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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).

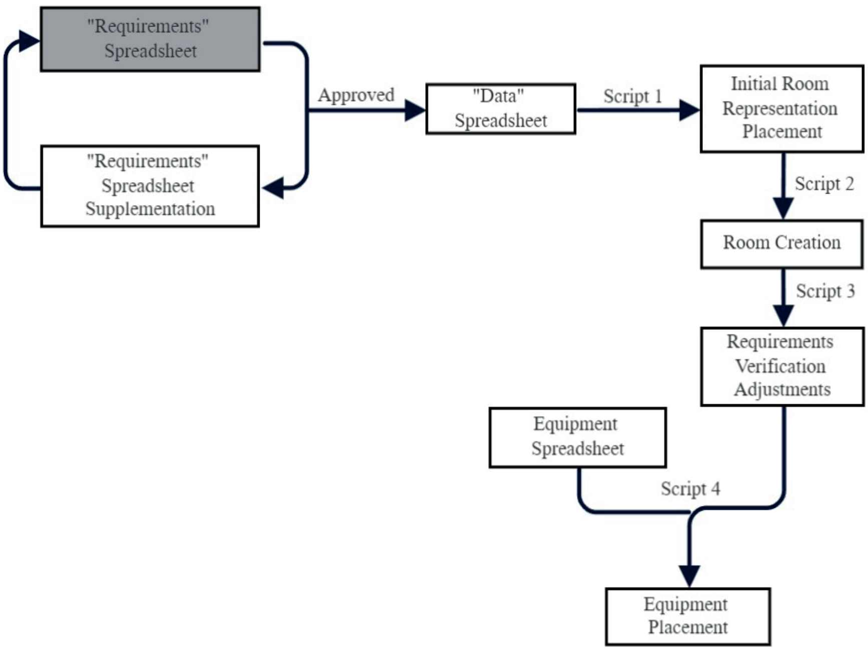

Fig. 1. Diagram showing the sequence of steps and scripts used. Items shown with a gray background are made by the tenant and with a white background by the architect. *Source: own study*

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

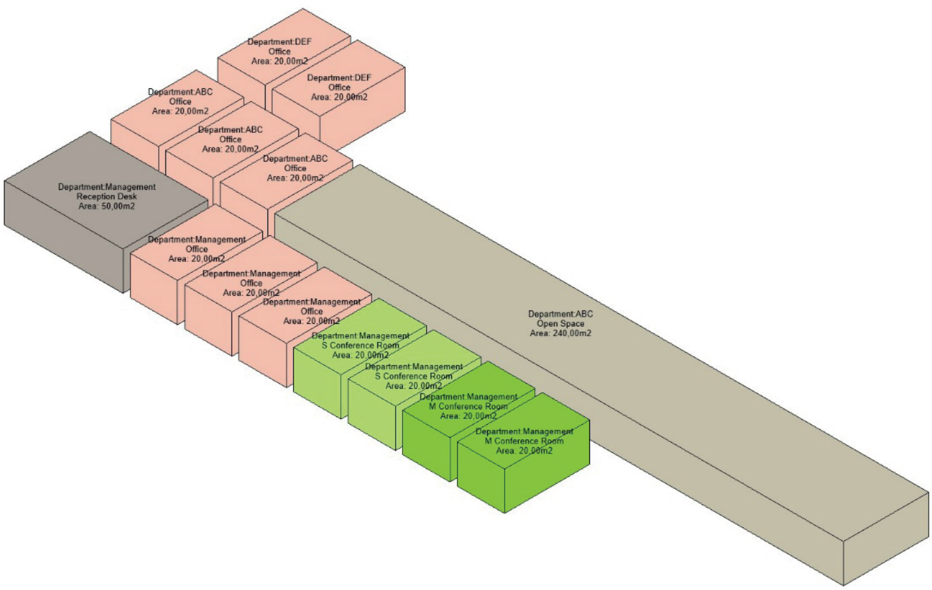

Fig. 2. Exemplary result of the script showing elements in lines of departments with color filter applied. *Source: own study*

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*

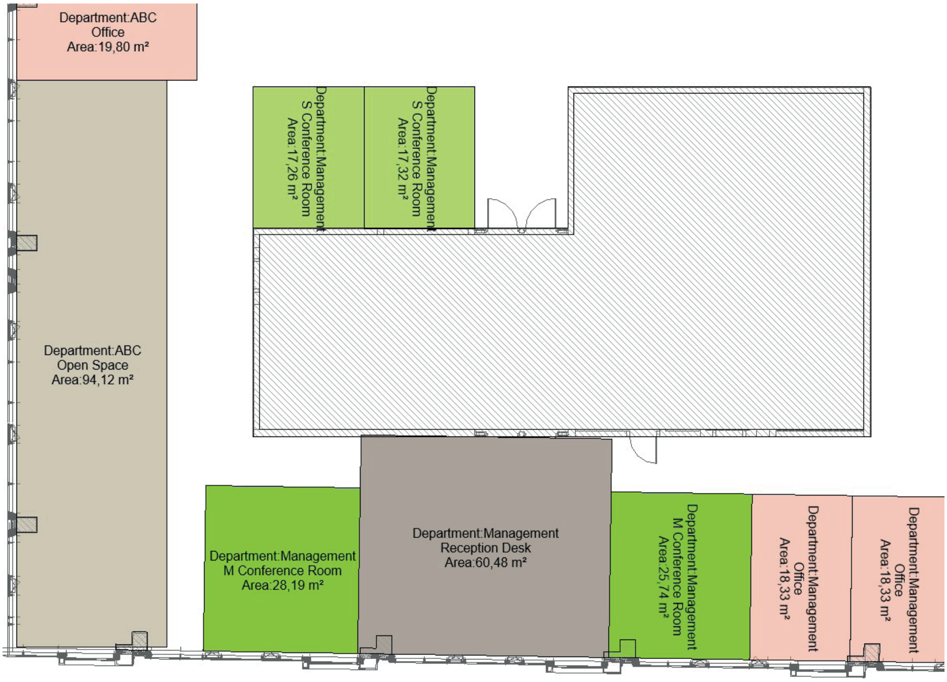

Fig. 4. Distribution of elements representing areas and other parameters on the floor plan. *Source: own study*

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.

