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Designing structured cabling systems documentation and model by using Building Information Modeling – Literature review

Sergey Pogorelskiy[a], **Imre Kocsis**[b]

[a]Doctoral School of Informatics, University of Debrecen, Debrecen, Hungary
pogorelski.serg@gmail.com

[b]Department of Basic Technical Studies, Faculty of Engineering, University of Debrecen, Debrecen, Hungary
kocsisi@eng.unideb.hu

Abstract. Offices, airports, factories and universities requires a local area network that combines computers, telephones, and peripheral equipment. A basis of computer network is a structured cabling system with the main elements as follows: telecommunication cabinets, copper and optical panels, cable lines and cable trays. The design of structured cabling systems as parts of complex building engineering systems—similarly to many engineering systems—is usually carried out by computer-aided design programs. This approach has a number of disadvantages. Therefore, more and more attention has recently been paid to the use of Building Information Modeling concept not only for the design of buildings and their engineering systems but also for the operation of them ([15, 20, 23, 26]). In a recent work, we touched upon the issue of designing telecommunication cabinets and the equipment inside them in the Building Information Modeling environment. We developed a novel 3D model of cabinets, which has a number of distinctive features: (1) the ability to select the equipment installed in a particular unit in the properties; (2) the ability to change and add equipment inside the cabinet; (3) automated creation of schemes for facades of cabinets and equipment inside; (4) automated creation of equipment specifications in cabinets [18]. Also, we analyzed the use of cable trays for modeling cable lines and found an optimal way to build tray routes and their elements. The goal of our further study is to build up the entire design cycle process using all the necessary elements in

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Building Information Modeling and then use the model during the operation. Till now there is only a small part of the research covers topics related to use Building Information Modeling for engineering systems. The authors aim to fill this gap with a qualitative analysis of the existing literature and the application of Building Information Modeling in information technology. The methodology includes several steps: Traditional literature review on the use of Building Information Modeling in the design and management of facilities in the field of engineering systems and then qualitative analysis of researchers content related to the design of engineering systems. The qualitative investigation of the literature has identified five main areas of Information and Communications Technology where Building Information Modeling tools and methodologies are used, namely (1) analysis of cabling systems; (2) production of working drawings; (3) optimized data center design; (4) preparation of documentation and models for further facility management; (5) monitoring system parameters. Literary sources have different degrees of correlation with the main research questions: weak, medium, and strong. In our study, we used medium and strong correlated topics of the study. The ultimate goal is to find an optimal solution to designing structured cabling systems documentation and model by using Building Information Modeling with the improvement of techniques available in the relevant literature.

Keywords: Building Information Modeling, BIM, structured cabling systems

1. Introduction

Structured cabling systems (SCS) are the basis for smart buildings and data centers. It is difficult to imagine a modern office without cable systems. Now they include not only computers, telephones and, peripheral equipment. This SCS applies to intelligent buildings for several reasons. Literally, the networked link between a building's systems allows the company operate within to automatically control security, environmental conditions, lighting, communications, and other factors. It is now more important than ever for an enterprise's operations to be efficient, effective, and economical. Furthermore, one of the most challenging environments is a data center, where structured cabling can be extremely beneficial and even necessary. Given the numerous active equipment elements that require connectivity. SCS include main following elements:

- telecommunication cabinets and racks in cross rooms of buildings;
- copper and optical panels inside telecommunication cabinets;
- telecommunication outlets installed in the offices;
- copper and optical cable lines connecting panels in the cabinet and information sockets;
- cable trays and boxes for laying cable lines in them.

