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APPLICATION OF BIM DESIGN MANUALS: A CASE STUDY

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ABSTRACT

A problem often encountered by contractors is that the information provided is not always equal to the information needed in the Building Information Model (BIM). Somewhere between the BIM design manual and the final BIM information is omitted. The purpose of this paper is to identify the source of the information loss. Therefore, the relation between model information requirements in BIM design manuals, tender documents and the final BIM was investigated. The research included a literature study, a document study and a case study. In detail, three discipline models (road, construction and lighting) were investigated from a design-bid-build project in Norway. The results showed that the requirements were mostly complied with (sometimes with a pragmatic approach). However, the requirements represent the client's focus on the design and the in-use phase. Whereas the contractor's focus on the production phase is not given the same attention. From that perspective, the results are twofold; 1) some of the required information is not provided in an exact and reliable form, while 2) resources are spent on providing not required information. This applied research showed that design manuals should reflect new project delivery methods to support lean principles for all parties involved in the project.

KEYWORDS

BIM design manual, infrastructure, lean construction, waste, standardization.

INTRODUCTION

BIM is a widely used term in the architecture, engineering and construction (AEC) industry. The acronym is used for both an action (Building Information Modelling) and a result (Building Information Model). While both descriptions of the term are true in most contexts, BIM is most of all a method for object-based computer modelling with attached information. According to Williams (2015), the term "Building" is misleading, because "BIM models are not exclusive to building projects". However, the term describes the current situation well as BIM is still mainly applied to buildings and the infrastructure sector is left behind (Shou et al. 2015).

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As public infrastructure is mainly owned by governments, public initiatives are necessary to increase the usage of BIM in infrastructure projects. In Norway, public clients such as the Norwegian Public Roads Administration (NPRA) have published BIM design manuals. While the usage of the design manual (and BIM) is not mandatory yet, the NPRA can force the AEC industry to use BIM for infrastructure projects. It is an important tool to stimulate and contribute to the digitalization of this industry.

The NPRA's design manual V770 (Vegvesen 2015) was first published in 2012 and has since then been applied to many road projects. Most recently, the NPRA started projects requiring only a limited number of drawings. The information that is normally conveyed in drawings must therefore be included in the BIM. A problem often encountered for the contractor is that the information provided is not always equal to the information needed in the BIM (Eastman et al. 2011). Somewhere between the BIM design manual and the final BIM information requirements are omitted. The results are twofold; 1) some of the required information is not provided, while 2) resources are spent on providing not required information.

Womack and Jones (1996) described the five principles of lean thinking (value, the value stream, flow, pull and perfection) based on the concepts and principles of the Toyota Production System (TPS) developed by Ohno (1988). Other researchers investigated the application of the TPS concept on the AEC industry and introduced lean construction (Koskela 1992, Ballard and Howell 1994, Howell 1999). Lean construction focuses on waste reduction; value increase and continuous improvement (Sacks et al. 2010). Hicks (2007) mapped the seven wastes of manufacturing reported on in Womack and Jones (1996) to information management. This is especially interesting, as recently "Better Information Management" was introduced as an alternative explanation of the acronym BIM (Borrmann et al. 2018, UK Roads Liaison Group 2018). This alternative understanding of BIM stresses the importance of information in AEC projects and the value that lies within BIM. While BIM and lean can be applied independently on AEC projects, Sacks et al. (2010) revealed several interactions, which were demonstrated by Fosse et al. (2016) through a case study.

The study presented in this paper identified the lean construction principles *waste reduction, value increase and improvement of the information flow*. To the authors' knowledge there is little empirical research on the relation between model information requirements in BIM design manuals and tender documents, and between tender documents and the final BIM. To examine this, the paper addressed the following research questions:

- What is the difference between the model information requirements in the BIM design manual and the tender documents?
- What is the difference between the model information requirements in the tender documents and the BIM model?

One design-bid-build project from Norway was studied. The project covered the concept development and detailed designing phase like outlined in Knotten et al. (2016). Other delivery methods like design-build or integrated project delivery (IPD) were not evaluated.

