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Orginal Article

Proposal of a workflow for data-driven design in combination with BIM technology for more efficient office space planning

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Abstract: The development of BIM technology, its dissemination and the resulting standardisation are visible globally. This technology gives access to data created during the design process, enabling their schedule, modification and analysis. The use of data is a common point with data-driven design which, in the context of this paper, is a design approach where data is the primary source of information that affects the design.

Considering the characteristics of modern office buildings and their layout, a workflow using data-driven design and BIM software was created. It makes the process more efficient in terms of the time needed for selected tasks as well as the use, transfer and management of information.

The paper presents solutions that standardise the input data of the type and number of rooms meeting the tenant's needs. Based on the data from the spreadsheet, using scripts, elements representing the area and other parameters of rooms are created. After the arrangement of the spaces, the creation of walls and rooms, the data is automatically transferred to the parameters of the rooms. The furniture is automatically placed using equipment standard spreadsheet data. To ensure the verification of the project's compliance with the requirements, a script was created which graphically shows the fulfilment of the conditions.

Keywords: BIM, space plan, data-driven design, office, automation

1. Introduction

Data-driven design is a broad term used in various fields. In the context of this paper, it is understood as a design approach where data is the primary source of information that affects the design. The final layout can be treated as data visualisation that has been put into the constraints of the architectural floor plan. In the case of projects performed in BIM (*Building Information Modelling*) technology, a 3D model is a source of schedules, calculations, analysis and other uses of information represented by geometry and parameters.

Both data-driven design and BIM technology can find applications in office layout design performed by designers and architects. The process can be more efficient in terms of the time needed for the design, management, use and transfer of the information. The use of BIM technology is growing fast in Poland, especially for high-rise office buildings. There are crucial aspects like repeatability, the high cost of removing collisions, the complexity of cross-industry elements, and their coordination for those buildings. Based on the information provided by the persons developing the project in BIM technology, such an approach reduces the costs of material take-off, architectural design and commercialisation of the building [1].

With the introduction of BIM technology, there are activities related to the standardisation of file elements and the entire process [2]. Countries in the process of introducing the mentioned technology at various levels, including national levels, use the knowledge and standards (e.g. PN-EN ISO 19650-2:2019 [3]) developed in other countries or international documents. At the same time, along with the introduction of new software, companies develop standards which facilitate the learning path for employees and are optimal solutions on the company's scale.

Although there is no precise data, observations of the domestic market show that the use of BIM in interior design is lower than in architectural objects. This may be related to the division of phases and different stakeholders (interior designs do not have to be a part of the building permit design), lower cost of possible collisions and additional work required. However, in the field of office buildings and considering their characteristics, BIM for space planning can contribute to a more efficient design process [4]. This paper presents the exemplary data-driven workflow approach for office space planning using BIM technology.

2. Characteristics of modern offices

Although there is not enough data to present exact numbers, modern office buildings share the same design principles from an architectural and construction point of view. The common characteristics are reinforced concrete structure, height maximisation, and floor-to-ceiling panes. The phase in which the premises is handed over to the tenant is shell and core. It contains a façade and a central core or cores, where common space, lifts, stairways and corridors are located [5]. As for installations, all needed electrical, mechanical, and plumbing infrastructure is placed in cores and accessible for expansion. A BIM model of shell and core in the scope of architecture, construction, façade, mechanical, electrical and plumbing installations should be delivered as input data for the space plan design, which enables the verification of possible collisions at an early phase.

The shape of the floor plan is the result of the site shape, required building area and architects' design. The floor plan is often presented in several options, showing different numbers of tenants and common space on each level. Based on the sum of the area, the profitability of investments is calculated. Space planning is the initial phase in the lease process and is done for multiple tenants (from the building owner's perspective) or multiple buildings (from the tenants' perspective). Its main objective is to check whether the company's spatial requirements can be fitted into the floor plans. Offices can be planned as a classic layout with private rooms, open space or a semi-open space, creating zone divisions in line with the company's structure [6] which can have implications for health and productivity. This systematic review examined office spatial design attributes associated with sitting and face-to-face interactions (FTFIs).

In terms of the standard of space finishing and the type of rooms, the requirements of recipients towards the workplace have increased. It could have been influenced by the international nature of companies and the desire to unify the standard of offices globally, the COVID pandemic [7], or solicitation for employees in some industries. Primary spaces that result from the functioning of offices, such as a reception desk, offices or other forms of the permanent workplace, conference rooms, toilets, and kitchenettes, are supplemented with rooms for cooperation and work in silence. Therefore, elements such as a brainstorming room, a meeting pod, a focus room, and a co-working table are included in space programs.

