result of Global Warming Potential (GWP) and Primary Energy Demand (PED). GWP is a measure of greenhouse gas emissions (kg CO<sub>2</sub>), such as carbon dioxide and methane and PED is a measure of the total amount of primary energy extracted from the

earth (MJ). PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar etc.).

### 3. Results

The results of the first LCA report (see attachment A “Tally report 1.pdf”) based on the impact categories evaluated are presented in table 2. Also, the contributions from different materials are presented. The total GWP is measured in kg CO<sub>2</sub> and result was 2,429,431kg and primary energy demand is measured in MJ and the total was 2.536\*10<sup>7</sup>MJ. The mass from the building is measured to 4,621,062 kg.

**Table 2: Results from first LCA report**

Measure	Global warming potential	Primary energy demand
Manufacturing Stage	77%	74%
Maintenance	18%	22%
End of life	5%	4%
Transportation	~0%	1%
Concrete	69%	58%
Masonry	2%	3%
Thermal and moisture protection	23%	30%
Finishes	5%	9%

The analysis of the stages in the life cycle process shows that the manufacturing stage and the maintenance stage are the most significant stages in terms of their associated environmental impact as they account for 77% and 18% respectively of the global warming potential. Also, the manufacturing and the maintenance stage is accountable for 74% and 22% respectively of the primary energy demand. The end of life stage is responsible for only 5% of the total GWP and 4% of the total PED and transportation only 1% for both GWP and PED (page 1-2, attachment A).

In the result per division, the concrete as the biggest contributor of global warming potential being responsible for 69%. Masonry, thermal and moisture protection and finishes were responsible for 2%, 23% and 5% respectively. For the primary energy demand, concrete, masonry, thermal and moisture protection and finishes were responsible for 58%, 3% 30% and 9% respectively (page 8-9, attachment A). The result shows a clear that the concrete is the biggest contributor to the GWP and PED. This is not a surprise though, given that most of the structure, walls and floors are made up by concrete. Looking into the result from the life cycle stages itemized by Revit® category, the manufacturing of floors, roofs and walls contribute the most to both the total global warming potential and primary energy demand (page 6-7 attachment A).

In this section the result from the second LCA report (see attachment B “Tally report 2.pdf”) where the thickness of the concrete structure in the floor and roof reduced. The total GWP is measured to 2,313,100kg CO<sub>2</sub> and the total PED 2,208\*10<sup>7</sup>MJ. The total mass was calculated to 4,523,848kg.

**Table 3: Results from second LCA report (Concrete structure thickness reduces in floor and roof)**

Measure	Global warming potential	Primary energy demand
Manufacturing Stage	74%	68%
Maintenance	20%	24%
End of life	5%	7%

Transportation	~0%	1%
Concrete	67%	56%
Masonry	2%	4%
Thermal and moisture protection	25%	30%
Finishes	6%	10%

The total GWP and PED shows a reduction, as well as the total mass. This is due to the reduction of the thickness of the concrete structures in the floors and roof. The results show a reduction in the manufacturing stage, both in terms of the global warming potential and the primary energy demand. This would make sense since the concrete is the main contributor to the total GWP and PED. The share from the other components shows a small increase in percentage.

#### 4. Discussion

The results show a reduction on the total GWP, PED and mass when decreasing the thickness of the concrete structures. This is a positive result of course, but in this paper the structural performance of the BIM model is not considered. This will have an impact on the decision making in the LCA process and will also be limitation. Changing the thickness of the concrete structure can in some cases not be possible. Other constraints in the designing phase are location, building type and gross floor area. The architecture can in some cases also be a constraint.

The results still show the power of the LCA and how it easily can be used in decision making. It is argued that the implementation of the LCA should be done in the early stage of the whole production (J.Basbagill, F.Flager, M.Lepech, & M.Fischer, 2013). The results show that the manufacturing stage contributes most to the total GWP and PED meaning that the production of materials is where to start. A huge portion of the material decisions which have the biggest impact and these decisions are made in the early phase. Choosing the materials, thickness and structure with the least embodied impact at this stage has potential to reduce the total environmental impact and the LCA should therefore be implemented here. Also, for the maintenance stage and the end of life stage, the decision of material is important in terms of need for maintenance and their potential renewable energy. Choosing materials which last longer and are produced from renewable resources can contribute to a lower primary energy demand and global warming potential. The decrease the impact of the transportation, local resources can be used and choosing manufacturers not far from the construction site.

The raising awareness towards sustainability and eco friendly buildings is something the construction industry is facing. The global warming potential is measured in kg CO<sub>2</sub> and gives a indication for how much pollution the construction of the building will make. To be able to reduce this should be encouraged more and more in the future, and with the use of LCA of a building we will be able to learn how we in the future can build more sustainable buildings under different conditions and constraints. This does not just apply to the manufacturing face, but also planning and construction buildings which can be self sufficient with energy and use renewable resources that does not contribute much to the global warming.

#### 5. Conclusion

The design option two showed a decrease in both GWP and PED, which was the intention for the result. Having this opportunity early in the planning stage of the construction of a building is beneficial in terms the strive towards a sustainable construction industry and is useful for the decision making. LCA as a tool integrated with BIM enhances the architect's and the engineer's possibilities to think sustainable and design in a sustainable way. Tally integrated with Revit® gives a simple output for where to begin in design and planning for a sustainable building, but the power of LCA is can be used in much bigger scale.

#### Attachment A

Tally report 1.pdf. First attempt to execute a life cycle assessment. Shows the GWP and PED sorted in life cycle stages, per division and per Revit® category.

#### Attachment B

Tally report 2.pdf. Shows the second attempt to execute a life cycle assessment. The thickness of the concrete structure in the roof and floors is decreased.

## References

- Azhar, S. (2011). *Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry*.
- Geng, S., & Mao, G. (2017). Building life cycle assessment research: A review by bibliometric analysis.
- ISO. (2006). *ISO 14040:2006(en) - Environmental management — Life cycle assessment — Principles and framework*.
- Kofoworola, O. F., & Gheewala, S. H. (2008). Environmental life cycle assessment of a commercial office building in Thailand.
- Lu, H. R., El Hanandeh, Gilbert, B., & Bailleres, H. (2017). *A comparative life cycle assessment (LCA) of alternative material for Australian building construction*. Retrieved from <http://era.daf.qld.gov.au/id/eprint/6011/>
- Ortizab, O., Castellsa, F., & Sonnemannc, G. (2009). *Sustainability in the construction industry: A review of recent developments based on LCA*.