CASE STUDY DESCRIPTION AND METHOD

A qualitative research design was selected instead of a quantitative because requirements in BIM design manuals are a novel topic. Therefore, the research reported on in this study included a literature study, a document study and a case study. A literature study was carried out according to the steps described by Blumberg et al. (2014): 1) build information pool, 2) apply filters to reduce pool size, 3) rough assessment of sources to further reduce pool size, 4) analyze literature in pool and 4) refine filters or stop search.

Thereafter a case was selected. The case was a road project (Fv47 Åkra sør – Veakrossen) in western Norway, consisting of 7 km highway and 3 km secondary roads. This case was chosen because it was one of the first road projects from the NPRA not demanding any drawings in the tender documents except legal binding ones. In fact, the ambition was to deliver the project with no drawings at all. One of the requirements in the tender documents was the usage of the client's BIM design manual (V770). The core element of this manual is a mandatory BIM approach for infrastructure projects.

Concerning the usage of BIM, the client and the designers agreed early upon waste reduction, one of the principles of lean construction as adapted by Koskela (1992). BIM was the means for this principle. In the examined case, drawings should only be produced when they conveyed the information more effectively than the BIM. Is must be mentioned that the project's design phase was not finished yet when it was studied. However, the authors regarded the models to be valid for the research intention and fresh results could be presented to the IGLC community.

The prescriptions as outlined by Yin (2018) were followed during the case study and documentation was used as the source of evidence. The BIM was examined, and relevant documents were studied. The first author was part of the project team and obtained the documents and had access to the BIM. In detail, the client's tender documents and an additional document clarifying the mutual understanding of the level of information in the discipline models were studied. This document was agreed on after the contract was signed and replaced those parts of the original tender documents concerning the level of information. Furthermore, a BIM execution plan (BEP) solely produced for the construction discipline model was examined. A BEP describes "how the information modelling aspects of a project will be carried out" (British Standards Institution 2013). All of these documents were chosen because they described the requested level of information in the models for the case study.

Thereafter, the discipline leaders for the three discipline models were interviewed. They were chosen because they were responsible for compliance with the information requirements. The reason for the interviews was to confirm that the authors' impression of the available information in the BIM was correct and to find out why some requirements were not complied with. The interviews were semi-structured and lasted between 15 and 30 minutes.

THEORETICAL BACKGROUND

BIM FOR INFRASTRUCTURE

According to Williams (2015) there are a variety of different terms used to distinguish the application of BIM to vertical and horizontal constructions, like "Civil BIM, CIM, BIM for infrastructure, Heavy BIM, etc.". The authors' impression is that the term "BIM for infrastructure" is mainly used, especially in Scandinavia, and they decided to use it in this paper. The main difference between BIM for infrastructure and "vertical" BIM is its geographical extend and its dependency on geospatial data and coordinate systems. In BIM for infrastructure projects real-world coordinates are assigned to all objects (EUREF89 NTM in the presented case) instead of local coordinates and a reference point like in "vertical" BIM. Something unique to BIM for infrastructure in Scandinavia, especially in Norway, is the wide use of a BIM tool which handles information and models comparable to a GIS tool, namely Trimble Novapoint (2019).

DIGITALIZATION

There are different definitions of the digitalization process used by practitioners and researchers. One definition, which the authors regard precise is from i-scoop (2018). They used the terms "digitization", "digitalization" and "full transformation".

