Required model content and information workflows enabling proficient BIM usage

Jure Cesnik¹, Marko Zibert¹, Martin Lah¹, Matic Skalja¹
¹Elea iC, Dunajska cesta 21, 1000 Ljubljana, Slovenia
jure.cesnik@elea.si

Abstract. The modern issue within the construction industry is its conservative approach to innovation and poor data management. In a world where information means everything and efficient workflows are becoming the norm for advanced businesses, not using the attainable data pool is a recipe for stagnation and even regression. Different ways to mitigate the risks involved in building projects have been developed at the design company Elea iC to become more flexible and efficient. Through several large-scale high-rise and tunnelling BIM projects in the past four years, engineers at Elea iC have identified two crucial development barriers for advanced proficient BIM usage. The first is organizing the BIM models: internal model structure, information required in models, and how this information is written into models. The second barrier is establishing crucial information workflows to achieve valuable practical results. Exploration of the required model content and its organization together with data workflows are thus the main purposes of this article. Incremental improvement from project to project was needed to provide a much-needed baseline for crucial project data which makes 4D, 5D and 6D BIM modelling possible. A database structure for model properties was developed, from which consistent properties can be inserted into all project BIM models. This provides a unified internal standard ensuring the correct level of information modelling. At the same time essential workflows for BIM implementation, modelling, data sharing, and information management were also developed. Standard BIM software was used to create the base models, but collaboration with other software developers and adapting their solutions was needed in order to attain the desired outcomes of advanced BIM analyses. As more and more clients require advanced BIM solutions for their projects, neglecting to develop and implement new ways of using BIM will diminish companies' potential in the market in the long run. This paper demonstrates that BIM, coupled with databases including standard model content requirements and information workflows, can provide a credible solution for proficient project data management in the construction industry. Therefore, BIM must not be seen as an impractical tool only requiring additional expenses, but as a system that needs internal company development to be adequately utilized and profited from.

1. Introduction
The construction industry has been, in comparison to other similar industries, such as electrical and mechanical, relatively slow on the uptake of new technologies. This has been attributed to its conservatism in regard to design and execution of its unique products [1] and fragmentation of the entire sector [2]. Such a state has led to the construction industry becoming almost 19 % less labour productive from 1964 to 2012 in comparison to other non-farming industries that improved their productivity for at least 150 % [3]. Although worrying, this fact shows there is a lot of space for improvement and implies
large derived gains for design and contractor companies if they evolve. One of the fields in which such progress can be made is information technology (IT).

Currently, different IT solutions are becoming readily available and large data sets with information flows are transforming many core business approaches in a variety of non-farm industries (mining, energy, manufacturing, transportation, etc.) ([4], [5]). Unfortunately, the construction industry is positioned at the tail of technological development [6]. In the 1990s the quick IT uptake started with the widespread use of CAD (Computer Aided Design) but the progress slowed down immensely and has only recently been re-incited with the arrival of BIM (Building Information modelling). BIM is regarded by many authors ([7], [8], [9]) as the spark that will kick-start the overall progress and eliminate stagnation in the construction industry. Others have already expressed concerns about the lack of project-based evidence regarding benefits of using BIM and warn the engineers against blindly believing such optimistic assumptions ([10], [11], [12]). Nevertheless, they all agree that there is currently no other technology available that project participants could effectively use in order to advance the construction industry and rare studies done on real projects confirm it [13].

Civil engineers create large amounts of data and information for their projects, most of it lost due to poor communication between project participants [14] and impaired data transfer to the next project stage [7]. Historically, most graphical project data was transferred only via 2D drawings, while only essential non-graphical data was delivered in its condensed form via reports or spreadsheets. Since data transfers were absent, the same information was independently reproduced multiple times (e.g. quantities calculations for resource planning), making the entire process inefficient. There was also no explicit connection between 2D graphics and non-graphical information. BIM represents a different approach to CAD since it heavily relies on an existing data pool included in the models themselves. Data and information can also be referred to with links and pulled into databases which provide a data source for the entire project. This opens up new possibilities, but also poses great challenges to data transfer because of its novelty and higher complexity [15].