## VI

# Building Information Modeling for Construction Management

*Helena Natalie Findinge*

### Abstract

Introduction: The focus of this research is to study the implementation of a sensor to the physical components in a construction to a virtual model.

Method: The method used for this research is a critical literature review which seeks to find the state of the art to understand the benefits and issues of implementing a sensor to the physical components to link the to the virtual model.

Results/discussion: The main benefit for the project management is being able to monitor the construction progress in real time to detect schedule delays early and make corrective decisions. If the cheaper version of sensors, passive RFID tags are used, problems may arise when the workers need to embed then information in the tags.

Conclusion: Implementation of RFID tags in construction benefits the stakeholders of the project, but the challenges are the cost of the tags and readers plus the extra work hours.

### Key words

Building Information Modeling (BIM), Radiofrequency Identification (RFID), Virtual Models, Physical Components, Construction.



## 1. INTRODUCTION

Virtual Building Information Modeling (BIM) is a set of technologies, processes and policies enabling multi-stakeholders to collaboratively design, construct and operate a facility. (Succar, Bilal, 2013) The use of BIM has supported a fundamental change in the process of constructing a facility. It has changed the information flow between stakeholders from 2D drawings with simple manually added descriptions of the components, to a complete model holding all information about the components and the processes. The BIM concept visualizes the construction of a facility prior to the actual construction, which aids to reduce uncertainty, improve safety and simulate potential impacts. (American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc., 2009)

Figure 1 shows the effect of change over time in a construction process from pre-design to operation.

The change from traditional design processes to the implementation of BIM have helped switching the blue -3- line closer to the preferred design process as shown on the figure with a black line -4-. This change is caused by the information flow of the construction process, where more information is contained in the model in the design phase. As shown on the figure, the cost of design changes early in the design process create a high project value with a relatively low amount of effort. (Volker, Mueller, 2009)

The use of BIM goes beyond the

planning and design phase of projects, extending through the whole life cycle of the building, through the construction phase, the operation phase to the demolishing/reuse phase.

This research will focus on the further implementation of BIM from a construction management point of view.

### 1.1 VIRTUAL MODELS AND BIM

Virtual models are used for almost all constructions made today in Denmark. The models are used in both the design phase and the construction phase. The models can contain only a geometrical 3D representation of the modelled objects but can also contain much more information. (Sørensen, K. B., 2009). Building Information Modeling can contain information about the modelled objects like materials, properties, quantities and coordination between different entrepreneurial disciplines.

Models can also contain time planning and construction simulation which can simulate the construction phase at any time of the project. This is also called 4D modelling. If information regarding cost and life cycle analysis is included it is 5D modelling.

BIM is also a information flow tool. In a construction process there are many stakholders and involved entrepreneurs who needs to communicate to make the project a succes. Figure 2 shows the shared project model.

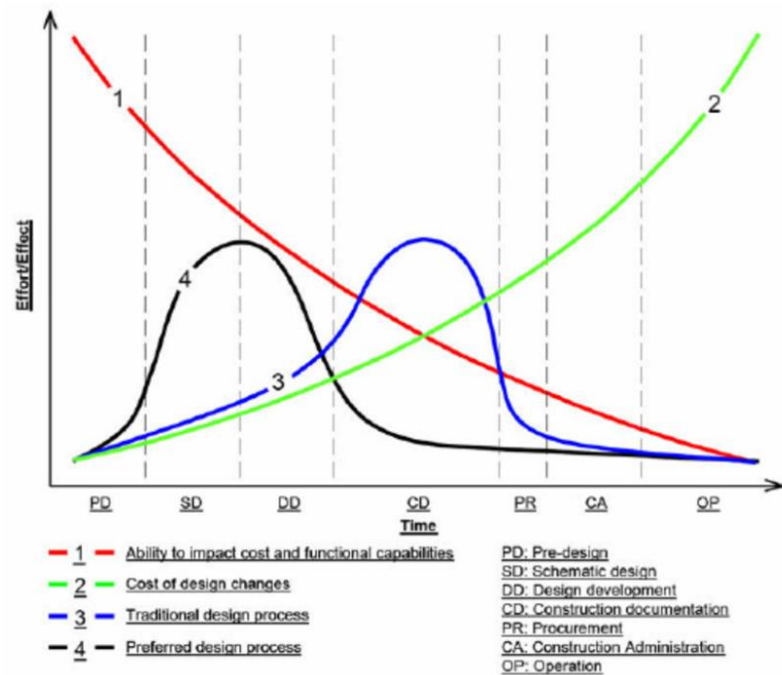


Figure 4: Effort/Effect curve. (Volker, Mueller, 2009)

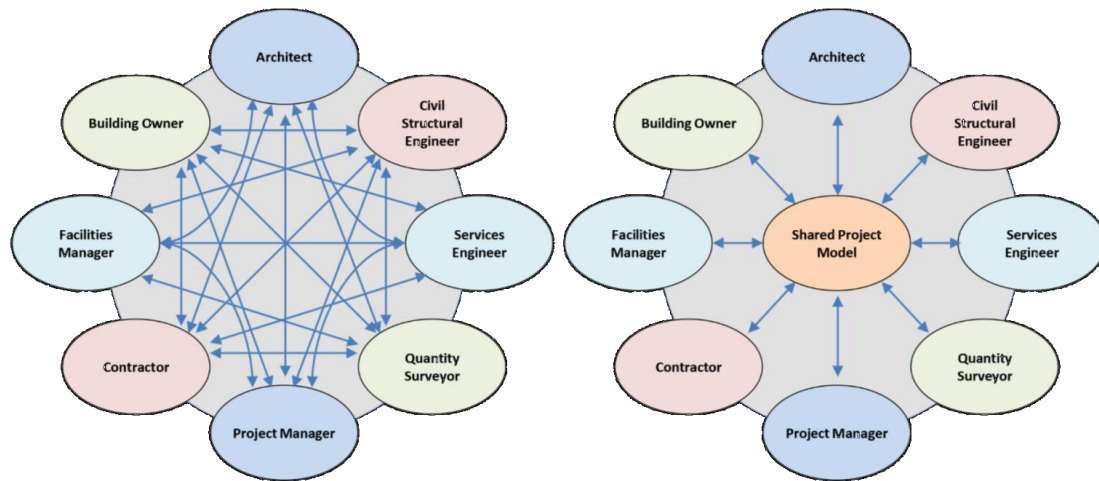


Figure 2: Information chaos vs. shared project model (The institution of structural Engineers, 2012)