- "digitization": *"transformation from analog to digital (...) with the goal to digitize and automate processes or workflows"*.
- "digitalization": *"use of digital technologies and of data (...) to create revenue, improve business, replace/transform business processes and create an environment for digital business, whereby digital information is at the core."* In other words, using the digitized data to create an improved product.
- "digital transformation": builds upon digitization and digitalization and *"encompasses all aspects of business, regardless of whether it concerns a digital business or not, ... ultimately leading to a new economy."*

DESIGN MANUAL V770

The design manual V770 was first published in 2012 and revised in 2015. The NPRA invited designers, contractors, surveyors and software developers to contribute. The purpose of the manual is to reduce the number of errors in the production phase by using BIM in the design phase. It defines delivery requirements for models of the existing and designed situation. These delivery requirements describe both the model data and the model content. However, it does not explicitly prescribe that all information must be included as property data on the object level in the models. Drawings and external documents are mentioned as an alternative. This was mainly due to the fact that infrastructure projects with only a limited number of drawings were not common at the time the V770 was published. The manual classifies models of the existing situation into four types and models of the designed situation into 19 discipline models. Besides the delivery requirements there are also process requirements, like multi-discipline collaboration, clash detection and the extraction of stakeout data from the discipline models. Finally, it requires as-built models to be delivered to the national maintenance base.

For the purpose of this paper three of the 19 discipline models were selected and investigated. In particular, the required information of the discipline models road, construction and lighting was examined. Table 1, column 2 shows the model information requirements for the three models investigated.

DESIGN PROCESS

The Norwegian approach called Next Step was used for the classification of project phases, reported on in Knotten et al. (2016). In design-bid-build projects for the NPRA designers usually are involved in step 3 (concept development) and step 4 (detailed designing). The deliverables are different types of plans. In the concept development phase designers deliver legally binding (municipal) zoning plans. If these zoning plans describe the project with enough detail no further permit is needed prior to construction. However, constructions (bridges and culverts) always have to be approved by the Directorate of Public Roads. In the detailed designing phase, designers deliver a construction plan. The construction plan is based on the zoning plan and is the foundation for the contractors in the production phase.

FINDINGS

This paper investigated the relation between requirements in BIM design manuals and tender documents, and between tender documents and the final BIM by answering the following questions.

- What is the difference between the model information requirements in the BIM design manual and the tender documents?
- What is the difference between the model information requirements in the tender documents and the BIM model?

DIFFERENCE BETWEEN BIM DESIGN MANUAL AND TENDER DOCUMENTS

A comparison of the BIM design manual and the tender documents (see table 1, column 2 and 3) revealed that there were no deviations for the road and the lighting discipline model. However, major deviations could be found for the construction model. Only two requirements from the design manual were reflected in the tender documents, but four extra requirements were added. One of these additional requirements were "all other information that is normally conveyed in drawings".

The reason for the deviations for the construction model are a changed approval mode by the Directorate of Public Roads. This was especially true for the "all other information" requirement. At all times, constructions needed to be approved by the Directorate. A special set of drawings had to be produced. However, when the tender was sent, the Directorate opened for model-based approval requiring only a minimal number of drawings. The basic principle of the model-based approval was that models should have at least the same level of detail as drawings used to have. This new approval mode was neither reflected in the design manual V770 nor in the tender documents. Instead, the Directorate required a detailed BIM Execution Plan (BEP) specific for the construction discipline model. The BEP contained one chapter describing information requirements which were much more detailed than the requirements in the V770 or the tender documents. This makes the construction discipline model somewhat special since it is based on requirements that were not part of the tender documents.

DIFFERENCE BETWEEN TENDER DOCUMENTS AND BIM

Varying deviations were observed between the tender documents and the final BIM for the three discipline models (see table 1, column 3 and 4). While there were no deviations for the construction model and only minor deviations for the lighting model, there were major deviations for the road discipline model.

There was only one requirement complied with in the road model (design criteria). Some of the requirements that were not met (slope, camber and super elevation) were due to technical limitations in the BIM software. The designers had access to these data in the design process, but they could not be implemented as property data on the object level. This information is typically included in drawings. However, having the lean principle of waste reduction in mind, the client and the designers agreed to not produce drawings. Instead, they chose to convey the information to the client directly through the BIM software in meetings.

Information about visibility (line of sight) was not included either. This could be technically implemented in the BIM software, but – thinking of waste reduction – the designers decided not to. They had access to this information in the design process and it was visually conveyed in the zoning plan. However, it was not regarded as important information for the following phases.