Furniture and special equipment for offices vary in exact parameters such as dimensions, but the types of elements are common. The primary element is the workplace, the dimensions of which directly impact the shape of the space plan and the number of desks that can be placed on a given level. It is also necessary to provide distances required by regulations and ergonomics for each such element. Other items of equipment that recur in offices include conference tables, kitchenette equipment (fridge, microwave, sink, dishwasher and others), and a reception desk. Space plans can be supplemented with additional elements such as plants, meeting pods and soft seating areas. Regarding technical equipment, which should be included in the space plan phase, the server room or cross room with the required number of racks should be included.

As indicated above, despite the various requirements placed by companies, in modern offices, there are common elements that result from the architecture and structure of the building, floor plans, type of rooms and equipment elements. Thanks to repeatability, it is possible to automate selected processes related to design works, which is discussed in more detail further on.

3. Automation of office layout creation

As discussed in the previous section, space plan design provides a field for applying automation using data-driven design and BIM technology. Its purpose is to provide better design process quality and automate repetitive tasks.

Considering the entire design process of the space plan, there are no uniform standards for providing input information, including the file format and its information. From the architect's perspective, this necessitates analysing and understanding the method of presenting data, which consumes additional time. From the tenant's perspective, it is necessary to develop the data, possibly for the first time, and to create a method of recording it. Standardisation benefits both parties and allows the data to be used in scripts in a later phase.

Based on the author's experience, it can be concluded that in Poland, space plans are predominantly carried out in 2D CAD programs. Developing standards and creating appropriate libraries makes it possible to improve the design process and verification of requirements also in such kinds of software and approach. However, there are limitations to automating such basic activities as time-consuming room area outline creation, room tagging, or tabular data summaries and verification.

In the example discussed below, the presented workflow is based on the use of data-driven design and BIM technology. The goal is to achieve a more efficient design process and automation by:

- providing standardised input data format
- introducing additional preliminary design phase performed in spreadsheets and approval to ensure correct input data
- verification of the total area covered by the project against the requirements
- verification of the level area against the initial room distribution

- automation of the creation of elements based on tabular data allowing for the preliminary arrangement of rooms
- automation of information transfer from elements to rooms
- automation of the placement of equipment elements based on the spreadsheet
- automatic legends, colour schemes, and annotate elements creation
- working verification of requirements with the use of the schedules in BIM software
- verification of requirements between the design in BIM software and the input data in the spreadsheet

The order of discussed phases and the scripts used is shown in Fig. 1.

In addition to the workflow goals mentioned above, there are additional advantages to using BIM software. During the project's development, a 3D model is created that allows a person who does not have contact with architectural drawings to better understand the design intention. The model can also be used later in the concept design and its visualisation. The space plan developed in the BIM software allows for the efficient generation of material take-off and the initial valuation of the arrangement [8].

The process presented in this paper is discussed on the example of spreadsheets made in Excel (.xlsx format), a project made in Revit version 2022 (.rfa format) and scripts developed by the author in Dynamo Core version 2.12.0.5650, Dynamo Revit 2.12.0.5740 (.dyn format).