The shared project model ensures easier information exchange, project integration and management of project information which improves programme, productivity and quality of the project. (The institution of structural Engineers, 2012)

## 1.2 BIM IN CONSTRUCTION MANAGEMENT

To ensure a lean construction process, careful coordination between the contractor and the sub-contractors is necessary. It is possible for sub-contractors to input all necessary information into the BIM model before beginning construction. This enables opportunities to pre-fabricate and assemble off the construction site and using a 4D model to ensure the arrival of resources on site just-in-time (JIT). Besides avoiding stock-piled resources, on-site waste can also be minimized. (American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc., 2009). An accurate BIM model where subcontractors are included in the design phase of the project can aid JIT arrival of people, materials and equipment on site. If the model is extended to also include material tracking, installation progress and automated position in the field, work hours and waste can be further reduced. (Eastman, Chuck, et. al., 2011)

It is argued by Sørensen, K. B. (2009) that a censor between the BIM model and the real resources in the construction process can improve information- and knowledge handling during the whole lifetime of the construction. One of the big challenges in construction is the cost of defects in the occurring during production, which can be reduced by virtual models and automatic object identification. (Christiansson, P. et. al., 2009).

## 1.3 RESEARCH QUESTION

The research studies the application of a censor between physical components in a construction and the BIM model. The positive and negative results of the censor are investigated. Hence this research will be addressing the following research question:

*“Is it beneficial to use a censor to connect the physical components of a construction project to a BIM model?”*

# 2. RESEARCH METHODOLOGY

## 2.1 INITIALIZING RESEARCH

The objective of the research is to answer the research question by making a literature review on relevant literature. The research explores the use of a censor to connect the physical components of a construction project to a BIM model. Sørensen, K. B. (2009) was a previously known paper used for

initial research on the topic, ensuring that the research was focused on the specified topic. Key-words and information from this paper was used to find and select other papers for further study. The research uses information from already available material and evaluates it.

## **2.2. SELECTING PAPERS**

To ensure a structured and valid approach of finding the most relevant papers and thereby research, selecting papers was structured into different stages.

Stage one was choosing keywords for the research. From the initial research, prior knowledge and discussions with colleagues, four keywords were chosen within the topic: BIM, virtual models, physical components in construction, RDIF construction.

Stage two was finding relevant papers based on their headline. The papers were found using the following online search engines: libray.au.dk, scopus.com and scholar.google.dk. Criteria's for exclusion of papers were: Non-related headline, languages besides Danish and English and papers older than 10 years.

Stage three consisted of reading abstracts of all papers and place each paper into three sorting's; A or B. This stage did not have defined criteria's for selection but based on subjective evaluation of the abstract. Five A-papers were identified, which were the most relevant papers to the research, and the rest of the papers were sorted into the B pile.

## **2.3 QUALITY CHECK AND FURTHER STUDY**

Stage four contained a read through of all A and B papers for quality check. To secure the quality of the A and B papers a fourth stage was introduced. Here the impact factors, author's H-index and number of citations were studied. This lead to four papers being used as main literature.

It was later found that there was a need to elaborate on how RFID tags and readers work, which led to the need for an extra online search to find relevant papers.

## **3. RESULTS**

A case study from Apelgren, S. et. al. (2005) looks at different "Stumble stones" in construction, where it is found that the direct and indirect production costs of defects are around 8%. An example of a stumble stone was a delay in the manpower needed to mount windows. This led to a need to store the windows until man-power was available, because it was not possible to contact the supplier before delivery. The main causes of these defects are found to be:

- 1) Bad communication and cooperation.
- 2) Mistakes in the product caused by a weak design.
- 3) Planning mistakes.
- 4) Insufficient information.
- 5) Mistakes by contractors due to lack of competences, motivation, trust and risk taking because of a lack of allocated resources.

Cause one, three and four can be addressed by adopting radio frequency identification technology (RFID) which uses radio frequency waves to transmit data between readers and tags. (Truijens, M et. al., 2014)

RFID is an automatic identification method which works by storing and remote receiving of data by using RFID-tags or transponders. When using RFID there is no need for direct contact between the

reader and the tags. A RFID system includes an antenna, a transceiver (RFID reader), and a transponder (radio frequency tag). (Alicot, J. F. et. al., 2011)

Figure 3 shows how the physical components are tracked from production through storage and transportation to the construction site.



Figure 3: RFID readers from production to construction site

The integration of RFID tags into the BIM model have been analyzed by Sattineni, A. et. al (2010). The tags are set up to be tracked in an interval such as 10 seconds or 1 second. The tags are located by assessing the position of the last reader to track it. Computing is then required to accurately assess the location of the tag within a pre-defined space. When the information is obtained it can be translated into a CAD filer or a similar format, so the information can be imported into the BIM model.

The BIM software allows the information to be overlaid onto a 3D model and be displayed. The resulting model can be monitored by the construction project manager and used to optimize the project.

### 3.1 BENEFITS OF INTEGRATING RFID TAGS AND THE CONSTRUCTION INDUSTRY

**Project management.** The main benefit for the project management is being able to monitor the construction progress in real time to detect schedule delays early and make corrective decisions. (Akanmu, Abiola A et. al., 2012)

**Equipment and tool management.** In larger construction sites, tools and equipment are often lost, using RFID tags on high-value assets both ensures less time looking for lost assets on the construction site, and less need to buy new assets.

**Inventory management.** With RFID tags, information about inventory can be stored so inventory which have been inspected and certified does not get tossed because the company was unsure of the item. When a construction component is tagged with a RFID tag, ensuring Just in Time (JIT) of the component on the construction site is automatically in the virtual model. This reduces the cost through elimination of waste and makes full use of the workers capabilities.

**Workforce management.** Another usage of RFID tags on hardhats of the workforce can track the number of workers on construction sites as well as their identities, and plot the efficiency in the virtual model, which is needed to use Location Based Scheduling (LBS) for larger projects.

**Enhancing safety.** When tracking the workforce, it is possible to ensure more safety in case of an emergency, where all the workers can be accounted for.

