

Short thesis for the degree of doctor of philosophy (PhD)

**BIM-based methods for optimizing the design and
maintenance of telecommunications infrastructure
in data centres**

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Background and objectives of the doctoral thesis

This dissertation examines various methods for optimising the work of engineers involved in the design and operation of technical systems in data centres. From a methodological point of view, they are divided into three levels: code level, algorithm level and user level.

A data centre is a high-tech and complex unit that processes, stores and transmits information for a specific organisation and manages the organisation's information system [1]. It is a specialised facility consisting of a complex infrastructure including [2, 3]: Information infrastructure, including server equipment that performs the primary functions of the data centre, such as information processing and storage.

The telecommunications infrastructure, which facilitates the interconnection of elements within the data centre and the transmission of data between the data centre and users.

The research involved several levels of work, including plug-in development at the code level, creation of models of basic data centre components such as telecommunications cabinets, equipment and cable routes, and integration between the building management system (BMS) and temperature equipment at the algorithm level. In addition, temperature management techniques were implemented using the corridor isolation method. These blocks were selected for the study because they are rarely studied and have real-world applications at the user level, for engineers.

In **Chapter 1**, I discuss the classification and the structure of data centre and background of the research.

The study commenced in 2020 with the principal objective of implementing a novel approach based on three interconnected levels for the subsequent design and operation of engineering systems for data centres utilising the Building Information Modelling (BIM) design concept. The study comprised several phases:

- A comprehensive literature review was conducted to identify the most under-researched areas related to the design and operation of engineering systems using BIM.

- Novel elements were created for the model based on the algorithmic level.
- An algorithmic approach was implemented. Systems design and verification;
- Development of a collision-checking plug-in at the code level;
- Testing of BIM elements (families) and plug-in at the user level;
- Data collection and analysis of implemented BIM elements at the operational stage.

Chapter 2 presents a methodology that can improve data centre performance by efficiently designing the placement of trays and cables and managing related information. The method automates the formation of facade schemes and ensures correct specification.

The tray design plugin and dynamic cabinet family, as outlined in this section, facilitate the design and specification process, whilst also enhancing the profitability of FM. In conclusion, the aforementioned issues have been addressed.

The plugin automates the construction of cable routes between cabinets. The positioning of fastening elements is automatically determined in accordance with the selected surface (wall, floor, ceiling), and all relevant components, including bolts and nuts, are incorporated into the specification.

The newly created cabinet family facilitates the automated selection of requisite equipment and its placement within the designated 'properties'. The capacity for each cabinet to be filled in a unique manner eliminates the potential for errors to be introduced during the creation of façade diagrams. Furthermore, all equipment is automatically incorporated into the specifications.

The results of this section will form the basis of the first thesis.

In **Chapter 3**, I discuss the methodology for collision checking, which based on several key factors. Such factors include adherence to the prescribed sequence of checking systems, the exclusion of irrelevant collisions, and the establishment of tolerances when integrating system components. I

developed a novel special-purpose plug-in, to facilitate the implementation of the methodology.

In the context of collision checking, three levels of analysis have been identified. At the code level, forms are created for data visualisation purposes, and computer code is developed for the logic that underpins the user interaction with the database. In the context of user-level interaction, users engage directly with the form for the purpose of searching for and visualising collisions, as well as eliminating individual collisions. The objective is to identify and eliminate collisions in accordance with a prescribed sequence. Once a collision has been eliminated, an identifier is incorporated into the form in the form of a checkmark. This serves to indicate the successful elimination of the collision, the date of the elimination, and the name of the user who performed the elimination. The three levels are inextricably linked and collectively constitute the fundamental building blocks of the plugin's functionality.

As collisions can lead to construction errors, it is of paramount importance to remove any remaining collisions between the engineering systems after they have been correctly modelled. The new approach to plug-in development enables engineers to improve their work in designing all the modelled systems. It allows for the identification and correction of intersections approximately ten times faster, while also excluding duplicated intersections and tracking the history of each one. The results of this section serve as the basis of Thesis 2.

In **Chapter 4**, I examine the method related to connection BMS and BIM model. The proper monitoring of temperature and indoor humidity ranges is crucial for ensuring the reliability of data centre equipment. To achieve this, regulating airflow can be used to control temperature and humidity. As the temperature rises, the equipment draws in a greater volume of cool air.

Additionally, the way in which data is collected from sensors and integrated into the facility management model is also important. Currently, most engineers use a BMS that is separate from the information model. However, in this research section, we suggest connecting the building management

system (BMS) directly to the model. This will improve the facility management of data centres.

With regard to the cooling of the equipment, there are several possibilities.

One of the most effective ways to improve the efficiency of a modern data centre is through the use of isolation systems. This is because the cooling system is the primary consumer of surplus capacity in the data centre. The lower the load on it, the higher the energy efficiency.

