BIM and Virtual Reality (VR) at the construction site

Citation for the original published paper (version of record):
Johansson, M., Roupé, M. (2019)
BIM and Virtual Reality (VR) at the construction site
Enabling digital technologies to sustain construction growth and efficiency, 19: 1-10

BIM and Virtual Reality (VR) at the construction site

Mikael Johansson & Mattias Roupé
Chalmers University of Technology, Sweden

ABSTRACT: *In Scandinavia, recent years have seen an increased effort to move away from traditional 2D-drawings at the construction site, and instead let site personnel extract necessary information directly from the Building Information Model (BIM). However, although BIM-viewers and mobile applications are constantly improving, there are still issues around user-friendliness and ability to extract information and correct measurements directly from the model. In order to improve on the current situation, this paper presents a VR-application that allows construction workers to interact with the BIM through a user-friendly interface. By using modern VR hardware, such as HTC Vive, they can enter and freely navigate, inspect, and interact with the BIM in scale 1:1 and extract information, take measurements, define section planes, and control visibility of individual components or sub-models. A core component in this interface is the concept of "3D-labels", which let the user easily place and arrange information and measurements as needed. From within the VR environment it is then possible to take snapshots that can be uploaded and accessed on portable units on the construction site. In addition to present technical details of the developed VR-system, we also present an evaluation of it performed at four different construction sites.*

KEYWORDS: *BIM, VIRTUAL REALITY, VR.*

1. INTRODUCTION AND BACKGROUND

Using the concept of Building Information Modeling (BIM), architects and designers can nowadays produce parametric, object-oriented 3D-models embedded with information to describe any building or facility in detail. As a digital representation of the physical and functional characteristics of a building, a BIM serves as a repository of information supporting a multitude of applications along the design and construction processes, including cost-estimation, energy analysis and production planning (Eastman et al., 2011). Still, due to regulations and use of conventional construction contracts, 2D-drawings remain the primary source of information that is handed over from design to construction (Jamil and Fathi, 2017). As a consequence, designers needs to put in additional effort to produce 2D-drawings from the BIM, at the same time as all of the rich data produced during design does not reach the construction site.

However, recently, there has been an increased effort in Scandinavia to move away from traditional 2D-drawings at the construction site. Prime examples include the Slussen project, Röfors bridge, as well Oslo Airport Terminal 2, where Building Information Models (BIM) has been used as the primary source of information (Cousins, 2017; Götborg and Olsson, 2016; Merschbrock and Nordahl-Rolfsen, 2016). In the case of the Röfors bridge – *a project realized entirely without traditional drawings* – construction workers had direct access to the BIM on tablets for easy overview and understanding of the project. In addition, BIM managers and designers placed at the construction site created so-called Production-Oriented Views (POV) from the BIM in consultation with the construction workers. These views are essentially enhanced screenshots from the BIM, typically containing color-coded elements, specific measurements and dimensions, object information, 3D-sections, or any other information the construction workers consider is necessary in order to perform the actual work on site (Fig. 1). After creation, the views are uploaded as images to a shared model repository and can then be accessed and used as a complement to the complete BIM on portable units, such as iPads. Nevertheless, although found to be a very powerful and successful concept, the actual creation of POVs currently requires a designer or BIM-specialists on site, thus putting additional demands on the project organization (Malmkvist, 2018).

Increasing use of BIM, together with a new generation of affordable head-mounted displays (HMD) has also lead to the AEC industries adopting Virtual Reality (VR) more and more. With BIM, the required 3D data can be extracted directly instead of creating it from scratch, making it more accessible in practice. Typical applications for VR today include construction safety planning and training (Hafsia et al., 2018; Azhar, 2017), production planning (Muhammad et al., 2019), as well as design review sessions (Roupé et al., 2016; Zaker and Coloma, 2018; Wolfartsberger, 2019). In the case of design review sessions, previous studies has shown that VR can clarify many aspects of the design that is difficult to comprehend from traditional design documents, such as clashes and lack of space for installations and maintenance (Zaker and Coloma, 2018). In addition, it has been found that people with less experience in using desktop CAD/BIM viewers (e.g. MEP subcontractors, people who work in service and maintenance) has a preference for using VR as it better resembles their real work environment (Wolfartsberger, 2019). Still, as with BIM, we mainly see the use of VR during the design phase, and almost not at all during actual construction.

In this paper we present a user-friendly Virtual Reality (VR) system targeted for use at the construction site office. The primary application is to allow construction workers and supervisors to have easy access to the BIM through a simple VR interface. By using modern VR hardware, such as Oculus Rift or HTC Vive, they can enter and freely navigate, inspect, and interact with the BIM in scale 1:1 and extract information, take measurements, define section planes, and control visibility of individual components or sub-models. From within the VR environment it is then possible to take snapshots of the created Production-Oriented Views that can be uploaded and accessed on portable units on the construction site. In addition to present technical details of the developed VR-system, we also present an evaluation of it performed at four different construction sites.