### 3.2 CHALLENGES WITH INTEGRATION OF RFID READERS

Passive RFID tags are the least expensive tags and requires an external energy source to emit a radio signal and have a much smaller range than active RFID tags. Active RFID tags have a build-in energy

source and can be read from long ranges but are more expensive than the passive tags. (Sattineni, A. et. al, 2010)

Chin, S. et. al (2008) examined the utilization of 4D CAD and passive RFID tags for progress management, where a system which renders virtual components in the 3D cad model according to the as-built status. To track the status of the physical components, the passive RFID tags are scanned, and the status information is transferred to the tags. Passive RFID tags requires a close range to update the virtual model and the workers who scan the components needs to be structured to scan all components. If a worker forgets to scan a component, the virtual model will not be updated which will result in much extra work and maybe mistakes in new orders.

Hu, W. (2008) found from his investigation that when the components are tagged with RFID tags and read with RFID readers to track their status from production to the construction site the tracking went easy. When the components are installed, workers use a personal digital assistant (PDA) with a RFID reader to manually add information into the tags which are transferred to the virtual model and updated the 4D model. Because of the manual work, the system is not suitable for large project scales with many components.

## 4. DISCUSSION

It was identified by Navon, R. et. al. (2007) that construction personnel spend a significant amount of the time working on recording and analyzing site data and Cheok, G. S. et. al. (2010) found that 2% of working time were spend on manual tracking and recording of progress data. The risk of mistakes is higher when manual methods are used compared to automatically. A change to automatically tracked data will increase the time working on value creating work and provide construction managers with timely and accurate information. (Navon, R. et. al., 2007)

The physical components in a building may be represented in a 3D revit model as shown on figure 4. The location of the components on the construction site, in transportation or in storage on the construction site is shown in the model together with a color code. The color code as indicated on the figure shows:

**Green** - If the item is finished installed or mounted and no further work is needed.

**Blue** - If the component is ready to be installed and placed on the construction site.

**Purple** - If the component is ordered from a production but haven't been produced yet.

**Yellow** - If information about the component is missing. This indicated that the contractor in charge of the component should check the component and add the missing information.

**Red** - If there is a mistake or crash regarding the component. This indicates that the construction manager should check the component and find the mistake as quickly as possible.

The location of the construction workers on site could also be embedded in the model and marked with a color code which flags if the worker is in an unsafe condition.



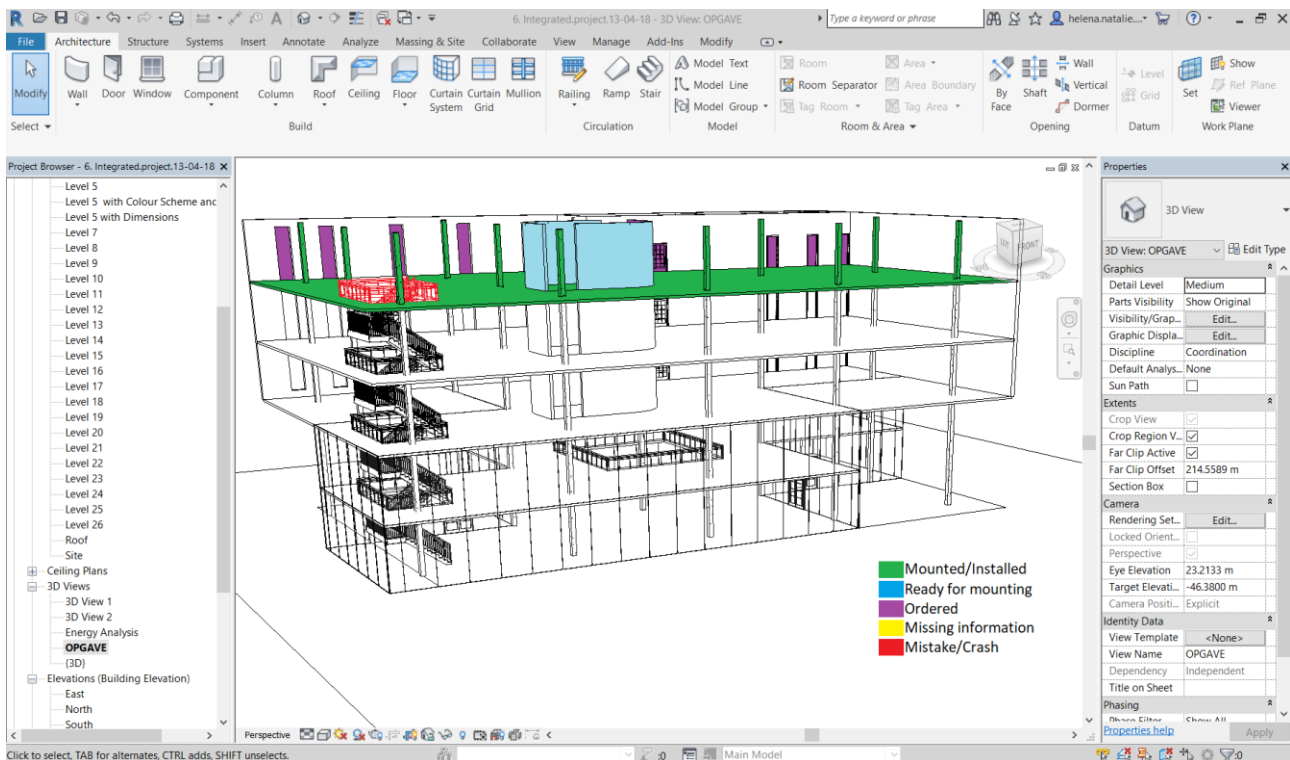


Figure 4: RFID status in the Revit model

RFID tags can be used for all project scales from dwellings to super hospitals. The whole supply chain in the construction industry needs to learn new information transfer protocols as discussed in Chen, B. C, et al (2016). The new way of transferring information and ownership was found to make the whole supply chain more mobility and transfer faster. Table 1 shows some of the different stakeholders in construction, what their problem is, and how it can be solved using automated RFID tags on physical construction elements.

No	Stakeholder	Problem	Result
1	Client	How to follow the time schedule during the construction phase.	Being able to monitor the construction progress in real time.
2	Construction Manager	How to ensure all entrepreneurs and suppliers fill out the BIM model manually when a component is delivered/mounted/installed. And when a mistake/crash is happening.	Being able to monitor the construction progress in real time to detect schedule delays early and make corrective decisions. (Akanmu, Abiola A et. al., 2012)
3	Architect	How to get immediate insight in the implications of design alternatives when a mistake/crash is happening.	Find mistakes or crashes earlier in the construction phase and make design changes accordingly.
4	Prefab concrete manufacture	How to accelerate the communication with entrepreneurs and engineers about delivery and when a design is changed.	Automatically monitor the concrete components at all time and minimize the risk of manual mistakes.
5	Structural Engineers	How to check and approve the quality of the structural elements during the construction phase.	Find mistakes or crashes earlier in the construction phase and make design changes accordingly.
6	Installation contractors	How to accelerate the communication with other entrepreneurs about delays and design changes.	Automatically monitor the construction progress and communicate earlier with other



			contractors if changes need to be made.
7	Fixture suppliers	How to improve communication with the client/engineers when modifications of building fixtures is made.	Automatically monitor the construction progress at all time and minimize the risk of manual mistakes.