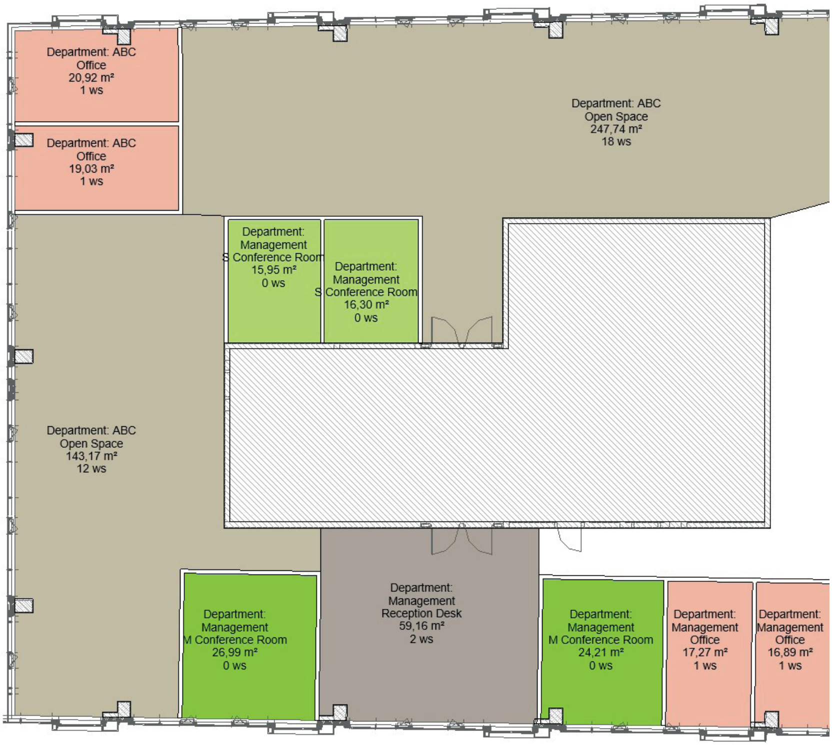

Fig. 5. Space plan with rooms' parameters transferred by Script 2 from cuboid's location. *Source: own study*

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.

Work Zone Department: DEF Name: Office	Rooms: 0 / 2	Desks: 0 / 2
Work Zone Department: GHI Name: Open Space	Rooms: 0 / 1	Desks: 0 / 40
Work Zone Department: Work Zone Name: M Conference Room	Rooms: 0 / 2	Desks: 0 / 0
Work Zone Department: Work Zone Name: XL Conference Room	Rooms: 0 / 1	Desks: 0 / 0
Support Department: Support Name: Copy Point	Rooms: 0 / 4	Desks: 0 / 0
Support Department: Support Name: Storage	Rooms: 0 / 5	Desks: 0 / 0
Management Department: Management Name: Reception	Rooms: 1 / 1	Desks: 2 / 2
Management Department: Management Name: Office	Rooms: 2 / 3	Desks: 2 / 3
Management Department: Management Name: S Conference Room	Rooms: 2 / 2	Desks: 0 / 0
Management Department: Management Name: M Conference Room	Rooms: 2 / 2	Desks: 0 / 0
Work Zone Department: ABC Name: Office	Rooms: 2 / 3	Desks: 2 / 3
Work Zone Department: ABC Name: Open Space	Rooms: 2 / 1	Desks: 30 / 30

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.

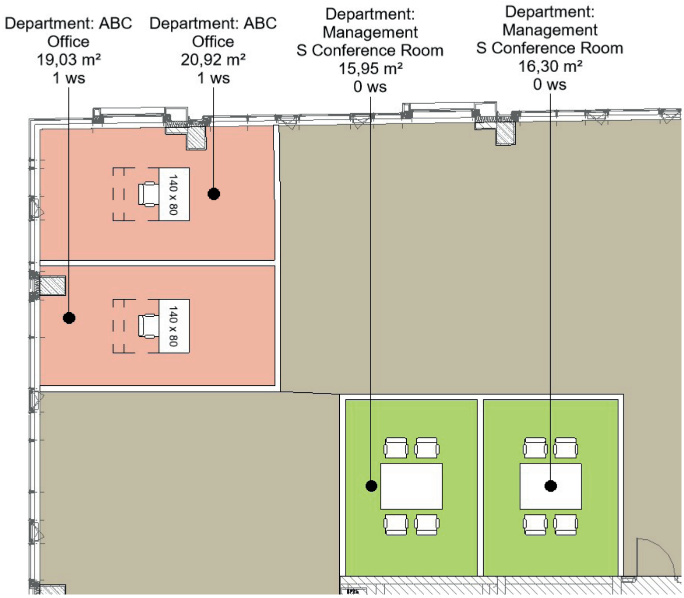

Fig. 7. Example of furniture placed in the floor plan by script. *Source: own study*

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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The influence of the police on vehicle speed in built-up areas

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Abstract: In many cases, the effects of road accidents have significant impact on human health. This translates directly into society, in both material and emotional terms. The severity of the injury in a road event depends largely on the speed of the vehicles. Excessive vehicle speed is of particular concern in incidents involving vulnerable road users. As confirmed by literature analysis and research, in most cases drivers do not respect the speed limits introduced by the road signs. Existing solutions allow to introduce permanent or temporary speed control. This paper investigates speeding and driver behaviour in built-up areas near schools and pedestrian crossings. The aim of the research described in the paper is to determine the influence of the effectiveness of police actions on speed reduction and improvement of road safety.

Keywords: speed limits, traffic safety, the police, road accidents

1. Introduction

In Poland, in 2018, most road accidents took place in built-up areas. Road accidents in these areas account for 71.2% of all road accidents. The most frequent causes of accidents are: failure to give right of way, failure to adjust the speed to the traffic conditions, and failure to give priority to a pedestrian at a pedestrian crossing. Drivers often do not comply with speed limits in built-up areas. This leads to collisions and road accidents. In the case of unprotected road users, incidents at speeds above 50 km/h often result in their death. Accidents and their consequences in the form of injuries and casualties cause significant losses to the state and society. In Poland, the cost of road accidents is about 2% of GDP [1]. By improving road traffic safety and reducing the number of accidents, their cost to the state budget can also be reduced [2]-[3]. The studies indicate the dependence of the number of accidents on the average speed and speed fluctuations [4]. Depending on the structure of traffic, an increase in average speed may cause an increase in the number of accidents, as in the case of the studies carried out in Bahrain [4]. In the case of studies carried out in the United Kingdom the speed fluctuations were more significant [4]. This may result from the characteristics of drivers' behaviour in different places, vehicle park, the shape of roads and prevailing weather conditions. Moreover, models for forecasting accidents have their limitations and are not universal enough. The number of accidents also depends on other traffic parameters, which should be taken into account in the models [5]. Determining the number of incidents is important when assessing safety and planning investments to improve safety [6]. In Poland, the results of police analyses indicate that drivers do not observe speed limits in situations where there is no control (supervision). Road managers and the police apply different methods of enforcing speed limits. Depending on the type of road, different measures may also be applied. In the case of motorways, these may be variable signs on which a change in the speed limit will depend, for example, on the prevailing road conditions. Research carried out in Canada [7] has indicated that the use of variable speed limits may reduce the number of accidents by 5-17%. However, there is a problem with legally regulating the above in Canada.