During the SCS design by using standard CAD systems, engineers faced with the following problems: (1) Drawings of cable trays are created in 2D; (2) Cabinet façade schemes are created manually; (3) The equipment for specifications are counted manually; (4) Cable lines specification counted manually; (5) Classic 2D schemes are not convenient to use for the further facility management; (6) Duplication of work between the engineers designing a system and engineers creating a model of the same system in Building Information Modeling (BIM). To avoid the above problems, it is necessary to use the concept of BIM design. BIM is a complicated idea that relies for management work, tools, and apps to facilitate information flow and, as a result, increase project productivity. The industry is evolving due to the use of BIM and the growing use of digital technology in building construction, building operations, and building maintenance. Instead of traditional application of BIM for buildings design, the technology could be applied for Engineering Design. Traditionally, the BIM concept in engineering systems is used to model and create projects for the following systems: heating, ventilation and air conditioning systems, pipelines, fire extinguishing systems. Less often we can find power supply systems. And the area of application of BIM for structured cabling systems remains unexplored. The aim of this research, therefore, is to start bridging that gap. In particular, we have prepared a traditional literature review on the application of BIM in information and communication technology and engineering systems.

2. Methodology

The methodology adopted to develop this qualitative review of the literature on the use of BIM in structured cabling design and data center research consisted of a traditional literature search on the use of (1) BIM in design and facility management; (2) Qualitative analysis of the content related to the design of structured cabling systems and data centers, disclosed in Step 1. Five main areas are identified in which BIM tools and methodologies are used; A breakdown was also made according to three criteria for the correspondence of literature sources to the main five questions:

- Weak: there is no BIM use with the same title proposed by the authors nor is there a BIM use that, in its description, focuses on the structured cabling design and data center engineering area that the authors identified.
- Medium: there is either a BIM use with the same title identified by the authors or there is a BIM use (or more than one) that focuses on the same topic proposed by the authors, even if the description in the guide is too general and never directly relates to the structured cabling design and data center engineering discipline.
- Strong: there is a BIM use with the same title identified by the authors and its description goes into detail about the structured cabling design and data center engineering area that the authors identified.

The qualitative investigation of the literature that the authors have conducted has highlighted 5 main BIM uses in ICT engineering: (1) cabling systems; (2) production of working drawings; (3) data center optimization; (4) preparation of documentation and models for further facility management; (5) monitoring system parameters.

3. Literature review

This article first reviews articles in the field of using BIM for the design and operation of engineering systems. The aim is to find the literature in recent years that has discussed these issues in general or for specific tasks. Based on the data obtained, there are a number of documents to date in which attention has been paid to various models and methods of operation. The most relevant documents are selected and discussed within the framework of this article, 27 articles-analyzed, and on the basis of them, a quantitative and qualitative analysis is carried out, as reflected in tables 1 and 2.

Table 1. Quantitative analysis.

Reference	Area of use				BIM Content		
	Plan	Design	Build	Operate	Is there a relationship with the BIM	Does the article correlate with 1 of the 5 main criteria	Level of correlation with main criteria's
[18]		+			+	+	Strong
[23]		+		+	+	+	Strong
[8]		+			+	+	Weak
[21]				+			Weak
[2]		+			+		Medium
[3]		+			+		Medium
[26]		+			+	+	Strong
[15]		+			+		Weak
[11]		+			+	+	Strong
[7]		+			+		Weak
[19]		+	+		+		Weak
[9]		+			+		Weak
[4]				+			Weak
[5]				+			Weak
[6]		+		+			Weak
[17]				+			Weak
[10]		+		+	+		Weak
[13]				+			Weak
[14]				+	+		Weak
[16]				+			Weak
[1]				+			Weak
[22]				+			Weak
[24]				+			Weak
[25]				+			Weak
[27]	+	+		+			Weak
[12]		+	+		+	+	Strong

Table 2. Qualitative analysis.