Table 1: Stakeholders problems and results when using automated RFID tags.

There are many benefits of the implementation of RFID tags, which the client needs to decide if it outweighs the extra cost of the tags, the readers and the working hours.

## 5. CONCLUSION

The aim of this research was to discuss the benefits and issues regarding the implementation of RFID tags on physical components in a construction to link it with a virtual BIM model.

All stakeholders from client, to architects to engineers and suppliers gain benefit from the implementation. The result of monitoring the construction process in real time is to ensure safety for the workers and detect schedule delays and making corrective decision earlier.

The challenges of the implementation are firstly the cost of the tags and readers. Secondly if a worker forgets to scan a component, the virtual model will not be updated which will result in much extra work and maybe mistakes in new orders. If the cheaper passive version of the tags are used, the range of the tags can also cause extra workhours on the construction site.

## 6. REFERENCES

- Akanmu, Abiola A et. al. (2012) An RTLS-based Approach to cyber-Physical Systems Integration in Design and Construction. Research Article.
- Alicot, J. F. et. al. (2011) Distributed Radio Frequency Identification Reader, EP Patent 2, 070, 000.
- American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc. (2009). An Introduction to Building Information Modeling (BIM) ([http://cms.ashrae.biz/bim/pdf/BIMGuide\\_Rev\\_110309.pdf](http://cms.ashrae.biz/bim/pdf/BIMGuide_Rev_110309.pdf))
- Apelgren, S. et. al. (2005). Snublesten i byggeriet, R-107, BYG-DTU.
- Chen, B. C, et al (2016) The construction of mobile RFID authentication mechanism and relative ownership transfer protocols for supply chain, EMERALD vol. 33 No. 6 pp. 1825-1834.
- Cheok, G. S. et. al. (2010) NIST construction automation program No. 4: non-intrusive scanning technology for construction status determination, NISTIR 6457, BFRL, NIST, Gaithersburg,Md, USA..
- Chin, S. et. al (2008) RFID+4D CAD for progress management of structural steel works in high-rise buildings, Journal of Computing in Civil Engineering, vol. 22, no. 2, pp. 74–89.
- Christiansson, P. et. al. (2009). Prototype development of an ICT system to support construction management based on virtual models and RFID. Virtual Models Linked with Physical Components in Construction. Journal of Information Technology in Construction - ISSN 1874-4753.
- Eastman, Chuck, et. al. (2011). BIM Handbook, A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.

- Hu, W. (2008) Integration of radio-frequency identification and 4D CAD in construction management, *Tsinghua Science and Technology*, vol. 13, no. 1, pp. 151–157.
- Navon, R. et. al. (2007) Assessing research issues in Automated Project Performance Control (APPC),” *Automation in Construction*, vol. 16, no. 4, pp. 474–484.
- Sattineni, A. et. al (2010) Techniques for tracking RFID tags in a BIM model, ISARC 27<sup>th</sup> international symposium.
- Succar, Bilal. (2013). Building Information Modelling: conceptual constructs and performance improvement tools.  
([https://www.researchgate.net/publication/260145769\\_Building\\_Information\\_Modelling\\_conceptual\\_constructs\\_and\\_performance\\_improvement\\_tools](https://www.researchgate.net/publication/260145769_Building_Information_Modelling_conceptual_constructs_and_performance_improvement_tools))
- Sørensen, K. B. (2009). Virtual Models Linked with Physical Components in Construction. Aalborg: Department of Civil Engineering, Aalborg University. DCE Thesis, No. 21
- The institution of structural Engineers (2012) BIM ‘An introduction’. (<https://www.engineersireland.ie/EngineersIreland/media/SiteMedia/groups/Divisions/structures/1-Intro-Engineers-BIM-120416.pdf?ext=.pdf>)
- Truijens, M et. al. (2014) Evaluating the Performance of Absolute RSSI Positioning Algorithm-Based Microzoning and RFID in Construction Materials Tracking. Research Article.
- Volker, Mueller (2009). Conceptual Design Tools: Establishing a framework for specification of concept design tools.  
([https://www.researchgate.net/publication/30873251\\_Conceptual\\_Design\\_Tools\\_Establishing\\_a\\_framework\\_for\\_specification\\_of\\_concept\\_design\\_tools](https://www.researchgate.net/publication/30873251_Conceptual_Design_Tools_Establishing_a_framework_for_specification_of_concept_design_tools))

## VII

### **Ways contractors can use data from the models and benefits of doing so while in the execution phase.**

*Morten Fjordgaard Jensen*

#### **Abstract**

This assignment is about BIM. A overall introduction for some of the subjects of BIM, and such as 2D, 3D, 4D(time), 5D(economics) and collaboration. It goes around some of the ways contractors can work with a material takeoff linked to a BIM model and how this takeoff is a direct source for the time scheduling and lists of tenders. This is both when it comes to how the contractors plan their time and how the make the planning a part of the actual design. The same counts for the economic figures of the project. Here the takeoff is directly linked to how the subcontractors are payed determent by the momentum. Besides the takeoff can be basis for economic figures showing both work executed and turnover for the entire project and help the project management to improve the overview. Prevailing for all projects there can be a great loss of knowledge from phase to phase and much of the lost information could have been avoided by linking the information directly to the model.

#### **Key words**

BIM, Revit, Revit lists, material takeoff, planning

# 1. INTRODUCTION

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The quest in this paper is to read a hypothesis and test it. Here the focus will be whether Revit is good at getting usable data for the contractor in the execution phase or not.

- What are the benefits of using data directly from the model?
- Where are the hindrance for the contractor?

## 1.1 WHAT IS BIM, AND WAY DO WE WANT TO USE IT.

Overall BIM is many things, it includes 2D, 3D, 4D(time), 5D(economics), collaboration etc. BIM is thereby used in all processes from the early stages of development, through the execution phase and into the usage of the buildings. It is important to note that when using BIM the best results is made by incorporating the tools from the very beginning. When doing so all project data can be gathered, and it is minimized what knowledge is lost in the process. This is one of the main points why we as a branch should work for a common measure and evolve the usage of BIM.