Traffic calming solutions are often used on the roads, e.g., speed bumps. However, this solution is ineffective, as shown by studies carried out in Italy among others [8]. This solution works only locally, similar to the use of speed cameras. Drivers often accelerate considerably after passing the obstacles. The shape of the speed bump is also of great importance. Should it be poorly designed, it may result in the lack of respect for the limit or may threaten to damage vehicles passing through an elevated plane. In the case of built-up areas in the vicinity of schools, housing estates, cultural centres and sports facilities, it is common to use all possible forms of physical traffic calming. The Netherlands has the richest experience in this field, which since 70 the beginning has commonly applied the traffic calming principles [9]. A review of reports from European countries shows the effectiveness of such solutions [10].

Traffic calming is used in virtually all countries around the world. This solution is increasingly popular because of its benefits. An example of such a solution is the traffic calming applied, in Ghana, where a significant speed reduction was observed [12]-[13]. The application of such solutions brings many benefits, among others, a positive impact on the environment. One of them may be the reduction of road noise, as indicated by studies carried out in Poland [14]. The traffic calming also has an impact on the emission of exhaust fumes and many other issues, which generate significant benefits [15]. An example of a properly designed road and traffic calming solutions are the 20 km/h speed zones in large cities in Great Britain [16]. In order to adjust and improve the quality of this method for each area, new manuals for the design of geometric traffic calming are developed, an example of which is the Polish manual [17]. The problem may be to assess the effectiveness of the traffic calming. In this case, the appropriate selection of measurement methods is important [12].

Speed reduction is particularly important in the case of accidents with unprotected traffic participants who are most at risk of serious injury or even death. One of the most at-risk groups are children, who are often injured on their way to or from school, or at pedestrian crossings [18]. Parents' perception of the way to school as dangerous may result in limiting the independent travel of children, whichmay result in the exclusion of the child from additional activities and may cause limitations in their development. Up to 47% of the roads to schools in Canada are considered as dangerous by parents [19]. The method of speed reduction in school zones and using special markings can theoretically achieve the intended effect of speed reduction. Traditional signs are less respected by drivers in relation to the presence of police in a dangerous place. The tests indicate that only flashing lights together with a text message or sign affect the speed reduction effect [20]. The location of signs, their visibility, colour and size also affect the result and in turn, children's safety [21].

The article attempts to determine the influence of police on the speed of drivers in the school areas. The aim of the research was to indicate the effectiveness of such actions in previously selected places in cooperation with the Voivodeship Police Headquarters in Lublin.

2. Objectives

The aim of the research was to determine the impact of preventive actions of the police on road traffic safety in built-up areas. The research was to indicate the extent to which the presence of the police in the analysed areas would affect the reduction of vehicles speed. The assumed impact of police presence in the analysed sections on speed reduction and improvement of safety is obvious to the authors. However, it was important in these studies to confirm that thanks to appropriate planning and coordination of police activities in built-up areas, it is possible to significantly reduce speed and improve road safety, which is also indirectly connected with increased comfort of people living in the vicinity of the road. The results obtained in the research will be used to formulate conclusions concerning appropriate planning of the speed controls on the analysed roads.

3. Methodology

The pilot study was planned on the territory of the Lublin Voivodship on the sections of voivodship roads in built-up areas and streets of the city of Lublin. Two measurement points were located at the entries to the city, the third was located at the pedestrian crossing near the primary school. In all the sections studied, the speed limits were 50 km/h. The speed was measured with a transverse radar and a normal manual radar. Measurements were made for one hour in the first and second stages. This time allowed the necessary number of vehicles to be measured. A precise speed recorder was set up in the measurement sections, which measured speed and other traffic parameters. Below, in Table 1, are the characteristics of the individual measurement locations.

Table 1. Parameters of the analysed sections. *Source: Authors*

DW 747 – Matczyn	Sławinkowska	Aleja Jana Pawła II
Single carriageway section	Single carriageway section	Single carriageway section
Footpaths	Footpaths	Footpaths
Bicycle paths	Bicycle paths	Bicycle paths
Inlet to the city	A large number of exits	Longitudinal slope below 2%
A large number of exits	Longitudinal slope below 2%	
Longitudinal slope below 2%		

The measurement was carried out in two stages. The first stage was the measurement in the assistance of the police at full visibility for drivers. Police officers carried out speed control of vehicles, did not stop vehicles and did not punish the drivers. The second stage was to perform tests without the presence of police. The measurements were taken in May and September 2020.

4. Results and Discussion

During the measurements, the number of vehicles with a division into a traffic structure was recorded in the 15-minute intervals (Q). The results were compared for the three analysed sections. The traffic intensity, the share of heavy vehicles (uc) and the average speed (v) in the analysed 15 minutes were given. The results were summed up and the average for an hour of time, 85 quantile, minimum speed, maximum speed, and standard deviation were calculated. The results are presented in Table 2.

Table 2. The results of measurements of the road traffic parameters on the analysed sections. *Source: Authors*

Quarter of an hour	Matczyn			Sławinkowska			Aleja Jana Pawła II		
	Q /veh/15 [min.]	uc [%]	v [km/h]	Q /veh/15 [min.]	uc [%]	v [km/h]	Q /veh/15 [min.]	uc [%]	v [km/h]
1	107	11	67.4	147	13	52.8	331	12	61.9
2	127	19	68.0	117	18	51.3	262	17	63.8
3	121	11	65.8	123	11	54.6	299	15	59.6
4	107	11	71.4	139	15	54.0	314	17	61.4
Sum/average	462	13	68.1	526	14	53.2	1206	15	61.7
k15	0.91			0.89			0.91		
V max	113			91			99		
V min	42			41			40		
Standard deviation	12.3			8.2			9.1		
V_{85}	84			64			75		

Based on the results obtained, similar values of the traffic parameters on Sławinkowska Street and the voivodship road in Matczyn were found. Due to a larger number of lanes, Aleja Jana Pawła II is characterized by higher traffic volumes. The share of heavy vehicles is similar on all sections. The vehicles were in free traffic. On the basis of the results obtained, it is not possible to state the effect of traffic intensity or the share of heavy vehicles on the average speed, as it is in the case with significantly loaded road sections [22]-[23]. In all the sections studied, the speed limits were 50 km/h. In case of all sections, speeding was observed. The greatest speed difference between the 50 km/h limit value is 18.1 km/h for the voivodship road in Matczyn. The second highest exceeding of the admissible speed was Aleja Jana Pawła II and the difference between the average vehicle speed in the analysed hour and the limit was 11.7 km/h. The smallest difference was recorded in Sławinkowska Street. In the case of Matczyn, the measuring point was located just before the end of the built-up area and a sign of the speed limit cancellation was visible. This situation caused drivers to start accelerating in the speed limit zone and in the pedestrian crossing area. Other drivers' offences such as overtaking at the pedestrian crossing were also observed (Fig.1).

Aleja Jana Pawła II is a two-roads street with two lanes. The geometry on this section (2 roads with two lanes each), which is beneficial for drivers, allowed them to feel comfortable, which is visible in the form of significantly increased average speed. The last section is Sławinkowska Street where the average speed in relation to the speed limit has been minimally increased. In the case of average speed, it does not sufficiently reflect the danger resulting from speeding in relation to the road accidents. It is important to analyse how many drivers exceed the given limits at what speed.

