Evaluating the Usability Aspects of Construction Operation Building Information Exchange (COBie) Standard

Mehmet Yalcinkaya,
Doctoral Student, Department of Civil Engineering, Aalto University
mehmet.yalcinkaya@aalto.fi
Vishal Singh,
Assistant Professor, Department of Civil Engineering, Aalto University
vishal.singh@aalto.fi

Abstract

Constructions Operations Building information exchange (COBie) is a rapidly evolving standard to capture the digital information of facilities. As the building information modeling (BIM) for facilities management (FM) research is gaining greater emphasis, COBie standard is becoming increasingly central to the discussion. COBie can be delivered in different formats. For the ease of use by the end users, spreadsheet format of COBie deliverable is the most applied one since spreadsheets provide some end-user implementation techniques and have been in use for decades. Although the end-users are familiar with spreadsheet actions, dumping all the facility data to a repository with number of workbooks and associated fields has some unintended effects and poses new challenges in handling and using the COBie data. Therefore, this research evaluates the functional and usability aspects of the COBie spreadsheet deliverable from the cognitive perspectives for end-users, and identifies the key points that can increase the functionality of COBie data structure. The research applies the initial phases of design thinking principles to identify the issues with COBie spreadsheet in general by reviewing the literature about spreadsheet design, human-spreadsheet interaction, spreadsheet errors, and information visualization. The identified usability issues and functionalities provide basic steps towards improving the current spreadsheet representation of COBie. The findings will contribute to future development of COBie, driven from the perspective of user interaction and usability.

Keywords: COBie, Facilities Management, BIM, Usability

1. Introduction

In the Architecture-Engineering-Construction (AEC) and Facilities Management (FM) industry, one of the central issues has been to determine how to structure digital information of a facility such that it enables data sharing among different disciplines throughout the project lifecycle. From that viewpoint, there is an increasing call to use Building Information Modeling (BIM) data in FM (Yalcinkaya & Singh 2015), because a lot of BIM data for an upcoming facility is generated in earlier phases of the project, especially in the design phase. Overall, the dependent facility information is created by numerous BIM, FM and construction management (CM) software applications throughout the project lifecycle. However, all these applications structure and present the FM data in their own proprietary formats which causes inefficiencies in interpreting and processing the data. Construction Operations and Building Information Exchange (COBie) is one of the most dominant, open and vendor-neutral industry standard that describes product and process of collecting and validating building lifecycle data generated during various phases of project lifecycle (buildingSMART 2010; East 2007). Although COBie is relatively new when compared with other AEC/FM standards, it is being widely promoted for BIM and FM. The end-result of the COBie specification can be considered as a common template in which the information structure and the delivery format of COBie specification is planned to reduce inefficiencies in facility information handover.

Currently, COBie-based information can be delivered in any of the three formats, IFC STEP (standard for exchange of product model) Physical File Format, ifcXML (extensible mark-up language format of IFC) and/or SpreadsheetML (open XML schema used by spreadsheet application such as MS Excel). IFC STEP and ifcXML can be interpreted and visualized in various parsers and/or web browsers. However, interpreting these formats requires some information technologies (IT) knowledge which not all end-users have. Given the end-users' inexperience and limited familiarity with the first two file formats, spreadsheet has become the most common way to represent COBie. Spreadsheet format of COBie deliverable provides some useful end-user implementation techniques such as sorting, querying, and/or simple mathematical functions if needed. It is human readable, checkable and editable as well. A COBie spreadsheet deliverable includes several workbooks and columns in which the users export the information from BIM and/or computer-aided facilities management (CAFM) software applications' data mapping or export tools; and/or fill in manually. The data is distributed in workbooks and associated columns such that each row includes specific entities of facility data. Depending on the delivery phase and the project size, a COBie spreadsheet can include thousands of rows of facility data.

Despite the easiness of spreadsheets and familiarity of end-users with spreadsheet logic and actions, storing and representing large amount of facility data in a tabular repository with number of dependent sub-sections may have unintended effects and challenges in handling and interpreting COBie data, for example, challenges in visualizing the overall content, duplication of data entries, understanding data dependencies, memory overload due to high amount of number and text-based data, etc. Similar issues are also discussed in the literature about the usability and cognitive aspects of spreadsheet (Chen & Chan 2008; Kohlhase 2013; Hendry &

Green 1994; Thorne & Ball 2008). Accordingly, the main difficulty that end-users have in understanding the data in COBie spreadsheet can be summarized as the high amount of data and lack of explicit dependencies between the cells and workbooks. Users need to recognize the data and their dependencies in COBie spreadsheet, which imposes a heavy memory load. The schema of the COBie spreadsheet is available in COBie Responsibility Matrix (East 2013) to check and interpret. However, handling two separate files or adding one more workbook to the existing COBie spreadsheet may increase the memory load even further. Responsibility Matrix (East 2013) to check and interpret. However, handling two separate files or adding one more workbook to the existing COBie spreadsheet may increase the memory load even further.