When designing buildings and projects in BIM all drawings are connected. Thereby the general 3D model in the overall base for the project, where all 2D drawings is generated. This makes it easy for the designers to make the right material fast, and all changes made in the project, is automatically a part of the final drawings. This is timesaving, and the number of faults is decreased(Matt Ball, 2014).

The building models are object based, which means that every single thing in the model is a object where properties can be linked. It can be technical capabilities, dimensions, object-id's etc. all usable when coordinating the project between stakeholders. To take time and economics into perspective, it is important to know the dimensions and quantity of objects. That is why both 4D and 5D are close related, and the data used to calculate are the same. To simplify collaboration between stakeholders before and during construction the models are generated in the Industry Foundation Classes (IFC) format, which helps importing and exporting object properties(Autodesk, 2018).

The traditional AEC collaboration is based on a lot of individuals communicating by e-mail, courier and post. That way all information gets to all the stakeholders. But with BIM the potential for collaboration through one model is there. By making the models shareable and making it possible for the different consultants to collaborate through the same model, and work contemporary the basis of the projects is getting better, and more consistent projects. By working with classification systems, the work teams know what an object is based off furthermore there need to be specified what level of detail the given objects are designed, since this is how it is concretize what information the model needs to contain.

## 2. WAYS CONTRACTORS CAN USE DATA FROM BIM MODELS AND BENEFITS OF DOING SO WHILE IN THE EXECUTION PHASE

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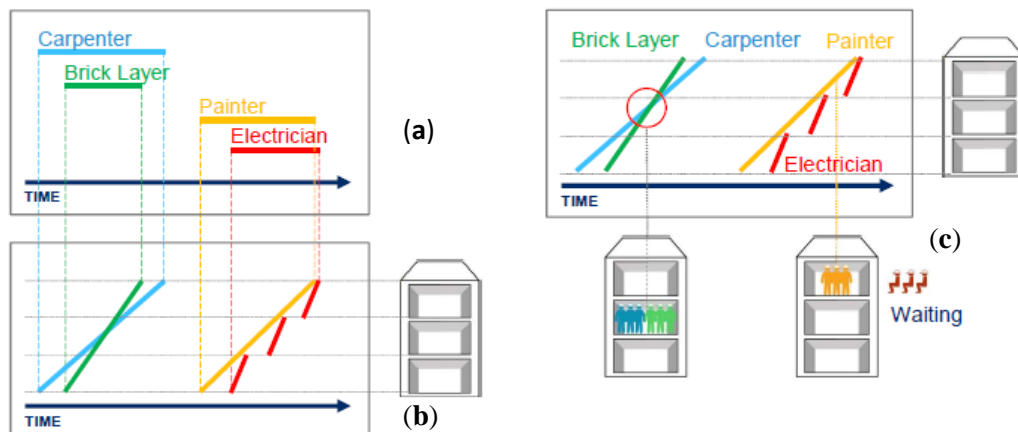
### 2.1 HOW CONTRACTORS USE/CAN USE DATA

When having a BIM model it is split up into sections. All sections then have objects in them, and the dimensions of all the objects can be used for time planning, economic figures and daily planning/ordering materials. This will be described in the following sections.

#### 2.1.1 Time scheduling

For planning it is wanted to get a great flow in all work activities on the construction site. When knowing the exact amount of work in each section, time units are used to get a estimate of how much time is needed. Thereby the contractors can plan the amount of personnel needed for the overall construction and sections, by doing so the planning goes from a Gant chart to a Cyclogram, *Figure Error! No text of specified style in document..5* (a) and (b). This is done to minimize the places where different contractors are working in the same areas of the site at the same time. By coordinating where each and every one is, the general work flow is performing

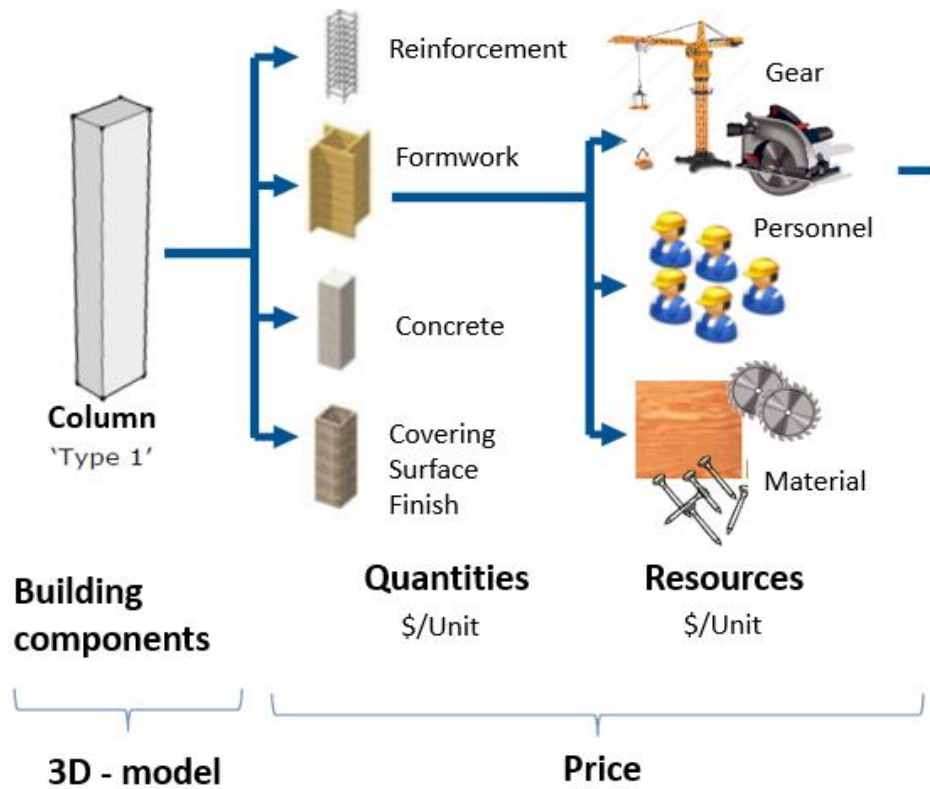
better. It is also known as locations-based scheduling. By planning location based the general overview of the project is easier to manage and becomes less time consuming. When visualizing in Cyclograms, it is easy to see where the overlaps and slips can become a problem, *Figure Error! No text of specified style in document..5* (c). In the figure it is shown how the bricklayer and the carpenter are at the same section at the same time, and if the task interfere something needs to be rescheduled. It is the same thing with the painter and electrician, here it is wanted to make a linear workflow for the electrician, and that is done by having less personnel on that task. For both overlaps and slips it is then noted that the slope is one of the main factors for problems. The solution for each problem is to change the slope, and it is done by changing the number of workers on the given task, this is possible since the tasks are generated by the amount of work in each section, based on the BIM model(Møller, 2017).