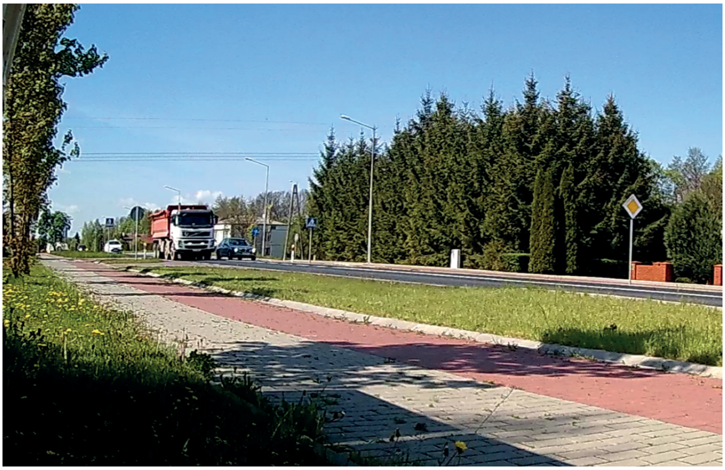

Fig. 1. Unauthorized overtaking manoeuvre at the pedestrian crossing in Matczyn. *Source: Authors*

Fig. 2 presents the results in the form of frequency histograms and speed distribution for the voivodship road in Matczyn. A group of drivers is visible, which moves at a much faster speed exceeding the allowed value by more than 10 km/h. The most numerous is the group traveling at a speed of 60-70 km/h at a speed limit of 50 km/h. There is a custom among drivers in Poland at a speed of plus 10 km/h to the limit by suggesting that they will not be stopped by the police in this case. The obtained results indicate that drivers most often move at a speed of 10-20 km/h higher than the permissible value. Despite the threat of losing their driving license, a group of drivers can be seen moving at a speed of over 90 km/h in a built-up area – it is 12 vehicles, which represents 8% of the tested vehicles. Comparing the entire study population, 83% of drivers move above 50 km/h and the V_{85} quantile is equal to 83 km/h.

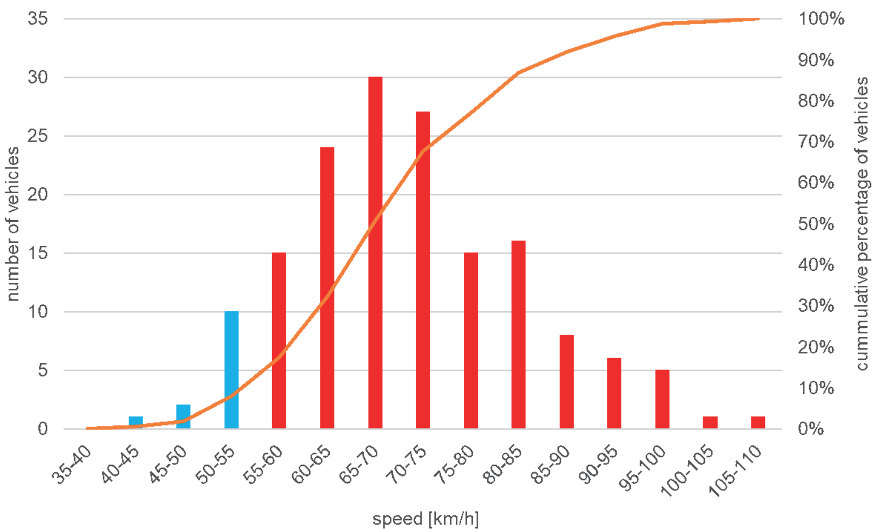

Fig. 2. The graph of the vehicle speed distribution in Matczyn. *Source: Authors*

In the case of Sławinkowska, the most numerous group are drivers travelling at a speed of 40-60 km/h. However, there is a large group of vehicles travelling at the speed of 60-70km/h – this is 27% of the surveyed population. Despite the correct marking of the pedestrian crossing in the school area and the speed limit, a group of drivers travelling at speeds above 70 km/h and one driver who was travelling at speeds above 90 km/h appear. In the case of Sławinkowska, 32% of the surveyed people exceeded the limit speed. The V_{85} quantile of speed is 64 km/h. The results are shown in Fig. 3.

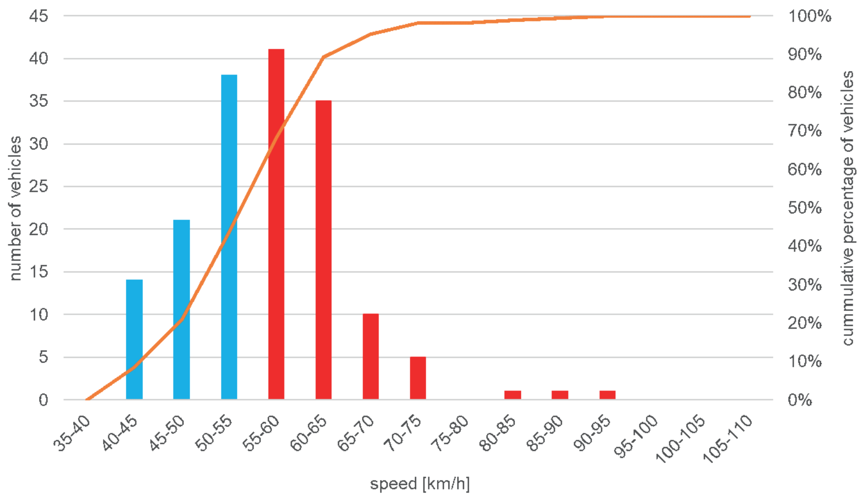

Fig. 3. The graph of the vehicles speed distribution on Sławinkowska. *Source: Authors*

On the Aleja Jana Pawła II most of the drivers, i.e., 70% exceed the allowed speed. The most numerous group are vehicles travelling at 60-70 km/h. Two drivers have exceeded the permitted speed by more than 40 km/h. The V_{85} quantile of speed is 75 km/h. The results are shown in Fig. 4.

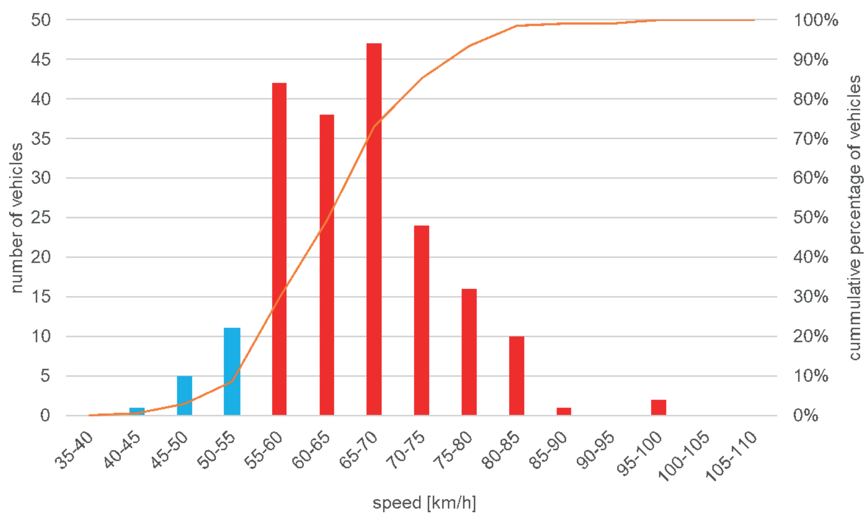

Fig. 4. The graph of the vehicles speed distribution on the Aleja Jana Pawła II. *Source: Authors*

These results indicate a lack of respect for the speed limits. In the case of road accidents, their consequences are directly related to the speed of vehicles, especially in the case of pedestrian crossing zones where tests indicate significant speeding [24].