There are two basic options for the installation of a containerisation system in an existing server room: the isolation of the cold aisle or the isolation of the hot aisle.

In this section of our study, we compare the two types of corridor isolation on a case-study example of a data centre, using computational fluid dynamics (CFD), and select the optimal option.

The results of this section serve as the basis of the Thesis 3.

In **Chapter 5**, I present the application of the research results. I have tested all these blocks in various real projects at CROC, ranging in size from small data centres with 15 telecom cabinets of 2kW each, to large commercial data centres with over 1000 cabinets of 6kW each, which rent their facilities to large organisations. During the testing process I received feedback and made the necessary adjustments. It can be concluded that all proposed methodologies are currently in use, being improved and updated.

Results of the dissertation

Automated equipment and cable trays design for structured cabling system in data centre

Thesis 1

Introduction of a novel systematic approach for design and identification of cable channels for a unified data centre cable infrastructure, allowing all cable channels elements to be automatically considered and specified.

I have developed a new dynamic family of telecoms cabinets for server rooms and data centres, allowing for different internal equipment configurations and optimising documentation for subsequent operation.

The equipment location design inside cabinets and the element specification in the model of SCS was optimized with a new specific dynamic cabinet family based on algorithm level.

As a result, the novel family that was created and implemented in Revit, reduces the duration of the design phase and creates schemes up to three times faster in comparison with traditional CAD design.

The key features are the following: by adjusting the family parameters different sub-families can be selected within cabinet units, sub-families can be modified and added within the cabinet, the creation of a cabinet facade scheme is facilitated on the basis of the equipment inside, specifications are generated automatically.

The improved solution for organising cable ducts was found based on user level, making it possible to automate the process of modelling and accounting for all elements of cable trays.

Related publications:

Pogorelskiy S.; Kocsis I., Designing structured cabling systems documentation and model by using Building Information Modelling – Literature review, Annales Mathematicae et Informaticae (2024). DOI: 10.33039/ami.2024.02.005

Pogorelskiy S.; Kocsis I., Automation for structured cabling system in data centres using Building Information Modelling. International Review of Applied Sciences and Engineering 13.3 (2022), pp. 335–345.
URL:<https://doi.org/10.1556/1848.2022.00424>

This section discusses the two primary factors that impact various aspects of a data centre: cable route design methodology and the proper placement of cabinets and equipment within them. These factors significantly affect the usability, reliability, and efficiency of data centres.

A structured cabling system is created to organise a single cable infrastructure that can be used by local computer networks, telephony systems, video surveillance, access control, and other systems for the transmission and processing of information.

The cable trays in the data centre serve multiple functions, including providing protection for cable lines of various systems from external influences. They protect cable lines of horizontal and trunk cable systems from electromagnetic interference.

They also physically separate different systems, such as fibre optic cables and low current cables, in separate trays.

In telecommunication cabinets of data centres, SCS are created using functional elements such as copper patch panels, optical patch panels, cable organisers, copper cables, and fibre optic cables.

A range of tools are available for creating information models. For this study, Autodesk Revit was selected as the most suitable tool for problem-solving and implementation. It enables the design of architectural, structural, and engineering elements by creating the necessary components.

Furthermore, it allows multiple specialists to collaborate on a single information model, download drawings for documentation, and create custom families, including dynamic ones with adjustable parameters.

BIM based collision tracking at the intersections of different building engineering systems at the design stage

Thesis 2

I developed a solution that allows to effectively track and visualise collisions based on BIM where different engineering systems intersect during the design phase, also allowing to reduce irrelevant collisions.

The efficiency of the collision reduction process was improved using a new approach in plug-in design.

The C#-based novel plug-in was developed based on code level, and has been tested in a real-life project eliminates intersections with engineering systems in data center models. It has significantly reduced the time needed to search for a single collision, as the conditional number of clicks needed to fix a collision has been reduced by 100 times. Collaborative fixing of collisions is enabled within the same model that saves extra work and communication. At the algorithm level, a unified database allows for easy tracking and reporting of each collision.

Related publications:

Pogorelskiy S.; Kocsis I., BIM based collision tracking at the intersections of different building engineering systems at the design stage, International Review of Applied Sciences and Engineering 1-11 (2024).

URL:<https://doi.org/10.1556/1848.2024.00833>

After creating the novel cabinet families and exploring better cable trays design, our research focused on collision tracking plug-in creation, due to cabinets and cable trays could gave intersections with other engineering system objects.

Each of digital information model elements are three-dimensional, allows for clear tracing of the location (x,y,z - position) in space and prevents their intersection.

Detecting and preventing collisions at early design stages can reduce the need for extensive revisions to the executive model, which serves as the foundation for the design documentation.