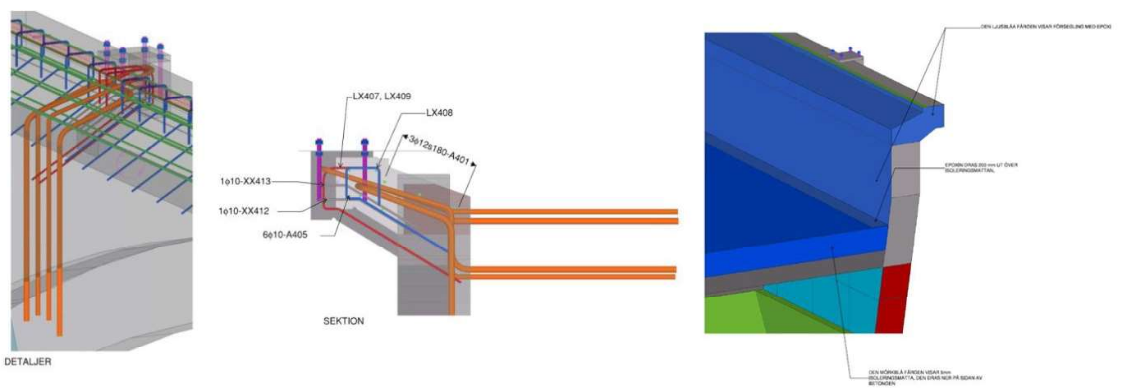

Fig. 1: Example of Production-Oriented Views (POV) from the Röforsbron project (Götborg and Olsson, 2016).

2. A VR INTERFACE FOR ON-SITE ACCESS TO BIMs

To support the ability to extract information and create POV directly in VR, we have used BIMXplorer as a platform and further customized it (BIMXplorer, 2019). BIMXplorer is a software application that has been specifically designed to allow real-time visualization of large and complex BIMs in VR. By taking advantage of efficient occlusion culling it allows very large and complex BIMs to be visualized in VR without the need for any preparation or optimization of the input dataset (Johansson, 2016). It works either as a plugin to Revit or as a standalone application that can import IFC-files through the xBIM Toolkit (Lockley et al., 2017). In the following subsections we further describe the VR interface and the different tool that were developed for use at the construction site office.

2.1 General VR interface

The VR user interface is based on a tools palette connected to one of the controllers (left). Using the other controller (right) the user can point and click to select a specific tool or change navigation mode (Fig. 2, left). Two navigation modes are available; Free flying, or “point-and-teleport”, where the user points at a location in the scene and then instantly teleports there. In general, selecting a tool will bring up instructions and any options on a panel connected to the right controller. Using the touch button on the right controller, the user can press left/right/up/down/middle to control the options. By using the layers tool the names of the individual sub-models (e.g. Architectural, Structural, Electrical, etc.) are displayed in a list on a panel connected to the right controller. The user can then press up/down/middle to select and toggle the visibility of the individual sub-models. It is also possible to select and hide individual objects by ray select (i.e. point-and-click). Using the section tool, it is possible to define a section plane through the model, either by selecting a face in the model that acts as a cut plane, or by using the controller as a real-time cut plane. In this mode the outlines of the sectioned geometry is also displayed to further indicate that only a subset of the model is visible (Fig. 2, right).

Fig. 2: BIMXplorer general VR-interface (left) and sectioning (right).

2.2 3D Labels

In order to create and fully control the arrangement of information for the Production-Oriented Views (POV) a concept referred to as 3D Labels has been implemented (Fig. 3). Upon selecting object properties or taking measurements (See 2.3 and 2.4) a 3D Label containing the information is automatically placed in the 3D scene. By aiming at the top bar the user can then grab the label and replace it if the initial placement was not optimal. Grabbing a 3D Label is similar to holding a mobile phone using a "selfie stick", which was found to be the most practical and intuitive approach to control placement and orientation among several different options tested during early prototyping (e.g. transform gizmo, fully automatic placement). Furthermore, a label can be deleted or folded/expanded by clicking the respective icon for it.