Comparing the places where road accidents occur in the European Union, it can be observed that 38% of the events concern built-up areas (Fig. 5) [25].

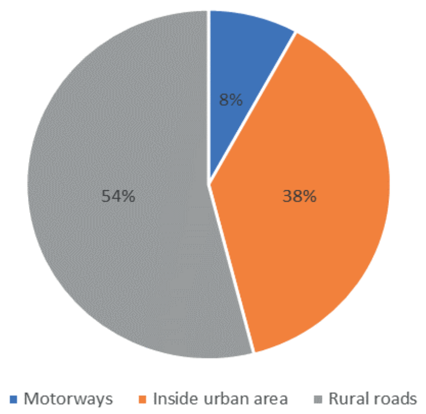

Fig. 5. Division of road accidents in the European Union by location. *Source:* [25]

In the case of the analysed roads, most accidents happened on Aleja Jana Pawła II. The smallest number of them was in Matczyn. Comparing individual months in individual years, most accidents in Matczyn occurred in February, in case of Sławinkowska in September, and in the case of Aleja Jana Pawła II in October. In all sections a large number of events took place in September at the start of the school year. Table 3 presents a summary of information on accidents for the period from 2007 to 2019.

Table 3. Summary of the total number of road accidents on the analysed sections in particular months for the period from 2007 to 2019. *Source:* [26]

Month	Matczyn		Sławinkowska Street		Aleja Jana Pawła II	
	Number of accidents	%	Number of accidents	%	Number of accidents	%
January	4	6%	19	10%	175	9%
February	12	19%	15	8%	149	7%
March	3	5%	12	7%	139	7%
April	6	10%	13	7%	138	7%
May	5	8%	23	13%	157	8%
June	2	3%	12	7%	173	9%
July	1	2%	11	6%	155	8%
August	5	8%	14	8%	130	6%
September	10	16%	26	14%	189	9%
October	4	6%	12	7%	226	11%
November	4	6%	8	4%	202	10%
December	7	11%	16	9%	187	9%

The analysis of the number of accidents was carried out from 2007 to 2019. The change in the number of accidents in particular years is shown in Figs. 6 and 7. Sławinkowska Street and the voivodship road in Matczyn retain similar accident values in the analysed period without major changes. In the case of the Aleja Jana Pawła II, an increase in events since 2010 is visible.

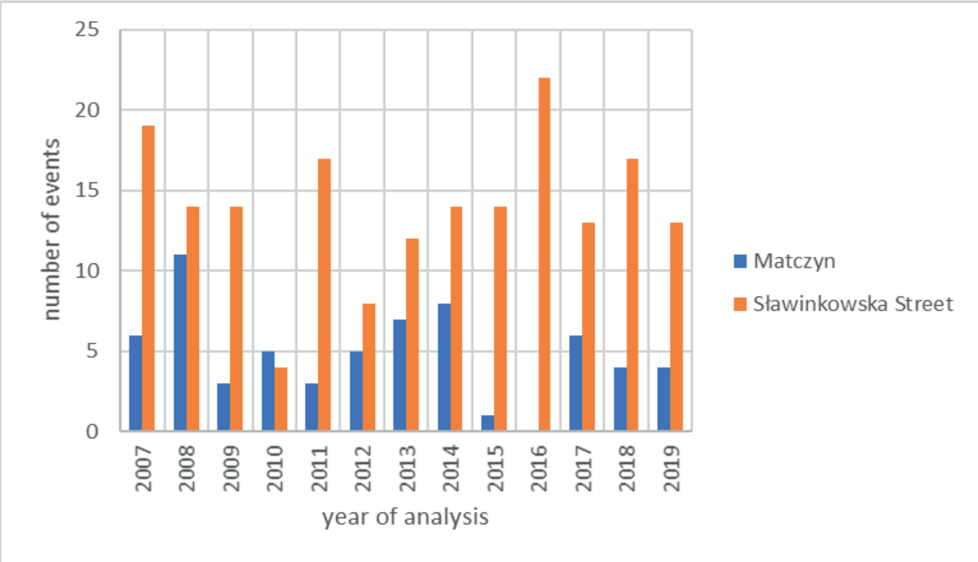

Fig. 6. Number of accidents in particular years on the Sławinkowska and DW 747. *Source:* [26]

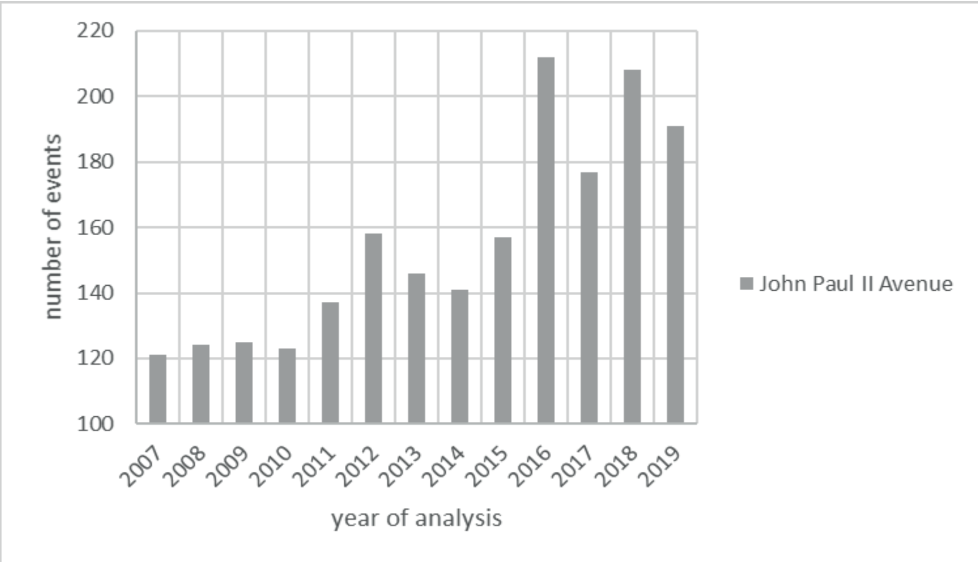

Fig. 7. Number of accidents in particular years on the Aleja Jana Pawła II. *Source:* [26]

The list of types of accidents on the tested sections is presented in Table 4. The most common type of events was a vehicle collision. In all cases, there were 54 pedestrian runovers, some of which took place at pedestrian crossings. In the case of Sławinkowska Street this is the third type in terms of accidents occurring in this section.