In this paper, we highlight and address the complexities and challenges involved while handling and interpreting the COBie spreadsheet. The contribution of this research is twofold. First, we present our findings by reviewing the literature about spreadsheet design, human-spreadsheet interaction, spreadsheet errors, and visualization. We have identified the issues that are common with the COBie spreadsheet representations. Second, we propose a framework to enhance the usability and functionality of COBie spreadsheet representation. Findings of this study and the proposed framework are expected to identify and outline the potential areas of future development for COBie, especially from the point of view usability and interaction with the data.

2. Background

2.1 Development of COBie Standard

In 1983, the National Research Council Building Research Board (BRB) proposed an integrated database solution for facility information (Scarponcini 1996). Other computerized systems such as CAFM, CMMS, etc. were already available to organize, manage and deliver FM information. The variety of software products and their versioning caused inefficiencies in automatic transfer of data. Consequently, the manual information delivery is still commonly used, even though it is inefficient, error-prone and tedious (William East et al. 2012). COBie specification was developed to overcome such challenges and establish a non-proprietary version of exchange data (East 2007). The development process began in 2006 under National Institute of Building Sciences (NIBS) FM and Operations Committee with an extensive review of literature and private industrial/association efforts. The development of COBie standard is mainly focused on two aspects. First, to determine the useful minimum in terms of specific information requirements, responsible actors and associated life cycle phases. Second, to define data exchange standards to eliminate existing inefficiencies in information exchange. The life cycle information exchange were evaluated based on business cases, specific business requirements, information handover plan and implementation with software applications (East 2007). Association efforts played a vital role in the development of COBie. Machinery Information Management Open Systems Alliance (MIMOSA), an industry sponsored non-profit organization, published important specifications such as the Open Systems Architecture for Enterprise Application Integration (OSA-EAI) (MIMOSA 1998) and for Condition-Based Maintenance (OSA-CBM) (MIMOSA 2006). These standards describe how to integrate asset information and how to transfer information in a condition-based maintenance system. Similarly, IAI and its open-source framework for exchange of facility information IFC, describes the majority of components, systems, ownership and the process history. Twelve published data exchange standards for the process industry were reviewed to identify equipment, process, systems, procurement, operations and management datasets for the development of COBie (East 2007).

The practices of the public sector were also considered in the development of COBie. US Naval Facilities Engineering Command (NAVFAC), Unified Facilities Guide Specifications (UFGS) provides Operations and Maintenance Support Information (OMSI). OMSI as an information package includes the key information produced during design, construction and commissioning of a facility. The information is organized in three groups: facility information, primary systems information, and product data (NAVFAC 2014). The OMSI package is generally submitted in three formats including hard copies, electronic (PDF) format and compatible with CMMS applications. The main information types and delivery phases were evaluated in the development of COBie. The Electronic OMSI (eOMSI) provides the required facility information in a structured spreadsheet file with a specified template, during the information handover. Besides OMSI, the Department of Public Works (DPW) of US offers a specification called Operations and Maintenance Manuals which covers a variety of facility information such as system descriptions, installed equipment lists, etc. This specification was also considered in the development of COBie. Besides these, such specifications and/or submittal processes provided by US Department of Defence and National Aeronautics and Space Administration (NASA) were also considered in the development of COBie (East 2007).

2.2 Human-Spreadsheet Interaction

Spreadsheet platforms are popular tools for storing, analysing and visualizing data across all domains, ranging from business to science. In Human-Computer Interaction (HCI) community, spreadsheet is often referred as a task-oriented platform with high computational power. By providing a combination of an expressive high-level formula language with an easy tabular format to organize and display data, spreadsheets are easy to learn and use. In addition, spreadsheet actions can effectively guide the decision-making process without the need for complex computing actions and professional support. Therefore, the flexible and direct approach to data manipulation and management in spreadsheets has led to a widespread usage (Panko 2000). Besides, almost in every business or professional domain, spreadsheets are not only used as a single-user application, but also in multi-actor environments as a collaboration tool, and as means of communication, exchange and integration of domain knowledge (Nardi & Miller 1990).