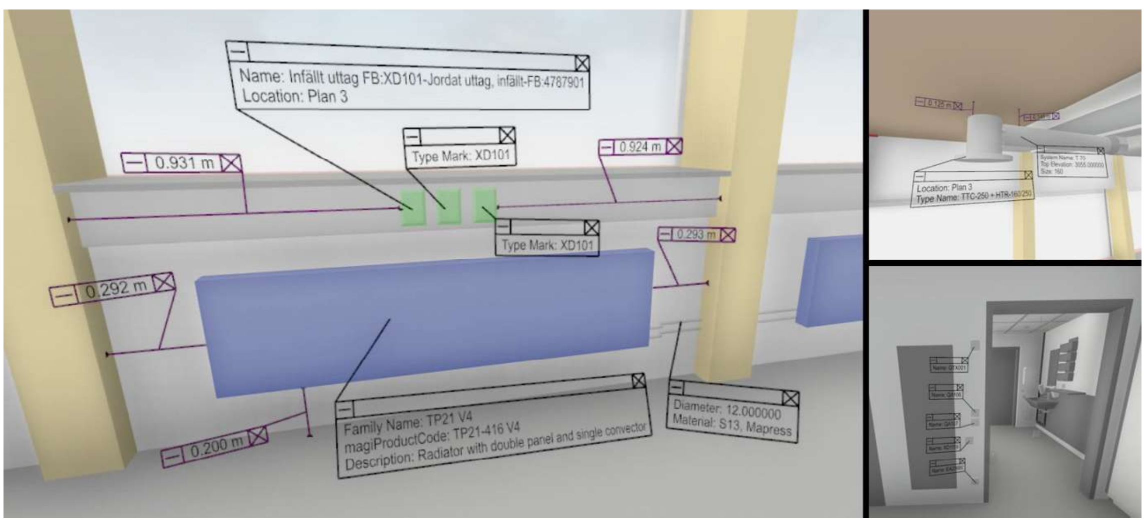

Fig. 3: Example of Production-Oriented Views (POV) created directly in VR.

2.3 Measurements

The system supports two types of distance measurements – perpendicular distance from a surface to any other surface, or distance between two arbitrary points. With perpendicular distance, the user selects an arbitrary position at a surface. The system then finds the closest intersection on a ray originating from that point in the direction of the surface normal. The perpendicular measurement is useful for quickly measuring the width of corridors or distance from floor to ceiling. Distance measuring between two arbitrary points works similar, with the exception that two points needs to be selected.

2.4 Information and recommendation system

By selecting an object, available PropertySets and Properties for that object will be displayed on a panel connected to the controller. By using up/down/middle on the controller it is then possible to select which properties that should be displayed on the corresponding 3D label. With BIM objects typically containing a large number of properties, a simple recommendation system was implemented that automatically adds the same properties onto the 3D Label as what has been previously selected for an object of similar type (Fig. 4).

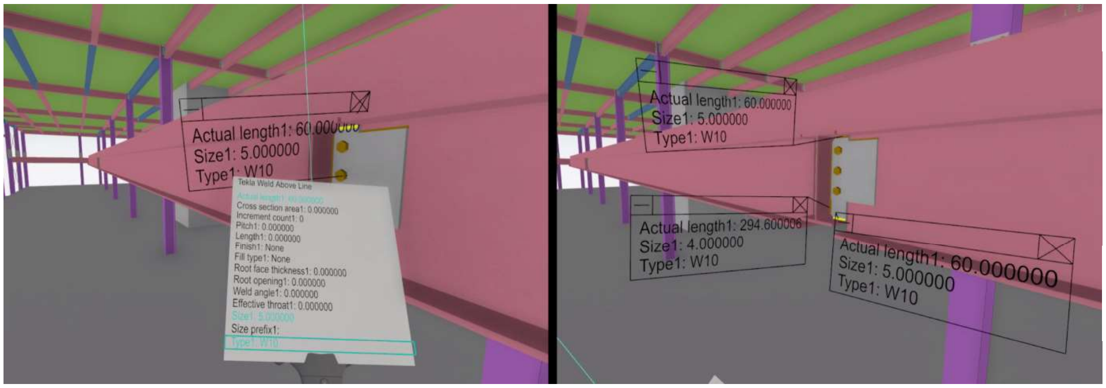

Fig. 4: The first time a weld object (i.e. IfcFastener) is selected, the user selects which properties that should be displayed on the 3D Label (left). When selecting subsequent welds, the previously selected properties are automatically added to the 3D Label (right).

2.5 Screenshots and production-oriented views

The user can easily take screenshots of what is displayed in VR, either on a fully prepared production-oriented view, or if it is just an arbitrary view of some detail in the model. These images are stored on the computer and can then be transferred to an iPad or smartphone for mobile use at the construction site. Using the add-on program VRCapture (VRCapture, 2019) it is also possible to record movie clips on what is being done in VR, which can, for example, be used to create instructional movies for various work tasks.

3. EVALUATION

The VR system has been evaluated at the site office at four different projects (Fig. 5). These projects where all ongoing, but in different stages (e.g. main structure has been erected, MEP work has just been started, MEP work was fully ongoing). In Table 1, model statistics for the different BIMs is presented. As can be seen, complete BIMs from these types of project tend to become very large and challenging to render in VR in real-time. However, this has not presented itself as a problem using BIMXplorer. All four projects has been either imported as IFC-files or taken directly from Revit without any need for further optimization. No issues regarding frame rate or lag has been noted.