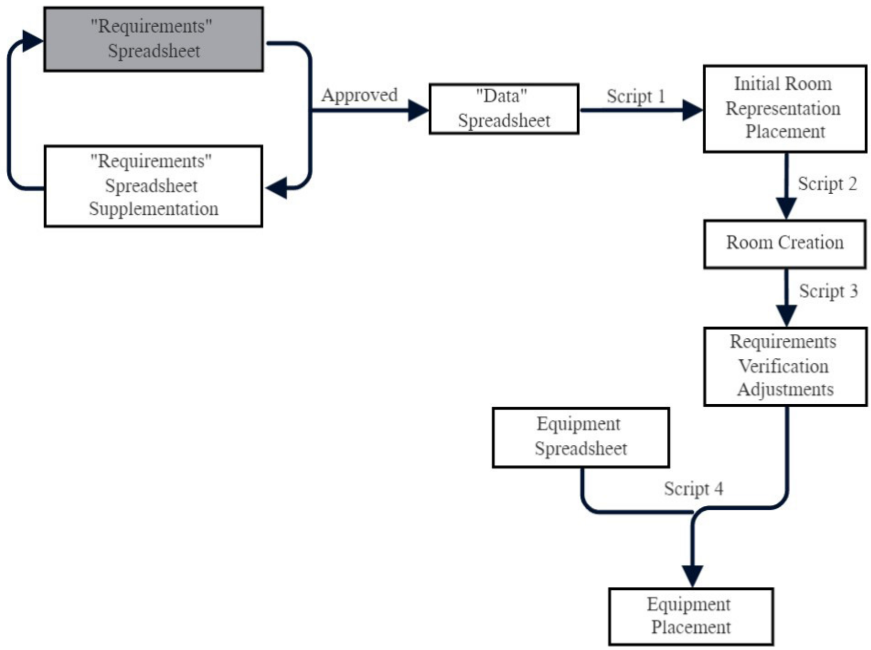

Fig. 1. Diagram showing the sequence of steps and scripts used. Items shown with a gray background are made by the tenant and with a white background by the architect. *Source: own study*

3.1. Standardisation of input data

In order to correctly describe the input data for the companys' structure space budget of 10 companies from branches of technology, IT, software development, banking, trade, publishing, innovation and state-owned companies were analysed. A spreadsheet was created based on this data, covering the most expanded structure. The columns are as presented in Table 1: Zone, Department, Room Name, Room Count, Room Area, Desks Count Per Room, Total Number of Desks (the product of Room Count and Desks Count Per Room), Neighborhood and Comments. As there is no consistent form of space budget submission to the architects, the spreadsheet's purpose is to standardise the tenant's information format.

The tenant can omit rooms required by norms or the area where the value is unknown. The architect should analyse the requirements and fill in the missing elements in such cases. It is a good practice to colour-mark elements introduced by given units and the columns, which are the product of the function operations. In the context of this paper, the spreadsheet is named "Requirements." Supplemented by the architect, this table can be verified and approved by the tenant. It reduces the chance of incorrect input and is a source of information on which the total area provided for the tenant can be checked.

The standardisation of the data form is the first step to introduce data-driven design and to enable their use in the project performed in BIM technology.

Table 1. Part of exemplary requirements table in line with guidelines for script usage. *Source: own study*

Zone	Department	Room Name	Room Count	Room Area [m^2]	Desks Count Per Room	Total Nr of Desks	Neigh-bourhood	Comments
Management	Management	Reception Desk	1	50	2	2	n/a	n/a
Management	Management	Office	3	20	1	3	n/a	n/a
Work Zone	ABC	Office	3	20	1	3	n/a	n/a
Work Zone	ABC	Open Space	1	240	30	30	Proximity to DEF Offices	n/a
Work Zone	DEF	Office	2	20	1	2	n/a	n/a
Work Zone	GHI	Open Space	1	320	40	40	n/a	n/a
Support	Support	Copy Point	4	5	0	0	n/a	Two on each level

3.2. Edition of input data

Editing the requirements table to adapt to the workflow can be treated as a data-driven design phase aimed at room distribution. This requires breaking down the items summarised for the entire office in the space budget requirements into specific levels. This process results in a table created based on "Requirements", which presents each room in the given number in the context of department and zone. Each such item is presented in a separate line. An example of such a room can be a copy point. The total number of such spaces in the requirements spreadsheet is 4. The assumption is that there should be two such rooms on each level, which is stated in the comments column. The example based on Table 1 is presented in Table 2.

The columns of Room Type and Level are added and should be filled in by the architect. Room Type information is needed to apply the colour scheme in the later phase. Level distribution is treated as a design phase in which it is possible to verify whether the distribution of the rooms does not exceed the total area of the level.

Table 2. Part of an exemplary "Data" table in line with guidelines for script usage. *Source: own study*

Zone	Department	Room Name	Room Count	Room Area [m^2]	Desks Count Per Room	Total Nr of Desks	Room Type	Level	Neigh- -bourhood	Comments
Support	Support	Copy Point	2	5	0	0	Copy Point	L01	n/a	Two on each level
Support	Support	Copy Point	2	5	0	0	Copy Point	L02	n/a	Two on each level

It should be noted that this is a manual data distribution process that is prone to mistakes. The verification of the "Requirements" table against the "Data" table takes place at a later phase.