Although spreadsheets are powerful, simple, easy-to-use, and facilitate the tasks of single/multi-user organizations, yet crucial errors can easily occur. Several studies mentioned the common mistakes and challenges of spreadsheets usage in different scenarios (Panko 2000; Powell et al. 2008; Chen & Chan 2000). There are two levels of a spreadsheet: (1) concrete and visible surface level, and (2) abstract and hidden level beneath the surface (Saariluoma & Sajaniemi

1989). The tabular layout appears at the surface level, while the connection of cells is established in a network defined by the dependencies in the deep/hidden level. One of the basic difficulties during the handling of spreadsheets is establishing the connections among the data distributed in cells and workbooks (Hendry & Green 1994). For large spreadsheets like COBie, tabular layouts for textual and numerical data do not show any direct mapping with the deep level; and in most cases, users deduce the semantic connection among the cells, columns and workbooks by visually checking them, which imposes a heavy memory load. Consequently, the process of investigating dependent data can be tedious and error-prone because many spreadsheets, including COBie, contain widely separated data.

Therefore, it is desirable that the data shown at the surface level, and its dependencies with the deep structure, are represented and integrated in a visual and interactive way, such that users can find the relevant information with lesser cognitive load. This remains a challenge in most spreadsheet-based solutions, and this limitation is carried onto COBie by default.

3. Research Method

The primary objective of this paper is to outline the issues which make COBie data less accessible and usable by users, including inexperienced and non-FM and/or operations and management (O&M), who would likely have difficulties in understanding and using the large COBie spreadsheet effectively. To reach this objective, it is essential to understand the characteristics of the existing representation, and the current challenges and expectations of the users, such that these can be addressed through ideations and enhanced features. This research adopts the initial steps of design thinking process which relies on the co-evolution of the problems and solutions through an iterative process (Dorst & Cross 2001; Poon & Maher 1997) to understand the issues with COBie representation, formulate the problem, and ideate the solutions with respect to the findings of the literature review.

The implementation steps of design thinking are generally organized in five basic steps which are: (1) Understand: understanding the experience and expectations of the users, whom we are designing for, through surveys, observation, interaction and/or self-experiencing the problem; (2) Define: processing and synthesizing the findings in order to form a user point of view for the proposed solution; (3) Ideate: exploring the variety of solutions by generating diverse possible solutions from a range of ideas; (4) Prototype: transforming the ideas into a tangible form to experience and interact with the proposed solution(s); (5) Test: testing the prototype, observe desired users' experience and get feedback to refine it. Following subsections present the understand and define sections of the design thinking as applied in this research to evaluate the current spreadsheet representation of COBie standard and understand the issues with it. Since this paper reports a work in progress, the next steps are currently underway and will be reported in future publications.

4. Problem Identification and Definition: Requirement for COBie Improvement

4.1 Step.1 Understand Spreadsheets and COBie Spreadsheet

The first step is to understand the problem context and assess the key challenges in effective usage of COBie spreadsheet in its current form. As described in previous sections, the underlying usability and navigational challenges with large spreadsheet is one of the key challenges and problems that is carried onto COBie by default, and this needs to be addressed. Therefore, it is important to understand how users interact with the large spreadsheets, navigate through the data, and establish the semantic connections; and what are the causes and effects which increase the cognitive load while handling spreadsheets.

Based on literature (Woods 1995; Woods & Watts 1997), it was found that navigation through large spreadsheets affects the decisions and actions that contribute to a user's ability to find and understand the relevant information. When the virtual representation of any type of data is distributed and much bigger than the actual computer screen, users cannot process the data parallel, in-mind, with what they see on screen. Instead, they split up the large structure and navigate the preceding/succeeding sections via zoom and/or move-to actions. In literature, this issue is referred as the key-hole effect (Woods & Watts 1997). Another issue in dealing with large spreadsheets like COBie is getting lost in which the user becomes lost in the virtual environment and fails to achieve the original task while he/she navigates and searches within the data. According to Woods (Woods 1984), the users "... do not know their present location in the system relative to the display structure and find it difficult to decide where to look next within the system" Another problem is referred as trashing (Henderson Jr & Card 1986). As in the COBie spreadsheet, when the user tries to find dependent information -sets- from different workbooks, he/she must serially shift among different workbooks which causes extra time and memory load. The increase in the memory load can also trigger the mental workload by focusing on the interface instead of the original tasks. While the user is experiencing the spreadsheet structure, he/she may need to memorize certain amount of semantic links and paths between different sections to achieve their task. In many cases, the professionals of AEC/FM industry are expected to deliver their tasks in a limited time and under limited sources; and experiencing the COBie spreadsheet within these conditions can be challenging. In this case, users generally tend to adapt their existing work style to the limitations of the environment/systems. To find a specific COBie data, user can simply use the search functionality of spreadsheet applications. However, in case of the need for checking the dependent information of the specific entity, user has to perform this action repetitively.