*Figure Error! No text of specified style in document..5* - (Møller, 2017). This is a figure showing the principles of location-based scheduling. (a) Normal Gant chart. (b) Basics of a Cyclogram, where activities is spread over locations. (c) What it means when the lines overlap in the cyclogram and, what it means when a line slip.

### 2.1.2 Economic figures

It can be a great challenge for the management team to know how much money they should contract, since the money in the project is payed though the execution phase to all subcontractors who want their money as fast as possible and can't wait to get payed until the whole project is finished. By using the quantities of both main sections and sub sections of the BIM model it can be estimated how much the subcontractor should be payed at a given time during execution. Is it possible as soon as the projects list of tenders is well specified. As shown on *Figur Error! No text of specified style in document..6* where all building components and dimensions are extracted from the model by using Revit's schedules/lists and then prices are calculated by using the price units from the list of tenders.



Figur Error! No text of specified style in document..6: Jeppe Harbo, Exigo, BIM 5D price calculation process

### 2.1.3 Daily planning and ordering materials

The digital output from the model can be used when ordering materials for a given task. If a subcontractor needs information of how much to order the data can be used to locate how many cubic- or square- meters is in a given section of the project. This makes less waste of materials and the process of finding the quantities is found in the model and not by using a ruler and a piece of paper.

### 2.1.4 Collision control

A mayor benefits the models have is the ability of make collision controls for an entire project. The collisions effect both time and money since faults cause delays and they can be expensive repair after other tasks have occurred. Thereby the models help the contractors by giving a better flow in their workflow and less times they must go back a make repairs.(Chris Donahue, 2015)



## 2.2 EXAMPLE - HOW TO MAKE A MATERIAL TAKEOFF

What is needed, is to find the menu “Schedules/quantities” right clicking and press “New material take-off”.

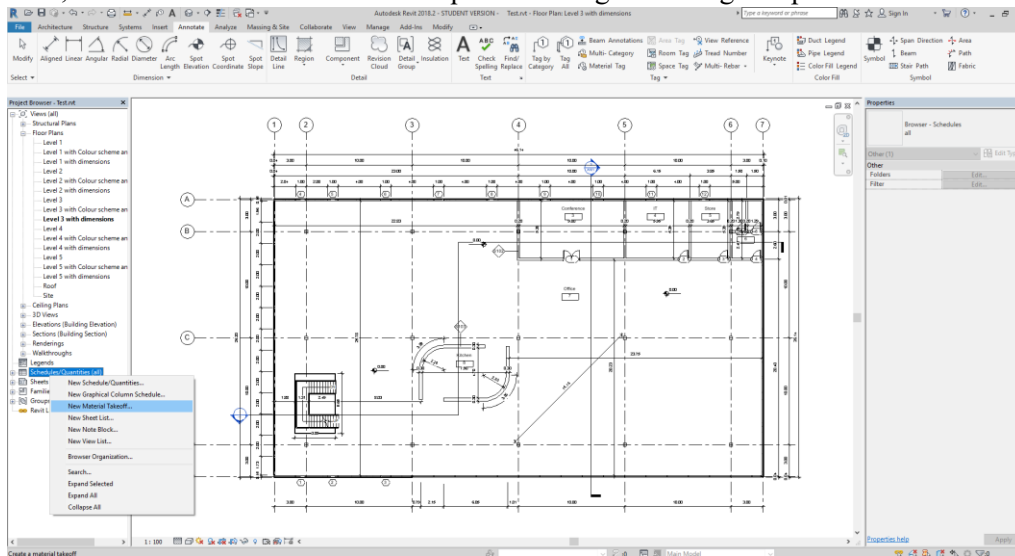


Figure Error! No text of specified style in document..7 -Finding the Schedule/quantities tab.

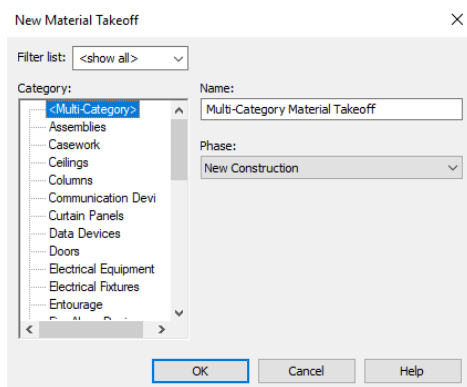


Figure Error! No text of specified style in document..8 - New material takeoff menu, choosing the category

This window is opened, and it is possible take make a material take, on any material in the entire project, for this example it will be done for all doors in the project. (Learn with Rich, 2016)

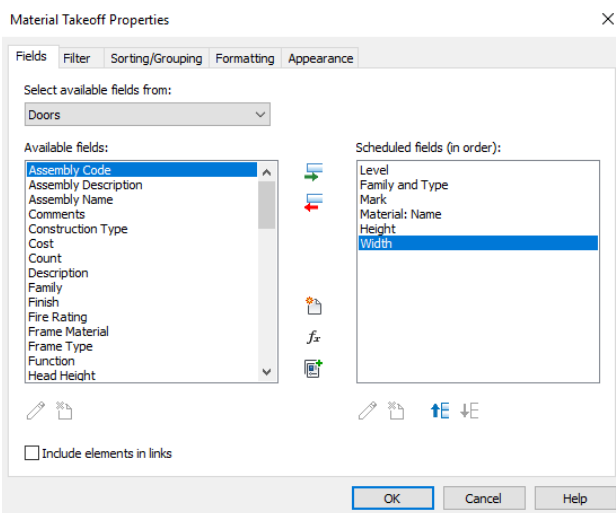


Figure Error! No text of specified style in document..9 - New material takeoff menu, choosing fields for the lists

When selecting “Doors” a new window shows up, and here the different fields that is wanted, needs to be selected.

The lists can be sorted to get a better overview. In properties, select “Sorting/grouping”. When sorting it is smart to sort by level for smaller projects, and for larger projects into sections or subsections.