Information about masses was not available in the BIM either. The designers had access to these data and delivered it in Excel sheets. Even though one could argue that this information would add value for the client, the requirement was not complied with since the V770 does not explicitly state that all information must be conveyed as property data on the object level. At this point it must be noted that the road discipline model was slightly less mature than the other two discipline models. This was due to a delay in the legal process which made extra design loops necessary for this specific discipline. However, the interview results indicate that the above-mentioned facts are still valid.

The only missing information in the lighting discipline model were the mounting details. These details are supplied in an external document.

Table 1: Model information requirements and their compliance in the BIM

Discipline model	Model information requirements set in the BIM design manual V770	Model information requirements set in the tender documents	Compliance in the BIM
Road	Design criteria	Design criteria	Yes
	Visibility	Visibility	No (in zoning plan)
	Mass haul balance	Mass haul balance	No (in Excel sheets)
	Mass overview	Mass overview	No (in Excel sheets)
	Slope	Slope	No
	Camber	Camber	No
	Super elevation	Super elevation	No
Construction	Road information	-	No (in drawing)
	Cross-reference to bridge design manual	-	No (in drawing)
	Cross-reference to detailed drawings and other models	Cross-reference to detailed drawings and other models	Yes
	Quality of materials	Quality of materials	Yes
	Type and weight of pavement	-	No (in drawing)
	Water level	-	No (in drawing)
	Ship impact load	Not applicable	Not applicable
	Rivers' direction of flow	-	No (in drawing)
	Clearance height	-	No (in drawing)
	Distance from road center line to nearest construction part	-	No
	-	Object code	Yes
	-	Object type	Yes
	-	Toponym	Yes
	-	"All other information that is normally conveyed in drawings"	Yes (geometry details, tolerances)
		[Specific BIM Execution plan (88 specific attributes)]	Yes

Discipline model	Model information requirements set in the BIM design manual V770	Model information requirements set in the tender documents	Compliance in the BIM
Lighting	*Light poles*		
	Pole number	Pole number	Yes
	Pole height	Pole height	Yes
	Type of pole	Type of pole	Yes
	Type of lighting	Type of lighting	Yes
	Type of foundation	Type of foundation	Yes
	Distance from shoulder	Distance from shoulder	Yes
	Station number	Station number	Yes
	Hight of bulb	Hight of bulb	Yes
	Color	Color	Yes
	Effect	Effect	Yes
	Lighting class	Lighting class	Yes
	Course number	Course number	Yes
	Mounting details	Mounting details	No (external documentation)
	Pull manhole		
	Number	Number	Yes
	Type	Type	Yes
	Dimension	Dimension	Yes
	Other technical installation		
	Number	Number	Yes
	Toponym	Toponym	Yes

DISCUSSION

In the presented case BIM supported the following lean principles; waste reduction, improvement of the information flow and value increase. Several types of waste were reduced by improving the information flow. Overproduction, waiting (Womack and Jones 1996), mass electronic communication and legacy databases (Hicks 2007) were diminished by direct access to information through the BIM instead of drawings. BIM created value for both the client, the designers and the contractor. BIM enabled the designers to remove some non-value adding activities by automating time consuming manual tasks. Value was also created downstream for the customer by preparing the information for the contractor. Instead of paying extra for the creation of data for machine control the contractor could extract the necessary information directly from the BIM.

The lean principle of waste reduction had a strong stand in the presented case. It was reflected in a pragmatic approach towards the compliance with the model information requirements. The client and the designers agreed that only necessary information was provided in the models. Drawings and documents were preferred when they were more effective to produce. This resulted in deviations from the requirements for the road discipline model. For this specific model, the geometry is most important in the production phase. Moreover, there are no specific parts that need to be changed in the in-use phase which would make detailed information about assets necessary (like for the discipline model lighting and construction).