	Number of Reference Document
(1) analysis of cabling systems	6.9%
(2) production of working drawings	24.14%
(3) optimized data center design	20.69%
(4) preparation of documentation for further facility management	37.93%
(5) monitoring system parameters	37.93%

Table 1 shows a detailed analysis of all literature sources used in this article. Table 2 shows in percentage terms the number of sources related to the 5 main criteria for qualitative analysis. The related articles attempt to answer the following questions:

1. The purpose of this article [1] is to provide an overview of the different types of maintenance strategies for critical infrastructure facilities such as hospitals in Malaysia. To obtain data, interviews were conducted with institutional management and end-users in selected hospitals. Hospital management should have a strategic maintenance plan in place to monitor each facility and help it operate well with less chance of failure. Therefore, end-user facilities in hospitals must be maintained and controlled according to their function. The results show that there is a correlation between operating strategies and customer satisfaction levels.

2. The article [2] reveals the definition and essence of information modeling in construction. The content and effect of using information modeling of various objects of the object's life cycle is described. Analyzed short-term and long-term benefits. An exploratory review of Revit software was carried out in search of Autodesk according to the criteria: tools, cost characteristics and profitability. A predictive calculation of the effectiveness of information modeling technologies in construction is given, examples of the successful implementation of information modeling in construction abroad and in Russia are found.

3. In recent years, cloud computing has developed rapidly. In order to implement them, we have to have a physical infrastructure in the form of a data center. Accordingly[4], the data center must operate efficiently, with all the necessary monitoring systems for parameters, to ensure the best level of use of IT resources. Through the effective implementation of data center operations management for cloud computing, it is possible to reduce the workload of staff and improve the efficiency of operational staff, improve the current state of business systems, as a result improves the overall efficiency of enterprise management.

4. The growing development of data centers is causing problems with energy

consumption. More than 1.3 percent of global energy consumption comes from electricity used by data centers, and this rate is growing. Articles show that most of the energy consumed in a data center is mainly due to the electricity used to run servers and cool them (70 percent of the total cost of a data center). Therefore, the main factor in this power consumption is related to the number of running servers. The main goal of this article [5] is to manage the on/off of servers in the data center over time in order to adapt the system to changes in incoming traffic in order to ensure good performance and reasonable power consumption. The system begins to gradually turn on the servers at a high level of requests. And turn off the servers gradually when the rate of receiving requests becomes low.

5. Data centers are about 50 times more energy intensive than conventional office buildings. The main goal of this study [6] is determined by the process of energy analysis, numerical studies and simulation studies to evaluate the impact of each technical component in order to create energy-optimized data centers. The methodology and program developed in this paper for evaluating the energy consumption of data centers should be used by engineers and designers when building data centers to evaluate the efficiency and economic benefits of cooling systems.

6. This article [7] presents a comparison of the development of design in civil engineering: traditional design and information modeling (BIM). The advantages and disadvantages of traditional design and information modeling are described. An office complex in Warsaw, designed using BIM software, was analyzed. The shortcomings and problems in the implementation of BIM are analyzed.

7. The aim of this study [9] is to develop a 4D BIM research model in EPC projects. This study differs from previous work in the following ways: Firstly, previous studies have not considered the context of project contract types, and this study focuses on EPC projects where a quantitative research method is appropriate, as some redundant variables can be avoided. Secondly, most of the research on the use of information technology was carried out in developed countries. This study focuses on China, which is a typical developing country with a huge construction market.

8. The study [10] presents a new concept that shows how BIM can be used effectively during building maintenance. BIM is now widely used in construction projects for quality control, time management and financial control. After the construction is completed, the digital model is transferred to the client for subsequent use in operation. BIM can help the owner optimize facility maintenance by exporting relevant information about the building being built and the requirements to run the systems that will be used throughout the facility's life cycle. The critical factor is the availability of a method to combine BIM with active data. The most important outcome of this study is

the definition of a conditions data model solution that: combines active and passive big data with BIM; provides dynamic services based on the shape of the building, building services technologies, the Internet of things and information about the actions of residents in real time; solves IT problems with the processing of large BIM files through an Internet browser and mobile applications; and allows to provide the data needed for the building's digital twin.