The construction industry needs to specify which topics are most relevant and need to be investigated by researches and be developed upon first. This article’s main purpose is thus to present our own attempt at BIM implementation and the barriers we faced, as well as to provide the academia with a practical base on which further work can be formulated. It presents a mix and comparison of two approaches, the reviewing of scientific papers and the analysis of practical BIM implementation. The projects in question cover a wide array of diverse fields from architectural and structural design to tunnel design and were executed by Elea iC, a civil engineering design company from Slovenia, part of an international iC group. Because of professional confidentiality some projects cannot be mentioned by name and are represented by generic names.

2. Literature overview
BIM began in the late 1980s, but most of the research in the 1990s was still focused on CAD as a change of technologies (physical to digital) and scientific studies of BIM only became prominent in the 2000s [16]. As it became apparent that BIM is not just a new tool, but could drastically change core workflows [17], most of the early scientific research focused on potential BIM uses and developed theoretical schemas which could be followed by developers to improve BIM software. Even though pilot projects were studied, the majority of papers stayed theoretical or were based on polls conducted among engineers and not real-world projects. This is not surprising since large BIM projects were rare.

In the early 2010s BIM projects started becoming more common with the adoption of the new UK construction strategy and similar national roadmaps. The focus of scientific discourse widened and started connecting BIM to other fields, such as MEP, facility management, sustainability, etc. This led
to a large number of guidebooks and guidelines created to define the required BIM model content for high-rise buildings, but very little was ever written on required model content for infrastructure.

Furthermore, process and business changes through BIM were scarcely studied [18] and most of the existing research was conducted from a theoretical or conceptual standpoint ([19], [20], [21]). Although academic explorations of workflow changes and implementations were well-conceived, they lacked practical testing on real-life projects [11], which could be contributed to a serious lack of universal metrics for BIM implementation assessment [22]. Even more scarce is the research on required model content and standard attributes for elements in BIM models. Some organizations (buildingSMART, NATSPEC, BIMForum, BIMobject, etc.) have tried to define them with mixed success. Additionally, Sacks [23] emphasizes the importance of clear-cut BIM protocols, guides and standards for large clients. These BIM documents define the framework for all future projects regarding all the information included in the models and workflows through which this data flows.

3. Practical implementation

As most civil engineering design firms, Elea iC has paid close attention to developing technologies to stay ahead of the competition, mitigate project risks, provide higher quality products and expand professionally into new fields. Even though BIM was first mentioned and emerged in the late 80s [7], early software lacked flexibility and functionality that CAD programs had and was not useful for our projects. Elea iC first used 3D modelling BIM software in 2003 when we modelled steel structural frames with ProSteel. From there on we expected a steady transition from 2D CAD to 3D BIM over a course of 15 years with minor planning. In the late 2000s the global financial crisis and the following lack of large construction projects in Slovenia forced us to focus on projects outside of Slovenia, mostly across Northern Europe. In 2012 Elea iC was involved in the Stockholm bypass design for tunnels and, for the first time, we experienced the difficulty of performing a good tunnel design in BIM and realized how BIM changes the way design companies communicate and work on a large infrastructure project abroad.

It became apparent that active implementation of BIM needs to be heavily incorporated into our work for us to follow the international trends and progress. The following year the very first office BIM implementation plan was set in place taking guidance from the newly developed PAS 1192-2 specification [24] and other BIM publications and guides ([8], [7], [25], [26]). Its major points were:

- Education of engineers and technicians in BIM software.
- Formulation of new office positions for BIM manager and BIM coordinators.
- Creation of new communication, naming and data exchange protocols and workflows.
- Development of in-house scripts and standard properties used in BIM models.
- Development of open BIM workflow between different in-house BIM solutions.
- Close collaboration with software developers.

During the next 6 years this process evolved incrementally with each project, as higher requirements from clients pushed us to adapt new workflows for modelling, communication, and planning to find practical solutions. This has allowed Elea iC’s engineers to mitigate the risks involved in building projects and generally become more flexible and efficient in our work, but it required extensive effort and technical ingenuity. Work on large-scale projects with advanced clients, e.g. the Karavanke tunnel on the Austrian-Slovene border and Logistics center LIDL in Slovenia (see Figure 1 and Figure 2), showed that software limitations always exist, but are not the main barrier for improvement. Two greatest hurdles were organization and definition of BIM model content and information workflow creation. Valuable practical results with BIM can only be achieved when engineers define the internal
BIM model structure, standard project information and how this information is written into models, as well as establish crucial information workflows for collaboration.