COBie data can be generated automatically with BIM, construction management (CM), FM software application and/or their add-on modules. This method provides efficiency by enabling faster production and preventing duplications. However, not every software application has the functionality to export all the data required in each workbook of COBie spreadsheet. Besides, COBie is not designed to handle every specific information requirements that can vary in each project. Therefore, users may need to enter the data manually which can cause duplication.

Since data entities in COBie have one or more dependencies, this mistake can cause duplication and/or omission of data for specific entities. As specified by (East 2007), the handover of COBie file should occur in different phases of the project. Therefore, the data in a COBie spreadsheet increases in each delivery with new data entries and/or addition of new attributes of the existing data. Users may want to see the changes in each phase of delivery or the information sets.

Visualization of any data improves human perception by increasing the cognitive capability and reducing the complex cognitive work. The easy recognition of sensory symbols based on shapes, colours, photographic images and their meaning in the human brain, facilitates recognition of patterns without the need for pre-attention (Duncan & Humphreys 1989). It is also because the rich content of visual triggers such as colour, size, shape, position, etc. reduce the need for explicit serial process of the data. Instead, the large network of neurons in the eyes can rapidly capture the features of visual representations and implicitly pick the visual patterns with the image-based meaning of symbols. In contrast, all geometric and non-geometric data of a facility is represented in numerical and textual form in COBie spreadsheet, which increases the cognitive load of users. Processing and deriving the semantics from COBie dataset is slower than any appropriate visualized form, because the textual or numerical data is processed in a consecutive series of activities while the visual representation is processed in parallel with the perception (Ware 2012). Therefore, one of the key issues of current COBie implementation is the lack of information visualization that could enhance comprehension and reduce cognitive load.

4.2 Step.2 Define Requirements with COBie Spreadsheet

The previous section gives an overall picture of COBie and spreadsheets, and the common challenges that a user is likely to face when they are interacting with them. As a next step, to outline the problem definitions and the potential enhancements, it is essential to state the target user's role and expertise assumed in this research. The proposed development is intended for all potential users of FM data, including inexperienced and/or non-FM/O&M people who have limited to no experience with the COBie spreadsheet. These users may need to interact with and use the COBie data in different ways, including potential responsibility to interpret and generate COBie data for the later phases of the project lifecycle. The reason why we also focus on the inexperienced users is to keep the proposed development as inclusive as possible. From our on-going and previous interactions with industry partners and collaborators, we know that in both FM and O&M domains, many professionals have expressed difficulties in understanding and using COBie spreadsheet. Therefore, we aim to define the requirements for a solution that can not only increase the efficiency of experienced users while they interact with the COBie data, but also enable lay users to access relevant COBie data. To keep the problem definition as discrete and simple to understand, we structure the requirements as a set of statements, each following the same template: **"As a user, I ... I need to/have to ..."** Based on this template, the list of requirements for targeted improvements in COBie can be defined as: **As a user, I**

- *lose my focus while navigating among workbooks*. **I need** *a platform in which navigation is easier (interactive)*.

- *am having difficulty to process COBie data within different workbooks*. **I need to** *see all the relevant COBie data and dependencies at an easy and abstract level*.
- *have difficulty to see the dependent information within workbooks*. **I need** to *explicitly see the dependencies of a specific COBie data*.
- *cannot search a specific data based on its dependencies*. **I need to** *be able to find the specific COBie databased on its dependencies*.
- *have difficulty in understanding the semantic links among different COBie entities*. **I need to** *see my search results in a simplified format*.
- *want to access a specific data entity and its dependencies.* **I need** *the functionality that does not force me to navigate repetitively*.
- *want to select the COBie data entity with the 3D BIM model and see selected entity's dependencies*. **I need** *a platform in which BIM model and COBie data is mapped with each other*
- *may have duplications when I enter COBie data manually*. **I need** *a platform that warns me for duplications and prevents multiple data entries automatically*.
- *have difficulty tracking the new COBie data in each delivery phase of project*. **I need to** *track previous and new information sets effectively*.