3.3. Script 1 – Automatic creation of room representations

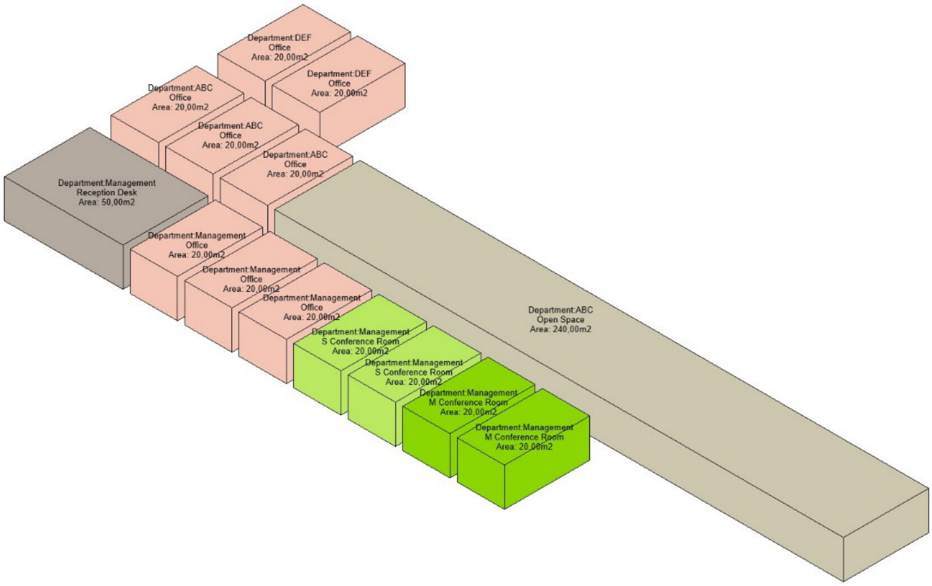

Fig. 2. Exemplary result of the script showing elements in lines of departments with color filter applied. *Source: own study*

The objective of the first script is to create 3D elements representing each room. This phase enables to assess rooms' location and relation without creating elements such as walls or furniture. A cuboid element with a category of the generic model was created to represent the room. The instance parameters of width, depth, comments, zone, department, name, neighbourhood, room type and the number of desks were embedded. The area parameter was calculated based on the cuboid base, which is a product of width and depth. A parameter of the desired area was included to represent the input data. The cuboids in 2D floor plans are rectangles. This approach is an example of data-driven design using BIM technology, where the data is the primary source of information for automated element creation.The script was created in Dynamo, "a visual programming tool" [9], working as a plug-in for Revit software. The input data is drawn from the spreadsheet, so its uniform structure is essential. The script creates rows which represent the number of departments on the level. The coordinates of cuboids' centres are determined using a Python script. It is based on the number of departments (the Y coordinate) and the distance between the two following elements with a margin of separation included (the X coordinate). The data from the spreadsheet is divided into lists and assigned to responding cuboids using dictionaries and values at key. The data is filtered for each level separately due to the design process, where initial assumptions are verified after the arrangement of each level. It requires the user to choose the level before each script run, the spreadsheet location, the cuboid family, and its depth. The depth results from the buildings' layout and the location of the designed communication. In this phase, it is assumed that it is coherent for all the instances but can be later changed appropriately for each element. For architects with no programming knowledge or capability, it is possible to use Dynamo Player, which enables the use of the script from the project level. In the view of each level, colour filters that are based on the cuboid's Room Name parameter are applied.

The result is the set of cuboids representing each room, arranged in lines of departments as presented in Fig. 2. The architect can move elements and align them to the core, façade or others. It is possible to change the dimension of each element separately, keeping the parameters of the desired area in the cuboid's properties. As buildings can be of different shapes, cuboids are data visualisation units and should be treated as such. The final room can be of different shapes. Rooms with work desks are created first, as access to natural sunlight is a critical limiting factor. Open space areas can be divided into more elements to avoid multiple rows of benches that are adverse both from acoustic and well-being points of view. To do this, rooms with other functions can be treated as dividing units. Cuboids representing open space are copied, and the number of desks and the desired area is reduced, keeping the sums coherent with input data.