Figure 1. BIM models used in the Karavanke tunnel project with different LODs

Figure 2. 4D and 5D analyses for Logistics center LIDL

The exact model content required for each type of project was developed and evolved as deficiencies were discovered in new projects. Collaboration and information workflows were intensely studied and tested through multiple high-rise and tunnelling projects. Each time a workflow was developed and defined for a certain project, the project requirements, designs, or participants changed during project development, causing modifications in the original workflow. BIM staff at Elea iC investigated these changes in model content, workflows, and properties throughout all projects. This allowed us to analyse which approach worked and which didn’t, develop better workflows, and apply gained knowledge to
similar new projects. Feedback from clients and other project participants of pilot BIM projects was also included in the analysis since pilot projects provided a perfect opportunity for knowledge exchange. Sharing useful results from projects with the rest of the iC group companies to obtain their assessment and vice versa allowed for the creation of a large knowledge base of various BIM projects.

4. Results and discussions
Comparing the existing literature regarding model content and information workflows, as well as our own experience with BIM implementation, clearly shows a disparity between the needs of the construction industry to solve real-life project challenges and the current scientific development. Even more worrisome, the existing research is mainly focused on high-rise buildings, even though large infrastructure projects can amass larger benefits from using BIM. Since academic research does not provide a detailed common ground, civil engineering firms like Elea iC are experimenting with different possible solutions and developing their own systems. In one of the few research papers analysing workflow implementation into a large construction project Nuttens [27] stated: “Our further BIM developments will mainly focus on adding more uniformity and intelligence to the models.” This implies the need of other companies to unify and standardize information included in BIM models as a prerequisite for better information flow. Our own internal research and development was thus focused on the required model content, element attributes, and data workflows.

Analysing other companies’ work and our own BIM projects, we realized that there are four large general barriers that are limiting our progress with BIM (see Figure 3): mentality, knowledge and skill, software, and hardware. A very similar conclusion was deducted by Hong [28] as he categorised influential factors into three groups: adoption motivation, organizational competency, and ease of implementation. To overcome these barriers different types of progress towards process development and BIM implementation must be made: behavioural, organisational, technical and financial. Three of these types were already researched by Zeng [29], although he omitted the role of finances.
Elea iC passed the first barrier, a change in mentality, when we decided to start implementing BIM in our regular project work. A conscious decision was made to upgrade our tools and optimise our work to improve our efficiency and competitiveness. Although slow at first, the company’s engineers started to recognize the benefits of using BIM and we heavily invested in software skills and education, which required additional financial support. Using BIM on smaller projects proved to be advantageous without a noticeable change in our organization since early BIM workflows and end results are very similar to old CAD ones. However, as we progressed and started using BIM on larger projects with higher employers’ requirements, old organisational workflows became inefficient. The main issue for proficient use of BIM was not the lack of skill, but out-dated approaches and workflows compounded with poor knowledge of reorganization. As we progressed from project to project, we started reforming our work processes and formulate new workflows involving different CDEs, project portals, BIM execution plans and BIM element attributes. We created our own internal standards of work which enabled us to breach the second implementation barrier, knowledge and skill [30-32].

Developing BIM workflows through projects even further enabled us to organize our information flow from a very chaotic and inclined to data-loss to a more fluent and intelligent one. This required more organisation and specialisation in workflow development, in addition to heavily investing in studying new software and pushing old software to its limits. Software improvement can only be done
in collaboration with software developers and, in our experience collaborating with Seequent for 3D geological modelling and Deswik for 4D and 5D planning, smaller and more specialized developers are usually more willing to collaborate and expand their software into new fields. For general BIM modelling software, we internally developed programming scripts, extending their versatility to suit our new workflows. Consequently, we pushed the third barrier until hardware itself started limiting us with longer processing times for large BIM models. The fourth barrier can be pushed higher with better hardware but is eventually limited by the increase in processing power. The processing power for processors roughly doubles every two years (Moore’s Law), but this is generally offset by more complex and less efficient software (Wirth's Law), therefore the future might be cloud-based computing.

The entire development process had to be accompanied by information standardization and workflow improvement since non-geometric information is becoming increasingly important for additional BIM use cases. Standard attributes for architectural and structural models for high-rise projects such as IKEA Ljubljana, Logistics center LIDL and Šumi Ljubljana were established. These included attributes for element location, quantities derived from and additional data appended to the element. Our goal was to internally standardize information as the electrical and mechanical companies have done in the 1990s through an iterative project-based process.