Table 4. Total number of road accidents on the analysed sections depending on the type of event in the 2007-2019 period. *Source:* [26]

Type of event	Matczyn		Sławinkowska		Aleja Jana Pawła II	
	Number of events	%	Number of events	%	Number of events	%
Lateral vehicle collision	23	36.5%	84	46.4%	880	43.6%
Rear-end vehicle collision	12	19.0%	39	21.5%	897	44.4%
Overrunning a pedestrian	2	3.2%	12	6.6%	40	2.0%
Overrunning an animal	4	6.3%	10	5.5%	9	0.4%
Frontal vehicle collision	8	12.7%	8	4.4%	37	1.8%
Vehicle overturning	3	4.8%	7	3.9%	10	0.5%
Hitting a tree	1	1.6%	6	3.3%	3	0.1%
Hitting a pole, a sign	1	1.6%	5	2.8%	77	3.8%
Running into a hole, bump, hump	5	7.9%	3	1.7%	2	0.1%
Others	4	6.3%	3	1.7%	25	1.2%
Hitting a security barrier	-		2	1.1%	16	0.8%
Hitting a vehicle that is immobilised	-		2	1.1%	24	1.2%

The speed of vehicles plays a major role in the occurrence of accidents. In the results of the measurements, a trend towards widespread speeding is observed. In many countries, including Poland, various solutions are sought [27]-[28].

One way may be to limit the speed, which always takes place when police patrol a given section. In order to investigate the influence of police presence on speed reduction, a measurement was carried out in the Matczyn section during the presence of the police patrol. Fig. 8 shows the results of average speeds for particular time intervals during examination with and without police. There is a significant difference between the maximum average speed without and with the presence of the police, which reaches even 30 km/h.

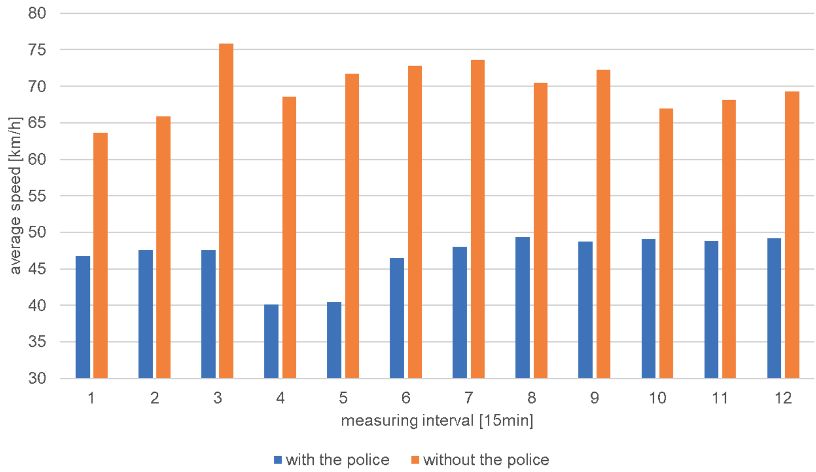

Fig. 8 Average speed in individual intervals during measurements with and without the presence of the police in Matczyn. *Source: Authors*

In all measurement intervals, it can be seen how effectively the presence of the police is influencing speed reduction. In the case of measurement without police, most drivers do not comply with the speed limits. During the presence of police, no driver exceeded the speed limit by more than 10 km/h. The results of these analyses are shown in Figure 9.

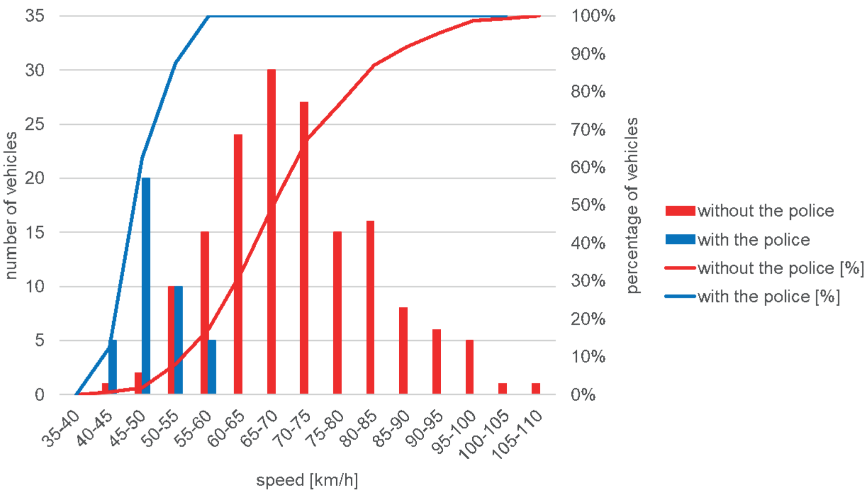

Fig. 9. The graph of the speed distribution of individual vehicles in Matczyn during measurements, with and without the police. *Source: Authors*

Analysis of the scattering of the measurement data confirms effective preventive actions of the police. The statistical analysis confirmed the significance of the measurement results. The results are presented in Fig. 10.

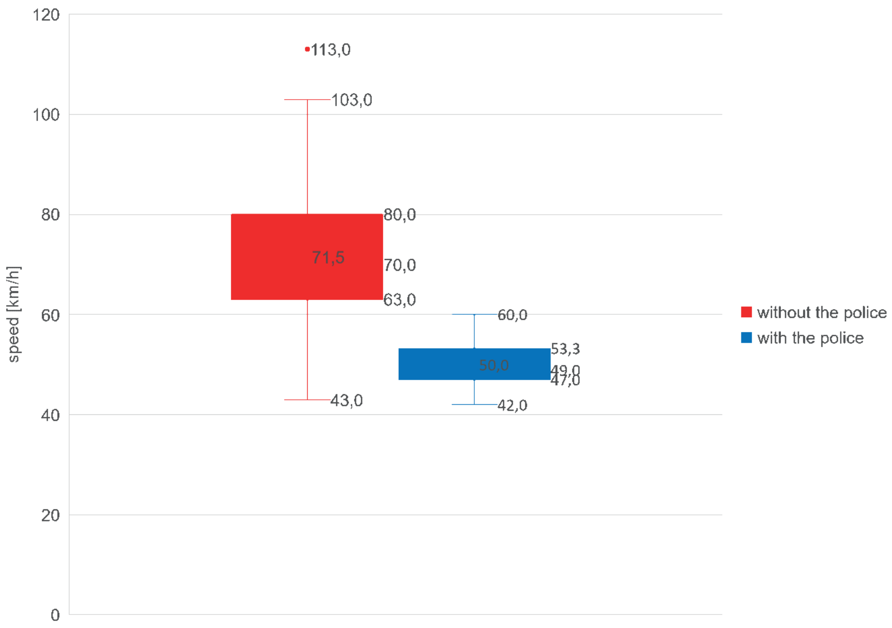

Fig. 10. A graph of the scattering of the speed results of individual vehicles in Matczyn during measurements, with and without the police. *Source: Authors*

Results obtained from the tests directly show the influence of the presence of the police on the speed of vehicles. The speed difference between the average values from the two measurement stages reaches almost 30 km/h. Individual results indicated even greater differences from the time when the police were at the place of measurements and when they drove away. This indicates the necessity to plan and implement preventive actions of the police. Another solution could be to use an imitation police patrol. This is a permanent solution. According to a study from Asia, it reduces the number of violations related to passing a red light and illegal turning [29]. In case of speeding, this solution may have a limited duration. Drivers may get used to the model and still not respect the speed limit.