These requirement statements were defined and validated through an iterative process in a collaborative setting. The iterative process led by the researchers, included other researchers, software developers and industry partners. More importantly, consistent with design science, the requirement definitions also evolved as the researchers conceptualized and ideated on potential solutions with respect to the current solutions. Consequently, some of the requirement statements such as *"... have difficulty in understanding the semantic links among different COBie entities. **I need to** see my search results in a simplified format."* have been more concretely defined.

5. Limitation and Future Work

The reported findings are part of an on-going research, which means the requirements and our understanding of the limitations of the current COBie implementations may improve further as we refine our prototypes and solutions for a visual and interactive COBie (VisualCOBie) representation that is currently being developed and tested. The VisualCOBie platform has already undergone a few iterations and it will shortly be introduced in another publication, once additional validation and usability tests are conducted empirically.

One of the other limitations of this research was the limited understanding and usage of COBie in Finland, where the research is being conducted. This limitation is further compounded by lack of academic articles reviewing COBie. This limitation can be seen in two ways. First, the authors had to rely on feedback with only those industry partners who had familiarity and reasonable understanding of COBie from international markets. Second, considerable amount of COBie related issues were identified from discussions within the research community, as well as from online discussion forums on COBie. Third, the lack of adequate understanding about COBie in the Finnish industry, and the lack of academic articles on COBie also prove the key point that even though COBie is being promoted as the key data format to enable the use of

BIM for FM, it is yet to capture the attention of the end-user. In addition, it also means that this paper raises a timely issue, bringing attention in the academic community towards COBie and its strengths and weaknesses in its current form.

6. Conclusion and Discussions

The main contribution of this paper is the evaluation of COBie from the perspective of end-user interaction, usability and functionality; and defining the requirements for improvement of COBie from usability perspective. The findings presented in this paper are part of an on-going research aimed at developing an interactive and visual solution for COBie data. Based on a critical review in a research that adopts design research methodology, the main limitations of the COBie standards are traced back to its dominant representation as a set of spreadsheets, with large amount of textual data. Consequently, the usability issues associated with large spreadsheets such as getting lost and keyhole effect automatically emerge with COBie as well. In addition, similar to many other situations where spreadsheets are used as collaboration tools, COBie spreadsheets are also expected to be filled and contributed to by various actors, and at various stages of the project lifecycle. This collaborative aspect creates further usability challenges, because users need to track the changes and additions to the data, leading to issues such as version management and duplication.

Based on the review, it is evident that the widespread use of spreadsheets, their low usage barrier, and their ease of information gathering and editing capabilities, were the dominant reasons for spreadsheets being the primary representation for COBie data. At the same time, it appears that one of the key reasons for the usability challenges associated with spreadsheets, and hence with COBie, is the lack of mechanisms to explicitly map and visualize the dependencies between the different data entities spread across different parts of the spreadsheets as well as across different workbooks. Thus, it can be argued that the information management issues and process view of data integration were the key factors considered so far in COBie development, while the usage and usability factors have so far remained overlooked. This problem of ignoring the usability and end-user perspective is not limited to COBie, but it is a typical trend in construction technology related developments. Not surprisingly, many of these technological developments fail to reach the desired rate and desired level of adoption, because users find them difficult to use, despite their technical capabilities. Singh et al (2011) make similar arguments, emphasizing that the support technical requirements that improve usability and focus on the end-users should be considered in parallel with the operational technical requirements, and not as separate add-on activities. Therefore, this research puts usability and the end-user perspective at the core of the chosen design science methodology, and such an approach is directed towards addressing the industry feedback and commonly reported grievances about the complexity and lack of understanding about COBie.

References

buildingSMART, (2010). Model View Definition Summary. Available at: http://www.buildingsmart-tech.org/specifications/ifc-view-definition [Accessed April 12, 2015].

Chen, Y. & Chan, H., (2000). An exploratory study of spreadsheet debugging processes. *PACIS 2000 Proceedings*, p.12.

Chen, Y. & Chan, H.C., (2008). Visual Checking of Spreadsheets. Available at: http://arxiv.org/pdf/0805.2189.pdf [Accessed October 2, 2015].