9. There are currently no monitoring strategies utilized in the design of mechanical, electrical and plumbing (MEP) engineering systems due to the complex structure of the components. In order to address this issue, this work [11] generated a directed representative graph using BIM data and integrated the graph with Internet of Things (IoT) for the aim of monitoring MEP systems. In a directed representative graph, edges are the connections between two representative adjacency points, and vertices are the representative points. Six Revit-created BIM object models were utilized to test the suggested methodology. The developed simulated system shows how to use IoT for intelligent MEP system monitoring on a directed representative graph.

10. The paper [12] examines the benefits and drawbacks of adopting BIM technologies in the planning of the Shanghai Baoshan commercial center. The mechanical and electrical components of the building's engineering systems are given special consideration. In this project, three-dimensional mechanical and electrical models interact, and the pipeline conflict problems are found when building the electromechanical system. As a result, the construction period is extended and more materials are wasted, which lowers costs and improves construction efficiency.

11. High performance computing (HPC) is inextricably linked to effective data center infrastructure management (DCIM). The cost and complexity of DCIM quality assurance is constantly reviewed and evaluated by companies such as Google, Microsoft, and Facebook. This article [13] demonstrates a system that uses big data strategies and 3D game technology to successfully monitor and analyze multiple HPC systems and a modular data center on a single platform. Big data technology and a 3D gaming platform enable real-time monitoring of 5,000 environmental sensors, over 3,500 IT data points, and display visual analytics of the overall operational health of the data center.

12. This article [14] presents a scenario for integrating augmented reality (AR) and building information modeling (BIM) to create an intelligent environment (AmI) for facility managers, in which mobile user interfaces will have data to facilitate decision making. The technological requirements for creating such an intelligent environment are also discussed.

13. Efforts were made in the article [16] to reduce operational risk, increase responsiveness and improve monitoring in data center infrastructure using low

cost and low power wireless sensors to monitor power, temperature, humidity, air pressure drop and vibration in the data center. The purpose of the study was to collect and analyze information in order to ultimately reduce downtime and operating costs, improve energy efficiency, and properly plan the use of space in the data center. Finally, an approach to time monitoring and data center infrastructure management was proposed. As a prospective research in this area, the authors consider predicting the performance and operation of data centers in the future.

14. The aim of this paper [20] is to develop a new methodology based on BIM and integration of facility management systems supported by an information model. The process of implementing the information model is described, including the information technology involved, the data and process requirements, and the methods used to assess the performance of the facilities. A first pilot study has been carried out on the example of operating theatres in medical centers. The methodology can facilitate maintenance planning based on the current state of the facility and the achievement of organizational, environmental and technical requirements. The practical results are as follows: improved assessment of technical and environmental performance; better visualization of the state of the building; improved decision-making process; easier planning of maintenance tasks and management of facility parameters.

15. In this paper [17], a new statistical approach, based on Monte Carlo methodology, has been proposed to estimate the lifetime performance of modular data centers. The approach uses component failure probability distributions over time of use to calculate component-level failure penetration, called a snapshot. At the same time, a generalisation in the form of a cumulative Tanh-Log probability distribution has been proposed to better fit real system failure data. Using the proposed distribution and analysis approach, the performance of three well-known topologies in the context of modular data centers, i.e. FatTree, BCube and MDCube2D, was studied. In addition, in order to make these topologies more flexible and independent with respect to the hardware and to increase their resilience to failures, some extended versions of these topologies, designated as FatTreeE, BCubeE and MDCube2DE, were introduced. It was concluded that the extended BCube topology, BCubeE, could provide better fault tolerance in terms of various performance metrics (depending on the tolerance range of the distributions used).

16. The article [18] compares classical design methods and the use of information modeling methods, using the example of modeling cable trays and telecommunication cabinets. It provides an analysis of the available cable tray design solutions and the choice of the optimal solution for cable route modeling and automatic element specification. Also, this article presents a new dynamic family of telecommunication cabinets, which was developed by the authors to simplify the creation of schemes for cabinet facades in data centers and

further automatic specification of equipment inside racks. The labor costs of engineers in design and modeling have been shown to be lower as a result of this study.