5. Conclusion

Based on the results obtained, it was found that drivers do not adjust their speed to the applicable road regulations. Depending on the cross-section and location, 30% to 80% of them exceeds the permitted speed in the analysed places. The highest number of drivers and the highest exceedances were recorded on the voivodship road passing through Matczyn. The existing road signs do not sufficiently influence the speed of vehicles. In the analysed sections, the highest number of accidents occur during the school year. One of the most frequent types of accidents is overrunning a pedestrian. Preventive speed checks carried out by the police significantly reduce the speed of moving vehicles, which is indicated by the results of the research. This has a direct impact on road safety, especially in the case of unprotected road users, and in the vicinity of educational facilities with high child traffic. A partial solution to the problem of speeding in case of necessary speed limits may be frequent presence of police on dangerous road sections.

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Orginal Article

Specificity of general zones in large modern European multispeciality hospitals – selected case studies

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Abstract: The present paper shows the results of research on general zones in large European multispeciality hospitals. A dozen or so institutions, flagship examples of large contemporary hospitals, were selected for the study. The research focused on internal zones, in particular the reception area linked to the main communication system of the hospital which functions as a public space offering a range of services, and provides the space for communication, waiting and meetings. This work aims to determine design trends in the location and forms of general zones, their characteristics and proportion to other zones in hospitals, architectural features and functional-spatial solutions. The relationships between the shape of the hospital, its internal general zones, and their percentage share in the total building area were examined. Art and greenery in these zones were also investigated, along with the presence of natural lighting, the colours, and the type of finishing materials used in this type of space today. The study revealed noticeable differences between the form of general zones in large contemporary as well as 20th-century hospitals. In addition to their form, the arrangement of zones has also changed, and they often do not resemble a hospital space. Art and greenery play an increasingly important role. The general zone is a hospital's essential communication hub, constituting the main public space where people may meet.

Keywords: general zones in a large hospital, multispeciality hospital, health care architecture

1. Introduction

Large multispeciality hospitals provide a broad spectrum of care. They can be divided into large general hospitals and university hospitals. The features of large multispeciality hospitals include the presence of at least a dozen specialised departments, a large surface area and a significant bed stock (representing several hundred or more patient beds). Hospitals are one element of the health care system that serves the inhabitants of a given area [1].

The buildings selected for research are among the largest hospitals in Europe. Nowadays, such constructions are rarely built, but if they are, they are usually impressive and complex, representing a great challenge for designers. Contemporary multispeciality hospitals largely resemble similar institutions from the second half of the twentieth century, but their form has changed significantly, as well as the method of shaping and arranging spaces – especially general zones. Hospitals built over the last number of years also reflect developments in these spaces. The reception area and main passageways connected with it constitute an accessible public space, which is also a representative part of the institution. The architecture allows for spaces which combine different functions, creating strictly defined zones as well as access to other areas. Their openness makes them suitable as social spaces [2].

2. State of research

Large multispeciality hospitals, both university and general, are a subject of research in terms of the architectural and functional solutions applied there [3], [4] as well as individual hospital zones [5]. Scholars also focus on aspects related to the therapeutic environment of the hospital [6]-[11]. This is also of interest in the context of the greenery present in hospitals [12]. Moreover, other issues influencing the hospital environment in terms of comfort are studied. These include the role of daylight [13] and colours [14] in hospital facilities. Wayfinding systems [15] which make it easier to navigate the hospital, thereby reducing anxiety and inducing trust [16], are subject to examination as well. Moreover, recent research focuses on the design of hospital interiors using virtual reality and Evidence-Based Design to maximise the quality of the space [17].

In recent years, research has also focused on art in hospitals, increasingly found not only in general zones but also in wards and patient rooms [7], [18], [19]. Some studies explore art in the context of the effects of sounds and music on health in hospital settings [20]. Hospital planning and design is studied in terms of Evidence-Based Design [21], [22]. Public spaces are explored in relation to the quality of hospital environment, its impact on the physical and psychological comfort of the patients and other visitors [23]-[26], and influence on the relationship between patients and medical staff [27]. Studies embrace not only internal public spaces in hospitals, but also external ones – more specifically their design assumptions and therapeutic benefits [28]. General hospital zones have also been subject to more extensive research, presented in a doctoral dissertation on waiting spaces [29].

A review of the literature on large hospitals has shown that there are many studies on different aspects of the hospital environment and its relationship with user comfort. Beyond that, researchers deal with more specific topics connected with the hospital environment such as art, greenery or the role of light and colour. Some scientists study public spaces in hospitals, focusing on their impact on visitor comfort. However, an initial review of the literature prompts research on public spaces in hospitals that addresses another aspect – internal general zones and their percentage share in all hospital zones. In addition, their shape and how they relate to hospital structure, as well as characteristic features were investigated.

3. Methodology

Fourteen hospitals from eight European countries were selected for the study. These are large facilities providing multiple medical services. The group encompasses both large general hospitals and university hospitals. The main selection criterion was the number of medical specialisations in a given facility. The vast majority are among the largest hospitals in their respective countries. The hospitals studied were built between 2000 and 2020 (the first of the researched facilities was opened in 2007, but the classification also includes the planning and design period, which in the case of this type of establishment takes at least several years until construction work can begin). Other selection criteria included the area of the hospital and the number of beds. The facilities investigated are often characterised by original architectural and spatial-functional solutions. It is also noticeable that their design draws on contemporary research on health care buildings – as evidenced, among other things, by the presence of art and greenery in the facilities. Despite their large scale, the selected hospitals have a less institutional character than similar buildings from the previous century and place greater emphasis on patient comfort. Firstly, various contemporary hospitals in Europe which met the study criteria were taken into consideration. Approximately 40 large multispeciality hospitals in Europe were built between 2000 and 2021. The facilities selected for examination had materials available including drawings, floor plans and similar studies necessary for carrying out research. Hospitals where access to detailed materials was difficult were not included in the detailed study.