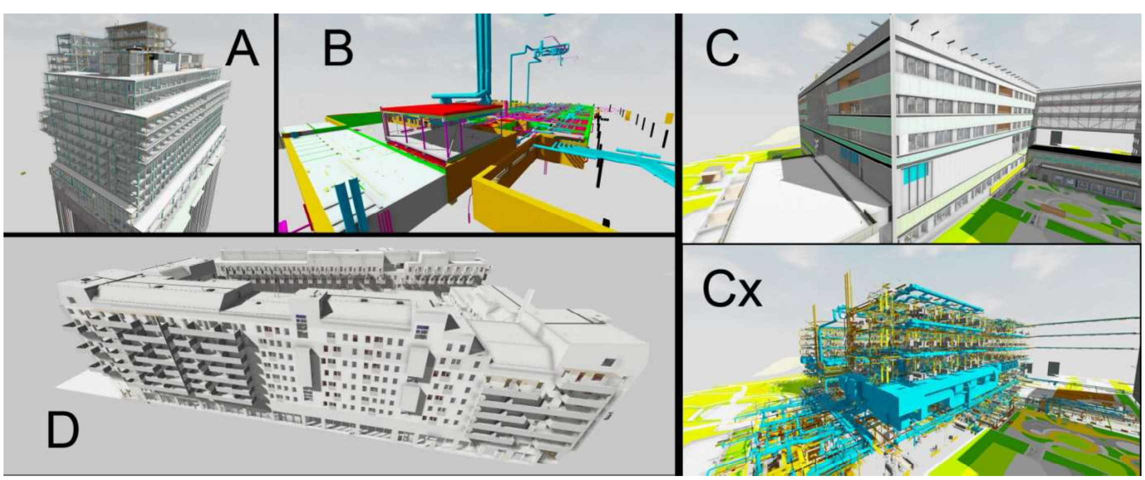

Fig. 5: The four different projects used during the evaluation (Cx shows the MEP sub-models in project C)

Table 1: Project and model statistics.

Project	Type	Source	# of objects	# of triangles
A	Office/hotel	IFC	299,273	44,878,455
B	Hospital	IFC	67,641	4,059,012
C	Hospital	Revit	386,169	165,155,703
D	Residential building	IFC	267,846	52,838,080

3.1 Data collection

During the evaluation phase we (i.e. the authors) visited the site office for each one of the four test projects. The VR equipment used for all projects was a gaming laptop with a NVIDIA GTX 1080 graphics card (GPU) and a HTC Vive VR-headset. On every site-visit a short presentation of the project and its purpose has been kept for an initial test group, and then the equipment has been available for the rest of the day to allow site personnel to come and test it continuously (Fig. 6). Except for the site manager in each project, none of the respondents had been given any information about the visit in advance. No particular tasks were given to the users other than asking them to try out and evaluate the VR interface and the different tools. In that sense we can consider the user tests as more explorative than driven by specific objectives or tasks to perform in VR.

Prior the site visits, a questionnaire was prepared containing both open and closed questions regarding the respondents' professional role, their knowledge and use of BIM, what information they require to perform their work, and how they experienced different aspects of the VR system and its functionality. In addition, data has been collected by means of observations and conversations with the participants during and after their tests in VR.

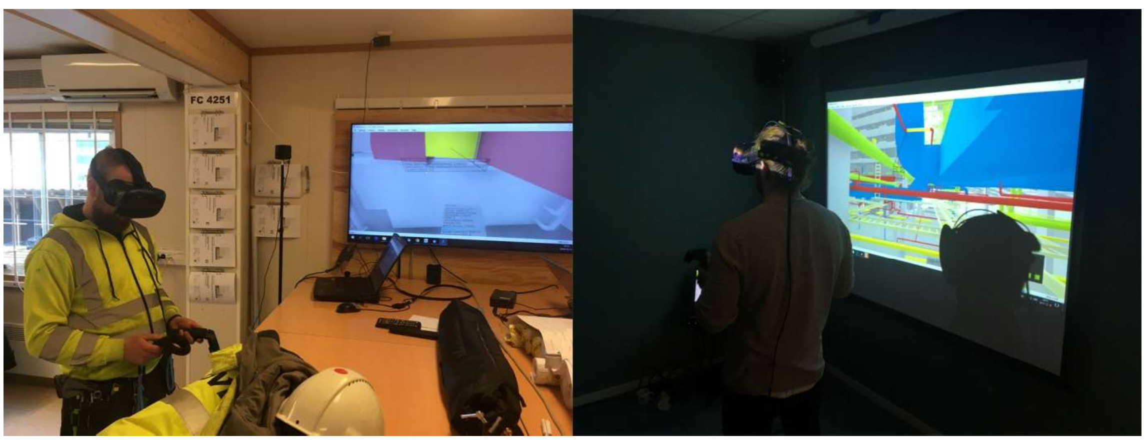

Fig. 6: Photos from the evaluation at project C and D.