<Control Schedule>

A	B	C	D	E	F	G	H
Level	ED_Zone	ED_Department	ED_Name	Count	ED_Area [SUM]	ED_AreaDesired [SUM]	ED_NrOfDesks [SUM]
L01	Work Zone	ABC	Office	3	61,44 m²	60,00 m²	3
L01	Work Zone	ABC	Open Space	2	241,67 m²	240,00 m²	30
L01	Work Zone	DEF	Office	2	40,00 m²	40,00 m²	2
L01	Management	Management	M Conference Room	2	53,93 m²	40,00 m²	0
L01	Management	Management	Office	3	56,67 m²	60,00 m²	3
L01	Management	Management	Reception Desk	1	60,48 m²	50,00 m²	2
L01	Management	Management	S Conference Room	2	34,58 m²	22,00 m²	0

Fig. 3. Exemplary control schedule with visible differences in actual and desired area. *Source: own study*

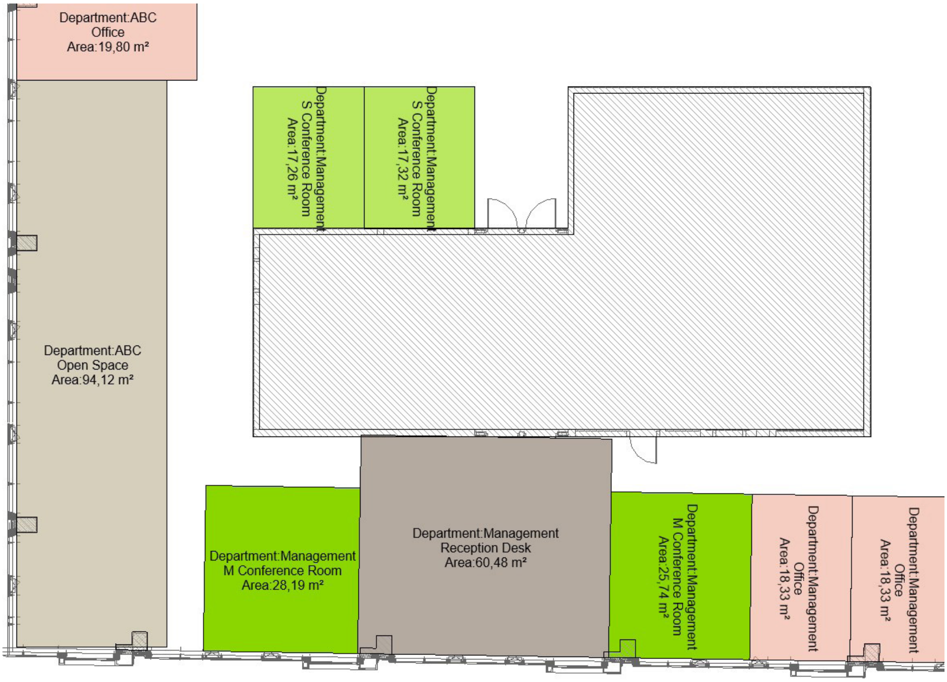

Fig. 4. Distribution of elements representing areas and other parameters on the floor plan. *Source: own study*

Using the advantages of BIM technology, control schedules based on the project file can be created. It enables working verification of potential mistakes like copying elements or running a script more times than needed. An exemplary control schedule with visible differences in the actual and desired area is presented in Fig. 3.

The first script helps assess the possibilities of arrangements faster than the regular workflow and places the required number of workplaces. It allows for avoiding the time-consuming input of redundant information. The room distribution cannot be verified based only on spreadsheet calculations. There are factors such as the length of façade with natural sunlight access, connection points for interior walls and façade, and the number of enclosed rooms with workstations. They are resultants of the floor plan, company's structure, and affect arrangement options directly. The example of cuboids' distribution is presented in Fig. 4. Once the elements are distributed and space budget needs are met, walls are created.

3.4. Script 2 – Automatic data transfer between room representations and rooms

The second script aims to transfer the information from the cuboids to the room properties. It represents the use of data in BIM software to transfer the information between different element categories. Rooms are placed automatically by software within borders – walls and room separation lines. It is essential to include a core outline, including columns. Due to the façade complexity, if the BIM model for these elements is not available, linking the 2D file should be considered. In such a case simple outline for the interior border can be introduced.