The methodology proposed in the research part for checking collisions is based on several key factors. These include compliance with the sequence of checking systems, exclusion of irrelevant collisions, and setting tolerances when joining system elements.

In our methodology for collision checking, we have introduced three levels: code level (plugin developer), algorithm level (BIM coordinator) and user level (engineers performing the check). At the developer level, forms are developed for data visualization and code for the logic of user interaction with the database.

At the algorithmic level, the function of the plugin can be represented by the following sequence of actions:

- Assignment by the BIM coordinator of the sequence of checking various systems and tolerances for intersection, docking;
- Generation of a collision report in XML format;
- Loading the report into the plug-in.

At the user level, the user directly works with the form for searching and visualising collisions and eliminating single collisions. The user's task is to check collisions in a certain sequence and eliminate them step by step. After elimination, an identifier is placed in the form of a checkmark to enter information into the database that this or that unique collision has been eliminated, information about the date of elimination and the name of the user who last performed the action.

The aforementioned levels (code, algorithm, and user) are inextricably linked and collectively serve as the foundation for the plugin's functionality.

Efficiency improvement with data centre monitoring based on building information modelling and computational fluid dynamics analysis

Thesis 3

I combined a BMS in a data centre with a real-time BIM model to improve its operability. The utilisation of CFD modelling and the identification of an enhanced cooling methodology for data centre equipment has facilitated the optimisation of cooling efficiency for equipment within cabinets, thereby enhancing their operational efficacy.

The communication between real sensors and BIM was improved with a new approach, based on algorithm level.

The direct connection and communication between BMS and EcoDomus were facilitated through a web interface.

As a part of the new solution, relevant information is visualized through graphics about the equipment's sensors to support all building engineers.

The methodology was tested with 54 temperature sensors and 5 humidity sensors where the digital copies of the sensors were connected to the facility management software.

The proposed method enables the detection of deviations from sensor parameters and immediate notification of the operator. In contrast to the classical BMS, changes in the position of the sensors or the addition of new sensors are automatically duplicated in the information model.

Also, CFD model was established to simulate real data center scenarios, by analysing the required elements, materials, and geometry of a BIM model of a server room and conducting hydrodynamic modelling to identify temperature flows. The contrast between hot-aisle and cold-aisle insulation was analysed through a temperature analysis of various vertical and horizontal cross-sections of a server room.

Related publications:

Pogorelskiy S.; Kocsis I., Efficiency improvement with data centre monitoring based on building information modelling on

the facility management stage, Designs 7 (2023) 3:1–3:15. URL: <https://doi.org/10.3390/designs7010003>.

Pogorelskiy S.; Kocsis I., BIM and Computational Fluid Dynamics Analysis for Thermal Management Improvement in Data Centres, Buildings 13(10) (2023). DOI: 10.3390/buildings13102636.doi:10.3390/designs7010003.

The BIM process is demonstrated from the initial design phase through to the operational stage of a data centre, with a particular focus on the implementation of a temperature and humidity monitoring system.

Energy efficiency is improved by constantly controlling the temperature range in data centres. The approach of continuous temperature control is widespread and is a generally accepted standard of data centre operation.

Telecom cabinets housing IT equipment are located in the data centre. Constant cooling is required for this equipment. In order to prevent overheating, it is essential to provide cool air to the cabinet's front door and remove hot air from its rear. However, if there is no barrier between the two zones—cold and hot—the two flows can mix, reducing cooling and increasing the load on the air conditioning units.

To prevent hot and cold air from mixing, it is essential to construct an air containment system. The principle is as follows: the closed container stores the cooled air, preventing it from mixing with hot air and ensuring that high-load cabinets are adequately cooled. The air container should be located between two rows of cabinets or between a row of cabinets and a room wall. All sides of the container separating the hot and cold zones must be separated by partitions so that cold air only passes through the IT equipment.

The energy consumption of IT equipment is directly related to the power requirements of the cooling fans. One can calculate the cooling power requirements of a data centre as per the rack inlet temperature. When the temperature rises, the IT equipment's efficiency declines, and power consumption rises.

In this instance, a solution was devised through the utilisation of both CFD

analysis and BIM during the design and CFD stages. The findings indicate a need for a combined investigation of BIM and CFD.

The objective of this research project was to conduct a comprehensive review of the literature on corridor isolation systems, with a view to analysing the use of corridor isolation and identifying the optimal method.

In order to ascertain the optimal method, a BIM of the server room was conducted, and an analysis was performed on the requisite elements, materials, and geometry. Additionally, hydrodynamic modelling was employed to ascertain the distribution of temperature flows. The CFD provides a reliable model that simulates real data centre scenarios with a high degree of accuracy. To illustrate the contrast between hot- and cold-aisle insulation, the temperature in diverse vertical and horizontal sections of the server room corridor was examined.