The results showed that the requirements set in the BIM design manual were reflected in the tender documents to a varying extend. While both the road and the lighting model fully complied, the construction model had major deviations. However, a closer look revealed that these deviations were due to a changed approval mode after the tender documents were sent. In this respect, the construction model was not generally representative for this comparison.

Disputes between clients and designers often root in diverging interpretations of the content of the deliverables. Contracts and tender documents with clear requirements are necessary to establish a common understanding between them. In the presented case both parties agreed on a document clarifying the requirements from the design manual and the tender documents for all discipline models. Thus, they created reliability which is one of the principles in lean construction (Howell 1999).

Legal requirements seem to have the biggest impact on the BIM application in AEC projects. On the one hand, this could lead up to obstacles like continued demand of drawings (zoning plans and overview drawings in the presented case). On the other hand, it could also raise the level of information. The discipline model construction had the highest level of information because a specific BEP was required by the Directorate of Public Roads for the approval process.

Requirements set in the tender documents were only partially reflected in the final BIM, varying between the three discipline models investigated. The discipline model lighting and construction complied with most requirements while the discipline model road had major deviations. These deviations are partly based on limitations in the BIM software used and partly based on pragmatic decisions by the designers thinking of waste reduction.

All requirements from the tender documents were fulfilled in the construction discipline model. While this model only had four requirements in the tender documents it is actually the model with the highest level of information. The BEP has approximately 80 different properties on the object level though providing "all other information that normally conveyed in drawings". The higher level of information is due to the fact that the construction discipline model is the only one that needs to be approved by the Directorate of Public Roads. At the same time this model is the only discipline model that has additional, obligatory drawings. Even though the Directorate has opened for model-based approval, one overview drawing per construction is still mandatory and detail drawings might be requested. Some of the required information (cross-references, type and weight of pavement, river's direction of flow and clearance details) is therefore only included in drawings. This puts the construction model in a special position.

CONCLUSION

In this paper, the relation between requirements in BIM design manuals and tender documents on the one hand and between tender documents and the final BIM on the other hand was investigated. The results showed that the requirements were mostly complied with (sometimes with a pragmatic approach). However, both the BIM design manual and the tender documents were made by the client and thus represent the client's perspective. It seems like the focus of the NPRA is on the design and the in-use phase. Especially the detailed requirements for the lighting and construction discipline model indicate this. Whereas the contractor's focus on the production phase is not given the same attention in the requirements. From that perspective, the results are twofold; 1) some of the required information is not provided in an exact and reliable form (mass balances are only conveyed as Excel sheets, not directly in the BIM), while 2) resources are spent on providing not required information (lighting details for the in-use phase).

Contractors need exact and reliable information about the planned assets, especially on cost drivers like masses or constructions. Providing the necessary information in one single source lays the foundation for a digital transformation of the AEC industry. Single source in this respect means either all information is available directly in the BIM, like for the construction discipline model, or by using a linked data approach where the same data is used in different ways. If the NPRA wants the AEC industry to be digitally transformed and not just digitalized, the manuals have to reflect this. In short, the contractors' perspective must be given more attention. Having in mind the trend towards design-build projects, not just in Norway (Eriksson et al. 2017; Ma et al. 2018), where the contractor is responsible for both the design and the production, this finding is even more relevant.

The design manual V770 was an important step to force the AEC industry into using BIM for infrastructure. However, since it's first publication in 2012 BIM software has evolved and new project delivery methods have been applied to projects in Norway. The manual should reflect these new delivery methods and have more focus on the contractor and their need for information.

It was the intention of the authors to present results of an ongoing industry PhD project to the IGLC community to get feedback. It is not yet clear whether the mismatch of the information requested and provided is a systematic problem or was unique to this case. The presented case was the first of a series of case studies covering different delivery methods (design-bid-build, design-build and integrated project delivery (IPD). Future work should focus on the contractor's perspective and investigate the following; 1) relevance of information for the contractor, 2) evaluation of experiences with delivered information and 2) comparison of the available information in different delivery methods.

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