4. RESULTS AND DISCUSSION

28 people completed the questionnaire directly after testing the VR system on site. In addition, 29 persons tested the system, but for various reasons were unable to conduct the questionnaire (e.g. time constraints, something happened at the construction site that needed immediate attention, etc.). However, by always being present as an observer/assistant, in cases where the test persons have not been able to complete the questionnaire, we have still been able to capture their thoughts, opinions, and wishes linked to the system and the way of working. Overall, we have not been able to see any significant difference between the people who tested and completed the questionnaire and those who only tested the system but were unable to do the questionnaire. We therefore believe that the results from the questionnaire provide a representative overall picture of the evaluation

4.1 Overall rating of the system

The questionnaire contained 10 questions where the respondents we're asked to rate various aspects of the VR interface on a scale from 1 (poor) to 5 (excellent). In Figure 7 we present the results on how the respondents rated the user-friendliness of the different tools. Figure 8 further presents how the respondents rated the VR systems ability to get them an understanding of the project as a whole, as well as how they perceived the VR interface in comparison to 2D-drawings and other BIM-viewers.

As the results clearly show, it is a predominantly positive image of the VR technology being conveyed. Given that it is almost exclusively the first time these users came in contact with VR, it can be concluded that this is technology that is perceived as user-friendly already in an initial test. Of particular note is "Understanding of the project as a whole", which is also very clear from the observations and the open questions (see section 4.2.3).

Based on these ratings, we can see that "Measure distance" has the most potential for improvement (discussed in more detail in 4.2.2). However, even here, there is a clear overweight to the positive, which means that even more advanced applications such as measurement and information extraction based on BIM models are fully possible even for non-experienced users.

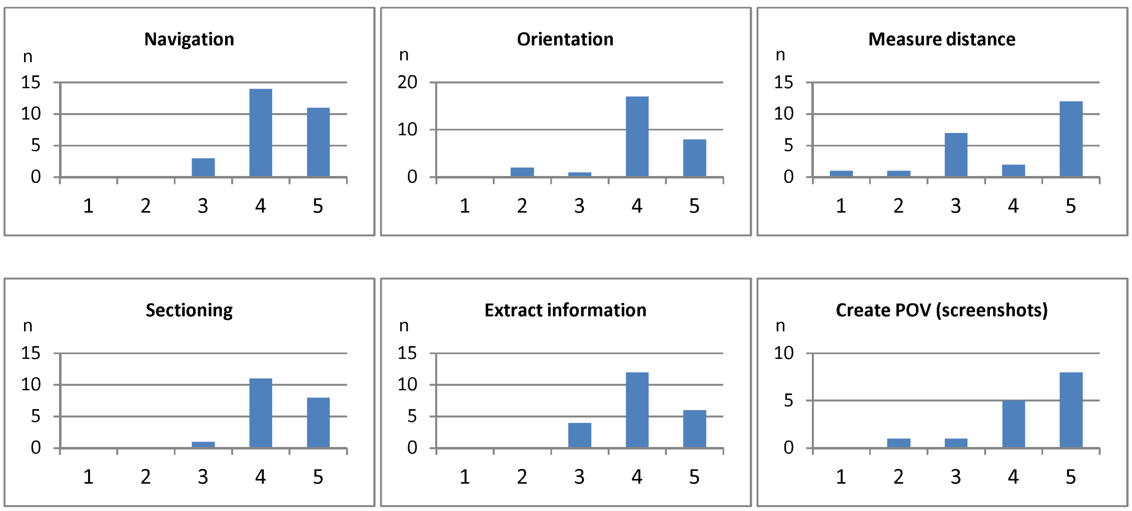

Fig. 7: General rating of the VR interface and different tools on a scale from 1 (poor) to 5 (excellent).

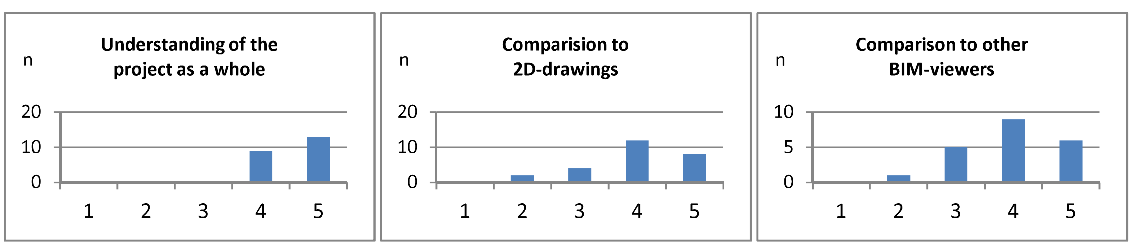

Fig. 8: Rating of different aspects regarding the VR interface on a scale from 1 (poor) to 5 (excellent).