As mentioned before, Elea iC developed a general project information and knowledge feedback loop (see Figure 4), starting with our company’s BIM implementation plan and iteratively developing from project to project. Revisions of BIM projects gave us an overview of workflow development and changes over time as projects progressed and employer’s BIM requirements increased. We used this knowledge to update our workflows and the attribute database scope and depth and use them for new projects. Such incremental project-based progress is required so the struggle for project optimization can be studied to discern useful information and processes for new projects (so called learning by trying) [11]. Such an approach creates an open-ended process with steps directed by the company’s BIM implementation plan but no well-defined final stage and requires development by experimenting (continuous learning and improvement) [7]. Our efforts have clearly pointed out major deficiencies in BIM development:

1. Disparity between academic research, state of software development and required practical BIM software and workflow solutions in design and contractor companies.
2. No standard property data sets or comprehensive classification for different types of building elements.

![Figure 4. Iterative project-based BIM implementation process](image)

For this purpose, great financial and professional effort was put into creating our own SQL database containing an element type classification with all our standardized attributes. Even though classifications Uniclass 2015 and OmniClass are both highly influential and prominently represented in all major BIM software, they are not exhaustive enough and leave out large portions of building element types. We constructed our own classification combining both of them with IFC4 and our own past experience from
each new project. The defined attributes were then assigned to element types derived from this classification. Notably, such internal development is important for tunnelling projects where the IFC schema or any sort of classification is non-existent. The database was developed, expanded, and later on also tested on tunnelling projects such as Karavanke South and North, Sydney tunnel, and Austrian railway tunnel projects. Only with well-defined attributes used in all models were additional tasks performed on the BIM production model even possible – this is where the benefits of such a database become apparent. These tasks include BoQ creation, scheduling (4D), and cost planning (5D) using activity rules (see Figure 2).

Using our SQL attribute database still requires some manual handling with queries and different scripts, but we are able to pull this information into some BIM modelling software (e.g. Archicad) and also include it into BIM execution plans (BEP). In our experience a well-defined BEP is vital to limiting the number of inconsistencies during design development and enabling engineers to implement advanced BIM use cases on complex engineering projects. A well-defined BEP needs to provide the entire design and construction team with:

- Detailed workflows and information flows definition.
- Optimal segmentation of project to partial models.
- An appropriate classification system for element types.
- Definition of required properties (names and values) for different BIM use cases with finely defined levels of development for each element type.
- Quality control of the content during design development.

5. Conclusions
The modern issue within the construction industry is its conservative approach to innovation and poor data management. Many civil engineering and contractor companies still only see BIM implementation as a simple change of tools and thus struggle with it. Companies which want to improve their work processes with BIM implementation need to formulate a company BIM implementation plan to overcome four general progress barriers: mentality, knowledge and skill, software, and hardware. The heights of these barriers depend on the main goals defined by each individual company and require behavioural, organisational, technical, and financial progress.

BIM implementation process is an iterative process demanding constant feedback from projects. Such an approach enables companies to develop their own project workflows to improve information flow between different BIM use cases. These workflows can enable proficient use of BIM models for further analyses, mainly 4D and 5D. For these analyses to be at least semi-automatic and produce useful results, standard attributes with classifications need to be established. Scientific research in this field is somewhat lacking, which forces companies and organisations to undertake the task themselves. More collaboration between design companies and smaller software developers is also needed to create software that can use uniform data sets produced for such use cases. Consistency and uniformity of information in BIM models can be provided with SQL databases connected to planning documents and BIM software. Our next steps in Elea iC are to provide this connection for all our documents and software automatically and to develop internal standard attributes for other fields besides high-rise and tunnelling.

Without such undertakings proficient BIM model usage for 4D and 5D planning and other use cases would not be possible and following the design changes during projects would be very manual labour intensive if not nearly impossible. As project requirements keep on rising, there is a great need in the construction industry for more development using real projects for research material, since it is
impossible to determine neither the required model attributes nor develop the workflows without them. Using such an approach, BIM can provide a credible solution for efficient project data management in the construction industry, where companies can consequently reap larger benefits from it.

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