17. In the article [23] the authors focus on data centers. This article provides a practical example showing the problem of designing and then preparing a model for use in Facility Management (FM). The importance of this study lies in the fact that the proposed method demonstrates a direct relationship between the following three components: temperature and humidity sensors, FM and Building Management System (BMS) software, and BIM. This method is implemented by a direct link between the BIM model and the program for FM, which in turn is linked to BMS.

18. The authors of the article [3] considered 3 stages of integrating BIM systems in the design of data centers: 1. Building an information model using the selected BIM tool. 2. Design of engineering systems depending on the level of complexity of the object. 3. A method for implementing the data center model with information modeling has been formulated, taking into account the requirements of the Uptime Institute classification. The main advantages of BIM in the design of data centers were also described.

19. BIM is mainly used for the design and construction of new buildings. However, one of the main challenges facing the implementation of BIM for existing or old buildings built without considering their modelling is to obtain accurate data about the existing building and convert it into a BIM model. Based on this challenge, this study [15] develops a framework that uses different data collection methods for existing buildings and then converts the data obtained into 3D BIM models, with which the facility management processes can be improved over the life of the building. In particular, this paper looks at: 3D laser scanning techniques for collecting data from the interior and exterior of buildings. The captured data was then converted into a high-resolution 3D model. This confirmed the accuracy of this engineering model by converting 2D engineering plans into 3D plans using well-known engineering design tools. Moreover, the 3D model was integrated with the web-based Building Management System (BMS) platform. This research base helps in the development of engineering facility management processes and modern digital transformation processes aimed at accelerating the management of facilities during operation using modern technology.

20. The study [25] of modern cyber-physical systems (CPS) has been an important area of research for Internet Data Centers (IDCs). IDCs - support the reliable operation of many important online services. Along with the expansion of Internet services and cloud computing, the energy consumption associated with IDC operations has increased significantly in recent years. This massive energy consumption has placed an extremely heavy burden on IDC

operators. While most previous work has only looked at IDC's dynamic optimisation within electricity markets, IDC's response to the electricity market has been overlooked. Due to the fact that IDCs are typically large users in the electricity market, they may have market power affecting the electricity price. This paper investigates how to address the interaction between the performance of IDCs and the market price of electricity. To this end, a function for modelling IDC market power is proposed and the problem of minimising the total electricity cost is formulated as non-linear programming. A CMC algorithm based on the economic concept is also presented. The CMC algorithm not only solves the optimization problem efficiently but also determines the dynamics of workload allocation. Extensive performance evaluations demonstrate that the proposed method can effectively minimize the overall power cost for IDC by adaptively managing the interaction between IDC and smart grid.

21. The article [26] discusses the use of wireless sensors for monitoring the temperature parameters of data centers and their integration with BIM. Integrating a Wide Area Network with an existing data center BMS has a number of advantages, including cheaper and faster installation, which allows more sensors to be deployed for more accurate measurements and control, and the associated flexibility to deploy the temporary infrastructure needed to perform measurements. In limited time. This technique for monitoring temperature parameters in the data center allows to increase energy efficiency.

As can be seen from the presented study, the number of papers aiming to answer questions connected to the design and operation of structured cabling systems in offices and data centers is quite minimal. It is important to go deeply into this area because it is understudied.

4. Research gap analysis and future research

Due to research topic related to SCS is unexplored, in our research we would like to concentrate on practical aspects and check the concept. Our next steps are as follows: creation of a model and design of structured cabling systems of a industrial project; developing script for automatic cable routing and adjusting for cable trays; linking elements of a structured cabling network with elements of other engineering systems in the model (clash detection); testing of cable lines and comparison of actually built results with lines obtained in the cable specification in BIM; comparison of the parameters of cable lines, actually received and calculated.

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