4.2 Observations and open questions

A first interesting observation is that the users almost exclusively navigate to the place in the BIM where they currently work or have their focus. Although this may be considered obvious, it also demonstrates how important it is to present and evaluate new technology in its actual context and with examples that the people in question can relate to. Without offering them a model or project that they can relate to it merely becomes a demonstration of the technology itself, only allowing the respondents to speculate how they *can* use the technology, as opposed to how they actually *will* use it in a real project. In the following subsections we further present and discuss the results that were collected during observations, open questions, and discussions with the respondents.

4.2.1 Information content

As BIM elements typically contain a lot of information and properties, it might be a challenge for a user to quickly find only the relevant information for a specific task. One of the aims with the study was therefore to identify which information the different users felt was important to have quick access to, in order to be able to "filter out" less important information based on professional group. In Table 2 we list information and properties that was mentioned as important by several respondents within each professional group.

Table 2: Important information and properties according to MEP subcontractors and construction workers.

MEP subcontractors	Construction workers
MEP supports and hangers (3D geometry and properties)	Material information (e.g. layers in a wall)
System name (which system the component belongs to)	Sill height
Information about insulation	Dimensions for wall penetrations
Mounting height (in relation to floor/ceiling)	AMA codes (Swedish classification codes/instructions)
General component dimensions	General component dimensions
Floor/room identification (where the component is located)	Floor/room identification (where the component is located)

In addition, there were many requests for specific information which is difficult to generalize beyond "detailed information about the object", such as information connected to electrical components, electrical cabinets or control valves. There is also no clear consensus regarding if certain dimensions, such as sill height or installation mounting height, should be in the form of object properties or instead could be measured by the user in VR.

The BIMs in the various projects differed somewhat in terms of information content and during the evaluation we have seen examples of when the desired information is there, but also cases when it is missing. However, overall it has been difficult to clearly see what information they do not need, when the overweight instead has been that respondents want more information than what was available in the BIM. In this context, the recommendation system has proven to work well as an alternative to filtering or limiting information. In most cases, the user wants to have access to the same type of information, but on different objects, which in the case of the recommendation system means that you only need to specify what you want once.

4.2.2 Interface and tools

When it comes to navigating the VR environment, both the questionnaire and observations show that this is something that users - after a few simple instructions - master almost immediately. Still, several people express a desire for access to a map or overview that makes it easier to understand where you are in the model. Regarding motion sickness, about 20% of the users express that they experience some form of it, with comments ranging from "a bit", "slightly dizzy while flying" to "yes". However, it is also important to add that these users chose to "fly" around in the model, much because they felt it gave them more freedom to get anywhere quickly. Still, the problem of motion sickness should not be underestimated and it might be preferable to only allow teleport navigation, at least for inexperienced users.

With regard to the different tools, such as measurement and sectioning, not all respondents have chosen to use all the functions. Therefore, the evaluation basis cannot be considered as strong here as in navigation or general understanding of the project via the VR model. However, for standard dimensioning, it is clear that a snapping function is needed to make it more user-friendly, since many of the dimensions that the users want to put out are from an edge or corner. In this context, perpendicular dimension measurement is considered simpler as it is only an arbitrary point on a flat surface to be selected. Especially MEP workers also express a need to be able to easily take center-to-center measurements between components or between component and wall. Furthermore, the concept of 3D labels proved to work very well. As soon as users were given instructions on how to "grab" a 3D label, they could continue to move around easily and place them how they wanted. The same was true of the use of the sectioning tool.

Although the above gives a good picture of what the users experienced and wanted from the VR system, the overall purpose of the research project has been to simplify and streamline work in production. In this context, the comparison with what they use today becomes extra interesting. To better illustrate the respondents' thoughts, we give some examples of what they answered to the question *"How user-friendly is this interface compared to what you are using now?"*

"Can be good if you use it often"
"It goes a lot faster"
"Easier to see and get an idea, would have gone faster"
"Good complement to Solibri and Dalux"
"Great overall picture, good for quality assurance, understanding, coordination etc."
"Very user friendly"
"Does not use BIM today, but compared to drawings - a lot"
"No major difference compared to current 3D models"

Overall, we can see that the interface works well, but is far from perfect from a user perspective. To some extent, this is also due to the fact that the VR technology as such is new and there is currently no clear interface that users have experience of or can relate to. There is therefore definite potential for improvement, especially in terms of measurement. Despite this, we see how people without any previous experience with VR can almost directly navigate in - and extract information from - a BIM.

4.2.3 Understanding and communication

The overwhelming main advantage of VR was considered to be that it contributes to a much better understanding and overall picture of the project. The ability to "step into" a model and experience it on a 1:1 scale is highlighted as a great advantage and basically everyone who has tested the system believes that it provides a much better understanding of the whole project than 2D drawings do. A recurring description in this context is that "everyone sees the same thing" with VR, which is predicted to facilitate communication between different parties as it reduces the risk of different interpretations from, for example, 2D-drawings.