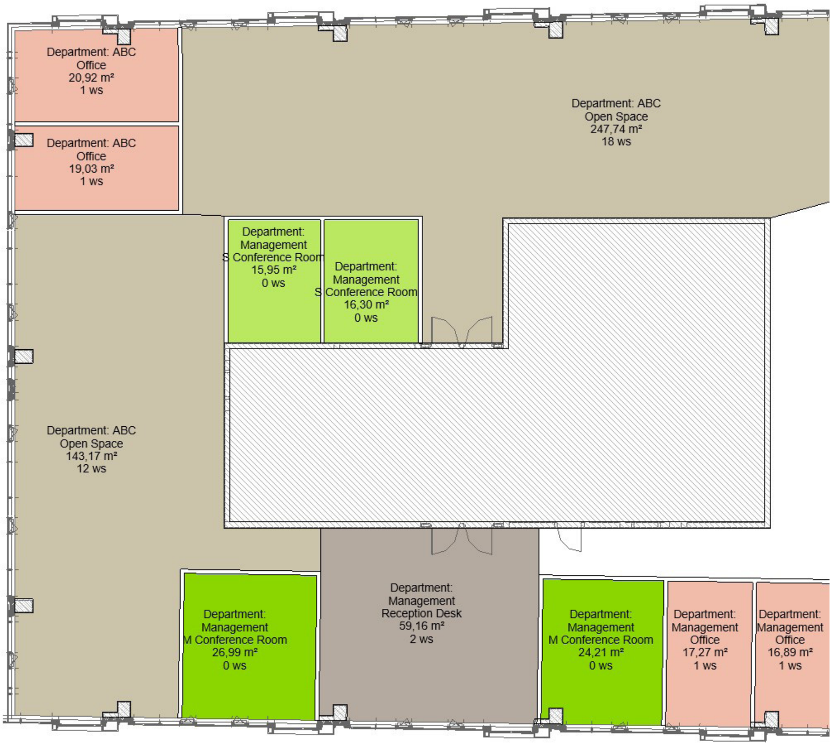

Fig. 5. Space plan with rooms' parameters transferred by Script 2 from cuboid's location. *Source: own study*

A second script limits the error possibilities of inaccurate data rewriting from cuboids to rooms. It also reduces the time needed for this task. The script detects the centre point of the cuboids and the perimeter of rooms on the given level. If the point is within the room's perimeter, properties of the name, department, the number of desks and others are transferred. The level filtering is applied to avoid heavy calculations and have greater control over the drawing. The floor plan with rooms' properties transferred from cuboids is presented in Fig. 5.

3.5. Script 3 – Verification board of the project with the input requirements

At this point (especially before project submission), the fulfilment of required parameters should be verified. The data is placed both in the spreadsheet and in the project file, which may result in a discrepancy.

Verification is performed against the spreadsheet "Requirements", the initial input data before the edition. The values are placed in an annotation element which contains the information about the zone, department, room name, room count in the project file vs required count of rooms, desks count in the project file vs required count of desks. Except for the project file information about the number of rooms and desks, all data come from the "Requirements" spreadsheet. The number of annotation elements is calculated based on the number of unique occurrences of the Zone-Department-Room Name combination. This information key assigns the data calculated in the project file. Importantly, these parameters are calculated and verified in the context of all levels in the project.

This process results in a verification board (Fig. 6) presenting graphically (colour marking) and numerically the fulfilment of the requirements in the context of the number of rooms and desks count. It is required to maintain consistent nomenclature in the process, taking spelling errors into account. In the case of entering data manually, this requirement is an additional factor that verifies the accuracy of the nomenclature.

The verification board presents the link between data and a space plan, which is a set of not only elements but also information within the BIM model.

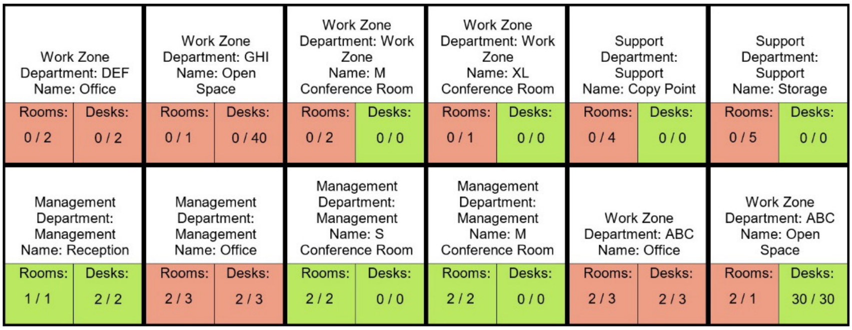

Fig. 6. Example of a verification board based on the "Requirements" spreadsheet and data included in the project file. Items that meet the requirements are marked in green, and those that do not meet them are marked in red. *Source: own study*

3.6. Script 4 – Automatic placement of equipment

After arranging rooms that meet the space budget, furniture is added. The fit-out requirements tend to state the size of desks that can vary between spaces. Other elements like plants, coffee tables, and armchairs are added, although not always specified in the requirements. A script placing elements in a given number is created to automate this process. The spreadsheet data is the ultimate data source for creating the elements in the BIM model, which is a principle of data-driven design.