Dorst, K. & Cross, N., (2001). Creativity in the design process: co-evolution of problem--solution. *Design studies*, 22(5), pp.425–437.

Duncan, J. & Humphreys, G.W., (1989). Visual search and stimulus similarity. *Psychological review*, 96(3), p.433.

East, B., (2013). COBie Responsibility Matrix. *National Institute of Building Sciences (NIBS)*. Available at: www.projects.buildingsmartalliance.org/files/?artifact_id=4093 [Accessed January 13, 2015].

East, E.W., (2007). *Construction operations building information exchange (Cobie): Requirements definition and pilot implementation standard*, DTIC Document.

Henderson Jr, D.A. & Card, S., (1986). Rooms: the use of multiple virtual workspaces to reduce space contention in a window-based graphical user interface. *ACM Transactions on Graphics (TOG)*, 5(3), pp.211–243.

Hendry, D.G. & Green, T.R.G., (1994). Creating, comprehending and explaining spreadsheets: a cognitive interpretation of what discretionary users think of the spreadsheet model. *International Journal of Human-Computer Studies*, 40(6), pp.1033–1065.

Kohlhase, A., (2013). Human-Spreadsheet Interaction. In *Human-Computer Interaction--INTERACT 2013*. Springer, pp. 571–578.

MIMOSA, (2006). Open System Architecture for Condition-Based Maintenance. Available at: http://www.mimosa.org/?q=mimosa-osa-cbm [Accessed February 13, 2015].

MIMOSA, (1998). Open System Architecture for Enterprise Application Integration. *An Operations and Maintenance Information Open System Alliance MIMOSA*. Available at: http://www.mimosa.org/mimosa-osa-eai [Accessed February 13, 2014].

Nardi, B.A. & Miller, J.R., (1990). An ethnographic study of distributed problem solving in spreadsheet development. In *Proceedings of the 1990 ACM conference on Computer-supported cooperative work*. pp. 197–208.

NAVFAC, (2014). Capital Improvements and Public Works Electronic Operations and Maintenance Support Information (eOMSI) Implementation Training. *Naval Facilities Engineering Command*. Available at: https://www.wbdg.org/pdfs/eOMSISpecificationTraining.pdf.

Panko, R., (2000). Spreadsheet Errors: What We Know. What We Think We Can Do. *Proceedings of the Spreadsheet Risk Symposium*. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.99.4875&rep=rep1&type=pdf [Accessed October 22, 2015].

Poon, J. & Maher, M. Lou, (1997). Co-evolution and emergence in design. *Artificial Intelligence in Engineering*, 11(3), pp.319–327.

Powell, S.G., Baker, K.R. & Lawson, B., (2008). A critical review of the literature on spreadsheet errors. *Decision Support Systems*, 46(1), pp.128–138.

Saariluoma, P. & Sajaniemi, J., (1989). Visual information chunking in spreadsheet calculation. *International Journal of Man-Machine Studies*, 30(5), pp.475–488.

Scarponcini, P., (1996). Editorial: Time for an Integrated Approach to Facility Management. *Journal of Computing in Civil Engineering*, 10(1), p.3.

Singh, V, Gu, N & Wang, X., (2011). A theoretical framework for BIM-based multi-disciplinary collaboration platform, *Automation in Construction* 20, 134-144.

Thorne, S. & Ball, D., (2008). Exploring Human Factors in Spreadsheet Development. *arXiv preprint arXiv:0803.1862*.

Ware, C., (2012). *Information visualization: perception for design*, Elsevier.

William East, E., Nisbet, N. & Liebich, T., (2012). Facility management handover model view. *Journal of Computing in Civil Engineering*, 27(1), pp.61–67.

Woods, D., (1995). *Toward a theoretical base for representation design in the computer medium: Ecological perception and aiding human cognition*, Lawrence Erlbaum Associates.

Woods, D.D., (1984). Visual momentum: a concept to improve the cognitive coupling of person and computer. *International Journal of Man-Machine Studies*, 21(3), pp.229–244.

Woods, D.D. & Watts, J.C., (1997). How not to have to navigate through too many displays. *Handbook of human-computer interaction*, 2, pp.617–650.

Yalcinkaya, M. & Singh, V., (2015). Patterns and trends in Building Information Modeling (BIM) research: A Latent Semantic Analysis. *Automation in Construction*, 59, pp.68–80.