In addition to evaluate the various tools and explore the information content of the BIM, the people who tested the system mainly used it to get a better overview of the project as a whole and to gain a better view and understanding of current or imminent work. As such, the evaluation setting was not that of an actual design or constructability review. However, despite this somewhat unconditional inspection of the model the respondents have still been able to quickly identify many problems, such as clashes, design errors, or lack of space for a certain work task. To better illustrate this, a number of examples of comments that emerged during the course of the study are given below:

"Here we will not be able to fit all the pipes. It is not possible, I see that immediately. There you also have one..., no, two clashes." [Ventilation subcontractor]

"In this room I have just looked at the blueprint, I know we should pull in three [...] here but I could not find out where ... Well, there you have those two! Ok, and then the third one is ..? No, it should actually come in here." [Electrical subcontractor]

"I saw surprisingly many clashes, particularly with the fixed furnishings. I mean, if they should have the closets there, then we can't pull the pipes that way." [Supervisor]

Still, comments like these must also be put into context. As the design often runs parallel to construction, it is not certain that the design was finalized in the places where the problems were identified. It is also very likely that a deeper examination of the drawing material could have clarified the respective situation or collision. However, it clearly demonstrates how intuitively people perceive the situation when they are in the VR environment, thus confirming findings in previous studies (e.g. Zaker and Coloma, 2018; Wolfartsberger, 2019)

4.2.4 Color coding

Color coding of objects was something that most people commented on and also had wishes about. There is a clear desire for objects to be color-coded as it facilitates understanding and clarifies individual objects. However, several respondents also expressed wishes around more flexible and "dynamic" color coding. For instance, in project B, the construction workers wanted to color the interior walls based on their classification code according to the Swedish building standard. In BIMXplorer it is possible to control visibility and color of objects based on their properties in a similar way that can be done in Solibri. By defining a set of rules the BIM was then color coded according to request from the respondents (Fig. 9). However, although this was perceived as very powerful and exactly what they wanted, they still consider the actual creation of the color coding rules an unwanted step and they simply wished to select – in VR – from a list of predefined color coding rulesets, such as “Color by material” or “Color by classification code”, etc..

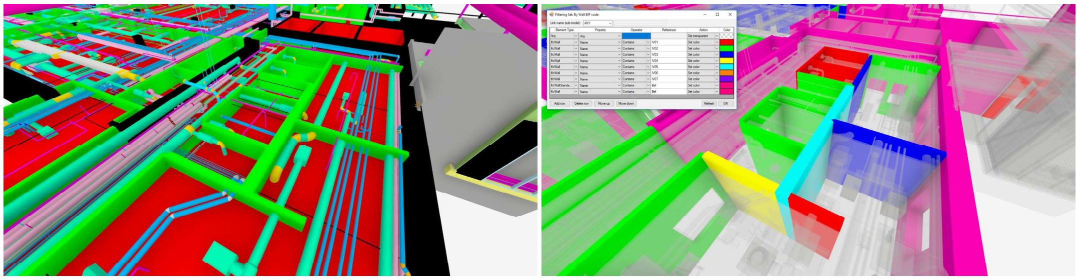

Fig. 9: Object colors from IFC-file (left) and colors by wall type (right)

4.2.5 Production-oriented views

Although the project's primary goal was to evaluate the concept of creating POVs directly in VR, it is difficult to give a clear answer to how well this concept actually worked in practice. Although many used the different tools to extract dimensions, information, and create screenshots of different details (Fig. 10), we cannot compare this with the examples highlighted from previous studies, where the production-oriented views were created and actually used in production. As previously mentioned, this can largely be due to the explorative nature of the evaluation with no explicit tasks given to the users. With the exception of two users, this was also the first time they tested VR, which was considered to be a totally new experience and concept in itself.