Application of the research results

A data centre comprises technical systems, such as telecommunications cabinets, air conditioning units, and systems for routing cables, pipelines, and air ducts. It also includes a temperature monitoring system, a cooling system for equipment, and an UPS system.

The racks, equipment, and cables are the key elements from an information systems perspective. To ensure proper operation, the object must be designed without unnecessary intersections with other engineering systems, while taking into account and correcting any emerging intersections. It is also necessary to effectively cool and monitor these parameters, which requires the correct selection of the equipment cooling system and accurate simulation of temperature parameters.

As part of research into optimizing the design of cable routes and equipment inside telecommunication cabinets, the results were used to model the data centre of CROC's company. The data centre is certified by the Uptime Institute at Tier III level, which corresponds to a fault tolerance ratio of 99.982%. It has a total area of 5000 square metres and can accommodate 800 racks, each with an average electric power of 6 kW. The total power supply capacity of the data centre is 8 MW.

The research involved creation a new plugin to identify and eliminate collisions between engineering systems. It was applied at a large private data centre, which comprises several floors with telecommunication rooms and over 1000 racks. The design of this data centre also utilized developments in cable routes and new families of racks from the previous part.

The fought part of the research was also tested in a private data centre. This involved the monitoring of climate parameters. Models were created for 54 temperature sensors and 5 humidity sensors evenly spaced throughout the room. The digital copies of these sensors were connected to real sensors located in 18 cabinets and areas in the operating data centre using FM software.

In addition, this section used CFD modelling to simulate a small private data centre. The model input data included a room with 15 telecommunication cabinets, each containing IT equipment measuring 600x1200x2000 mm and generating a heat load of 10 kW. The room also had one UPS measuring 600x1200x2000 mm and generating a heat load of 8.5 kW. The cooling system consisted of eight inter-row air conditioners measuring 300x1200x2000 mm.

Our materials demonstrate practical applications and used for designing and modelling tangible objects.

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Subject:

PhD Publication List

Candidate: Sergey Pogorelskiy

Doctoral School: Doctoral School of Informatics

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List of publications related to the dissertation

Foreign language scientific articles in Hungarian journals (4)

1. **Pogorelskiy, S.**, Kocsis, I.: Addendum To: Automation for structured cabling system in data centers using Building Information Modelling.
Int. rev. appl. sci. eng. 15 (2), 279-279, 2024. ISSN: 2062-0810.
DOI: <http://dx.doi.org/10.1556/1848.2022.11424>
2. **Pogorelskiy, S.**, Kocsis, I.: BIM based collision tracking at the intersections of different building engineering systems at the design stage.
Int. rev. appl. sci. eng. [Epub ahead of print], 1-11, 2024. ISSN: 2062-0810.
DOI: <http://dx.doi.org/10.1556/1848.2024.00833>
3. **Pogorelskiy, S.**, Kocsis, I.: Designing structured cabling systems documentation and model by using Building Information Modeling: Literature review.
Ann. Math. Inform. [Epub ahead of print], 1-12, 2024. ISSN: 1787-5021.
DOI: <http://dx.doi.org/10.33039/ami.2024.02.005>
IF: 0.3 (2023)
4. **Pogorelskiy, S.**, Kocsis, I.: Automation for Structured Cabling System in Data Centers using Building Information Modelling.
Int. Rev. Appl. Sci. Eng. 13 (3), 335-345, 2022. ISSN: 2062-0810.
DOI: <https://doi.org/10.1556/1848.2022.00424>

Foreign language scientific articles in international journals (2)

5. **Pogorelskiy, S.**, Kocsis, I.: BIM and Computational Fluid Dynamics Analysis for Thermal Management Improvement in Data Centres.
Buildings. 13 (10), 1-23, 2023. EISSN: 2075-5309.
DOI: <http://dx.doi.org/10.3390/buildings13102636>
IF: 3.1
6. **Pogorelskiy, S.**, Kocsis, I.: Efficiency Improvement with Data Center Monitoring Based on Building Information Modeling on the Facility Management Stage.
Designs. 7 (1), 1-15, 2023. EISSN: 2411-9660.
DOI: <http://dx.doi.org/10.3390/designs7010003>





List of other publications

Foreign language scientific articles in Hungarian journals (1)

7. **Pogorelskiy, S.**, Alava, D.: Building Information Modelling: Present realities and Future possibilities.

Int. J. Eng. Manag. Sci. 3 (4), 377-394, 2018. ISSN: 2498-700X.

DOI: <http://dx.doi.org/10.21791/IJEMS.2018.4.32>

Total IF of journals (all publications): 3,4

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