<Door Material Takeoff>					
A	B	C	D	E	F
Level	Family and Type	Mark	Material: Name	Height	Width
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	1	Glass	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	1	Aluminum	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	2	Glass	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	2	Aluminum	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	3	Glass	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	3	Aluminum	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	4	Glass	2.98	1.95
Level 1	M_Door-Curtain-Wall-Double-Storefront: M_Do	4	Aluminum	2.98	1.95
Level 3	M_Door-Interior-Double-Full Glass-Wood: 150	5	Glass	2.00	1.50
Level 3	M_Door-Interior-Double-Full Glass-Wood: 150	5	Cherry	2.00	1.50

Figure Error! No text of specified style in document..10 - Door material Takeoff, sorted.

By doing this, all doors and panels are sorted, for the floor/section they are located, and at the same time it shows which materials are needed for the specific door. Many larger firms are starting to make product libraries for all their products, and thereby the designer can choose the exact window, doors etc. and put it directly into the model and then all participants know what exact windows are where in the project. (Aliakbar Kamari, 2018; Lindab, 2018)

### 3. BENEFITS AND VALUES OF HAVING MATERIAL TAKEOFFS FROM BIM MODELS

There are many benefits of using the models, here is some of them:

It is faster to subtract data electronically rather than from a 2D drawing. As explained in 0

The entrepreneur can use his time more efficiently and potentially earn more money.

Potential of using less materials in the execution phase, by having a precise way of extracting data from the models. Materials can be many things, and in the case the amount of time used sorting papers, emails and other documents for information, rather than just looking directly in the model, is a great resource that needs to be considered. As seen on Figure Error! No text of specified style in document..11 where all information gathered throughout the phases are kept and stored for the next participant of the project.

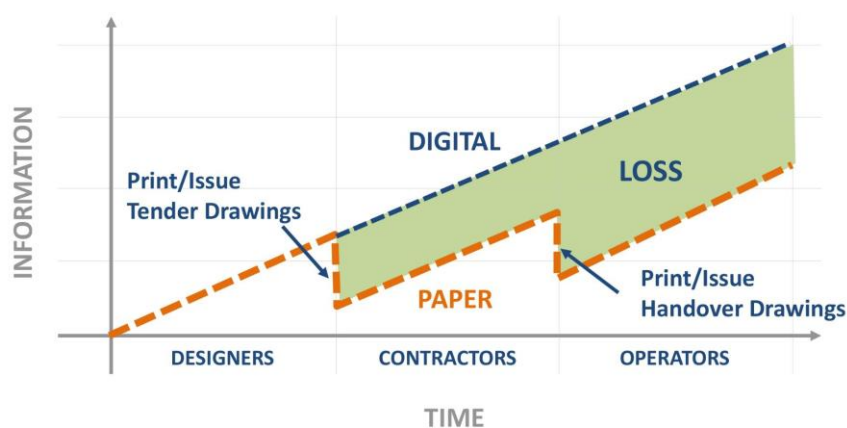


Figure Error! No text of specified style in document..11 – Information lost in the traditional project phases, compared to an all-digital project (Aliakbar Kamari, 2018)

The overall monitoring of the project can be visualized, since it is important for all companies to know they have a positive cashflow. By the traditional methods the project stand is made by estimates from the time

schedules and by looking and walking around the project looking what is done. This can potentially change when using time schedules linked to the material takeoffs. Then it is always known what material is used and how much at any given time. As seen on *Figure Error! No text of specified style in document..12* the data from the project, both visualized how much work that have been executed and the economic figures as well, for the main contractor to use. (Kjærsgaard, 2017; Møller, 2017)



**EXIGO**

*Figure Error! No text of specified style in document..12 - Example on use of data from the project (Møller, 2017)*

## 4. HINDRANCE FOR THE CONTRACTOR

For all material take offs to be possible, the architects and engineers of the early stages needs to keen in the way they label and mark the objects of the model. If they don't follow the same rules of how to label objects it can be frustrating and time consuming for the users of the model, since it can be a great deal of work to categories objects when the project is designed.

## 5. CONCLUSION

In general, Revit can extract a lot of information directly and dynamically from the model. This makes the schedule/quantitie lists a very viable tool for the contractor who wants information from the model fast. When making a setup for the different materials and objects the information is always there to look at. It is important for the users of the model that the design team has been keen with the naming of objects.

If a lot of information is extracted at once, the quantities can vary, since the model must be generated in a way where difficult details are modelled correct, before the overall material takeoff is correct.

Before the contractors can use material takeoff they don't need any specific skills for platforms such as Revit. But to make a material takeoff a short introduction for a person with interest in knowing and using BIM on a greater basis should be enough. This is based on the simple steps in 0. This would be my recommendation for the contractors to focus more on the simple tools that have the possibilities to make their work easier and some of their daily tasks less time consuming.

## 6. REFERENCES

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### References

- Aliakbar Kamari. (2018). *Building information modelling BIM*. Unpublished manuscript. Retrieved 16.02.2018,
- Autodesk. (2018). About the IFC file format. Retrieved from <https://knowledge.autodesk.com/support/revit-learn-explore/caas/CloudHelp/cloudhelp/2018/ENU/RevitLT-DocumentPresent/files/GUID-0D546BEA-6F88-4D4E-BDC1-26274C4E98AC-htm.html>
- Chris Donahue. (2015). The BIM revolution: The top 3 benefits of using BIM in construction. Retrieved from <https://www.ediscompany.com/blog/the-bim-revolution-the-top-3-benefits-of-using-bim-in-construction/>
- Kjærsgaard, E. (2017). *Interview med esben kjærsgaard fra MT højgaard*. Lystrupvej 50, 8240 Risskov:
- Learn with Rich. (2016). **Revit architecture lesson 21: How to create material takeoff schedule**. Retrieved from <https://www.youtube.com/watch?v=1PnFjGXgFjo&t=320s>
- Lindab. (2018). Revit library. Retrieved from <http://www.lindab.com/dk/pro/software/building-components/bim-byggekomponenter/revitlibrary/pages/default.aspx>
- Matt Ball. (2014). Building information modelling for the win: Top 11 benefits of BIM.
- Møller, L. (2017). *Interview med lasse møller*. Katrinebjergvej 93B, 8200, Aarhus N: Exigo A/S.

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Aliakbar Kamari, Poul Henning Kirkegaard (Eds.), Building information modeling (BIM) 02 Further exploration in Architecture, Engineering and construction, 2018