The spreadsheet states room name, family name and type. The names of elements such as furniture should align with the naming convention, which is a part of the BIM Execution Plan (BEP). The script uses filtering and data matching. The elements are created in the geometric centre of all rooms specified in the data source. The level parameter was also included for greater control over the automatic creation process. Some elements may need to be moved or rotated. However, there are rooms, such as conference rooms, where the central location of the furniture may be a desirable solution. The effect is presented in Fig. 7. Thanks to the automation of this process, the time necessary for placing the elements in the design and distribution in rooms is saved.

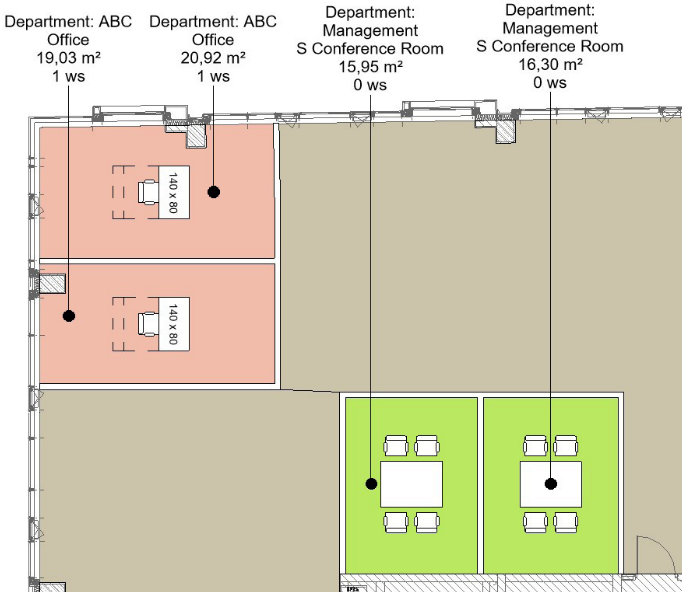

Fig. 7. Example of furniture placed in the floor plan by script. *Source: own study*

4. Conclusion

BIM technology is present in the design of architecture and structure of office buildings in Poland. In order to take advantage of the possibilities it offers, it is also beneficial to introduce it in space plans, which are now often made in CAD programs and with no developed standards adapted to the characteristics of such projects. Data-driven design in the office spaces can find a wide application because, in this phase of the process, the designer's primary task is to apply the numerical requirements of the tenant's desired structure of employment on the building's floor plan. This approach structures the process and gives access to data reflecting the design with BIM technology.

Considering the characteristics of office spaces and the repeatability of elements discussed in the paper, it is possible to standardise the form of data transfer and automate design tasks. The first phase is to standardise the form of communicating the input requirements. The spreadsheet "Requirements" is filled in by the tenant, then verified and supplemented by the architect. It is the subject of an additional approval process that minimises the possibility of mistakes in the interpretation and completeness of the data. The second phase is editing the spreadsheet, dividing the rooms into levels and verifying the sum of areas against the area of a given level. Then elements representing the rooms are created using a script and information from the created spreadsheet. It allows for the initial arrangement of rooms and verification of their placement on a given level. Once walls and rooms are created, a script is used to automate the process of data transfer from cuboids to rooms. The next step is to verify that the input requirements are met. A board is created using the script and annotation elements that graphically show the positions that do not meet the assumptions. In this phase, corrections to the number of rooms and desks are made. Once all the rooms are located, the equipment is automatically placed using a script and the information included in the spreadsheet.

Thanks to these steps, it is possible to structure the space plan creation process. The introduction of additional verification phases helps to avoid making significant modifications such as changes in available levels in an advanced design phase. Automation of selected tasks optimises (reduces) the time needed to perform them.

The presented process can be extended with more verifications and automation, which will be the subject of further research. In the context of future solutions, it is also worth noting the possibility of using generative design, which will provide the possibility of creating multiple variants and further optimisation [10].

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