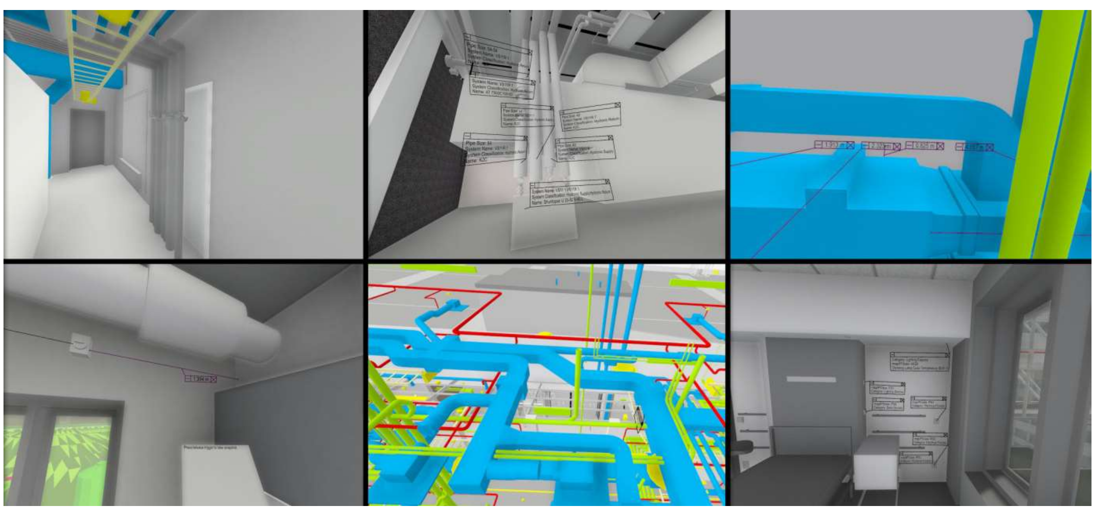

Fig. 10: Example of Production-Oriented Views created by the users during the evaluation.

5. CONCLUSIONS

The results from the evaluation show that there are great opportunities with a VR system at the construction site office. The greatest advantage is considered to be in understanding and overall picture of the project, but it is also a clear overweight to the better when compared to traditional 2D-drawings and other BIM tools. A recurring description is that "everyone sees the same thing" with VR, which is predicted by the users to facilitate communication and understanding between different parties as it reduces the risk of different interpretations based on, for instance 2D-drawings. Furthermore, it is also clear how the users, just by "stepping in" and viewing the model on a scale of 1:1, can almost immediately form an idea of any problems, such as clashes, design errors, or lack of space for a certain work task.

The developed VR interface was considered very user friendly. However, there is still development potential, especially when it comes to measurement. To fully satisfy the needs of all users, the measurement function needs to be both more powerful (e.g. support c/c dimensioning) and more easy to use (e.g. snapping functionality).

Regarding the concept of production-oriented views, it is difficult to give a clear answer to how well this actually worked in practice. The views that were created were primarily made for testing purposes and only in a few cases were they created for actual use on the construction site. However, the evaluation clearly shows that the technology is ripe enough for staff at the construction site to be able to create their own views from the BIM. Almost directly they handle navigation in the model and after a brief introduction to the various tools they can extract information and take measurements in the model. Given that for almost all users this was the first time they came into contact with VR, the technology must therefore be considered user-friendly and easy to take advantage of at the site office.

6. REFERENCES

Azhar, S. (2017). Role of visualization technologies in safety planning and management at construction jobsites. Procedia engineering, 171, 215-226.

BIMXplorer (2019). www.bimxplorer.com

Cousins, S. (2017). Total BIM: How Stockholm's £1bn urban transformation project is going 100% digital. Construction Research and Innovation, 8:2, 34-40

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

Götborg, A., Olsson, P. (2016). Digital deliveries: BIM as a source of information. Diploma Thesis. Chalmers University of Technology

Hafsia, M., Monacelli, E. and Martin, H. (2018). Virtual Reality Simulator for Construction workers. In Proceedings of the Virtual Reality International Conference (VRIC 18), Laval, France

Jamil, A.H.A. and Fathi, M.S. (2017). An Overview of Contract Documents for Building Information Modelling (BIM) Construction Projects. Journal of Advanced Research in Business and Management Studies, Vol. 8, Issue 2, 68-72

Johansson, M. (2016). From BIM to VR - The design and development of BIMXplorer. PhD thesis. Chalmers University of Technology

Lockley, S., Benghi, C. and Cerny, M. (2017). Xbim. Essentials: a library for interoperable building information applications. The Journal of Open Source Software, 2(20), 473.

Malmkvist, M. (2018). BIM i projekt Röforsbron(in Swedish). Report Trafikverket. Eskilstuna.

Merschbrock, C. and Nordahl-Rolfsen, C. (2016). BIM Technology acceptance among reinforcement workers – The case of Oslo Airport's terminal 2. Journal of Information Technology in Construction (ITcon), Vol. 21, pg. 1-12.

Muhammad, A. A., Yitmen, I., Alizadehsalehi, S. and Celik, T. (2019). Adoption of Virtual Reality (VR) for Site Layout Optimization of Construction Projects. Teknik Dergi, 31(2).

Roupé, M., Johansson, M., Viklund Tallgren, M., Jörnebrant, F. and Tomsa, P. (2016). Immersive visualization of Building Information Models. In: Living Systems and Micro-Utopias: Towards Continuous Designing (Proceedings of CAADRIA2016), 21, 673-682.

VRCapture (2018). store.steampowered.com/app/544420/VRCapture/

Wolfartsberger, J. (2019). Analyzing the potential of Virtual Reality for engineering design review. Automation in Construction, 104, 27-37.

Zaker, R. and Coloma, E. (2018). Virtual reality-integrated workflow in BIM-enabled projects collaboration and design review: a case study. Visualization in Engineering, 6(1), 4.