After analysing the criteria described above, fourteen hospital complexes which corresponded most closely to the research objectives were chosen. Therefore, the 14 hospitals selected can be perceived as representatives of large contemporary multispeciality hospitals in Europe. Secondly, the arrangement, scale and form of the general zones in these facilities were analysed. The results are graphically presented in Fig. 2, which shows the proportions and location of given zones in the context of the whole hospital establishment. The remaining zones marked in grey are administrative, diagnostic, consultation and operating areas.

Thirdly, the architectural solutions applied in general zones, the form of the zones, prevalent materials, colours, elements of art and greenery were discussed. Attention was also paid to the features and roles of particular zones. Research materials included photographs and information obtained from publications, websites of design offices, hospitals and architectural websites. The average area of the studied complexes of large hospitals was about 117,745 m^2.

For the purpose of this paper, the author defined a hospital general zone as a publicly accessible space, functioning as a public space where everyone is free to visit. This zone includes a representative entrance hall with a reception desk, information desks, a passageway with seats, a café/restaurant, a pharmacy, various types of shops (grocery, newsagent's, florist's) and services (hairdresser's, beauty parlour), a chapel, etc. It does not include corridors in other parts of the hospital, e.g. in diagnostic areas, outpatient clinics, bed wards and places of a similar nature, where there is usually some form of access restriction. People usually come to these zones for a specific purpose, such as an appointment or examination. Most often their identity is verified, e.g. when they are admitted to a ward or when they come to visit a patient.

Table 1. List of hospitals subject to research

No./ source	Hospital name	Town, country/	Number of storeys/ usable floor area [m^2]/ number of beds	Year of establishment
1 [32]-[34]	Hospital Infanta Sofía	San Sebastián De Los Reyes, Spain	2-5 storeys/ 126,790 m^2 257 beds	2007
2 [35]-[37]	Akershus University Hosptial	Oslo, Norway	6 storeys/ 137,000 m^2 953 beds	2008
3 [38]-[40]	Jeroen Bosch Hospital	Den Bosch, The Netherlands	5-6 storeys/ 170,000 m^2 1120 beds	2010
4 [41]-[45]	Klinikum Klagenfurt	Sankt Veit im Pongau, Austria	3 storeys/ 145,000 m^2 1470 beds	2010
5 [46]-[47]	Queen Elizabeth Hospital	Birmingham, UK	10 storeys/ 170,000 m^2 1231 beds	2010
6 [48]-[49]	Centre Hospitalier de Marne-la-Vallée	Jossigny, France	3 storeys/ 72,000 m^2 585 beds	2012
7 [50]-[51]	Rey Juan Carlos Hospital	Móstoles, Spain	3-8 storeys/ 94,705 m^2 570 beds	2012
8 [52]-[53]	Meander Medical Center	Amersfoort, The Netherlands	5-9 storeys /112,000 m^2 620 beds	2013
9 [54]-[56]	Can Misses Hospital	Ibiza, Spain	2-5 storeys/ 67,132 m^2 250 beds	2014
10 [57]-[58]	New Álvaro Cunqueiro Hospital	Vigo, Spain	5 storeys/ 297,000 m^2 1465 beds	2015
11 [59]-[61]	Hospital Lillebaelt Kolding	Kolding, Denmark	2-9 storeys/ 32,000 m^2 202 beds	2016
12 [62]-[64]	Landesklinikum Thermenregion Mödling	Mödling, Austria	4 storeys/ 54,800 m^2 338 beds	2019
13 [65]-[67]	Hospital Nova	Jyväskylä, Finland	3-8 storeys / 116,000 m^2 368 beds	2020
14 [68]-[70]	Rigshospitalet Hospital North Wing	København, Denmark	3-7 storeys/ 54,000 m^2 200 beds	2020

4. Results

4.1. Forms, shape and location of general zones

General zones, starting from the reception area, form the main communication routes in the hospital, while also being the most accessible and representative public spaces. They are closely linked to the form of the hospital. Changes in the approach to shaping the form of both the hospital and general zones can be observed in the institutions under study. The most popular layout of a hospital in the late twentieth century was a vertical structure with a "wide foot" or a "podium", which provided space on the horizontally extended ground floor for diagnostic, treatment and administrative zones, while the ward sections lay vertically above [30]. The first hospital type, distinguished in 50% of the facilities under examination, was developed on the basis of similar assumptions. The main difference is that the so-called "podium" occupies from 1 to 3 storeys above which are mostly wards or areas with similar functions. However, they are not structured like a high tower, but as fragmented low pavilions located above the podium in a more horizontal manner. Modern buildings featuring this structure usually have a linear layout as well [31], which also determines the shape of the general zone. Obtaining a legible and clear functional division in large hospitals, which facilitates movement around the building for all groups of users, is possible especially with a band-shaped arrangement of the hospital. It also allows the complex to be further developed while maintaining the functional transparency of the facility [16].

The second type of a hospital observed among the examined institutions is also linear and represents a combination of ridge and mono-block (with atria and courtyards) layouts. Fully mono-block structures (Centre Hospitalier de Marne-la-Vallee) and pavilion layouts (Can Misses Hospital) are the rarest. Regardless of the spatial layout, contemporary general zones are linear. In half of the hospitals included in the study, this zone was between one and two storeys high. 21% of the facilities had a three-storey zone and in 29% of them the height of this space ranged between 4 and 6 storeys. The common feature of the general zone in the hospitals studied here was good natural lighting via skylights or full roof and partial wall glazing (especially in the case of high glazed entrance atria) In some cases, good lighting is provided by courtyards covered with greenery which also provide relaxing views from general zones. One example of this form of the general zone is presented by Jeroen Bosch Hospital, where the greenery merges directly with the main communication zone, which is the general zone of the hospital.

The general zone is located in the centre of the complex, forming the main axis (axes) of communication and composition. It is usually the main hub of the site linked with other parts of the hospital, i.e. specialised spaces with controlled access. General zones account for almost 1/10 of the total space of the hospital complex. In their immediate vicinity, groupings of bed wards are located on the upper floors.

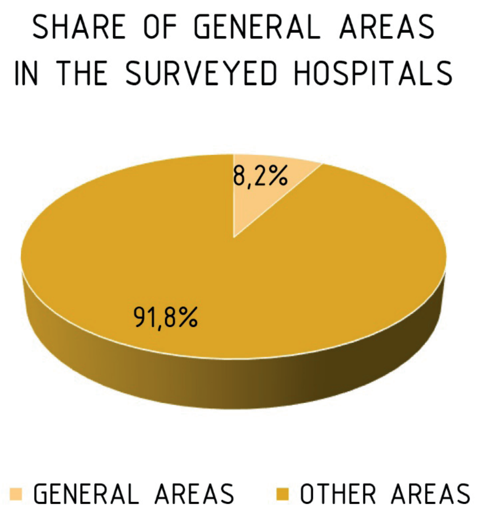

Fig. 1. Share of internal general spaces compared with the total area of the researched multispeciality hospitals. *Elaboration by R. Strojny 2022*

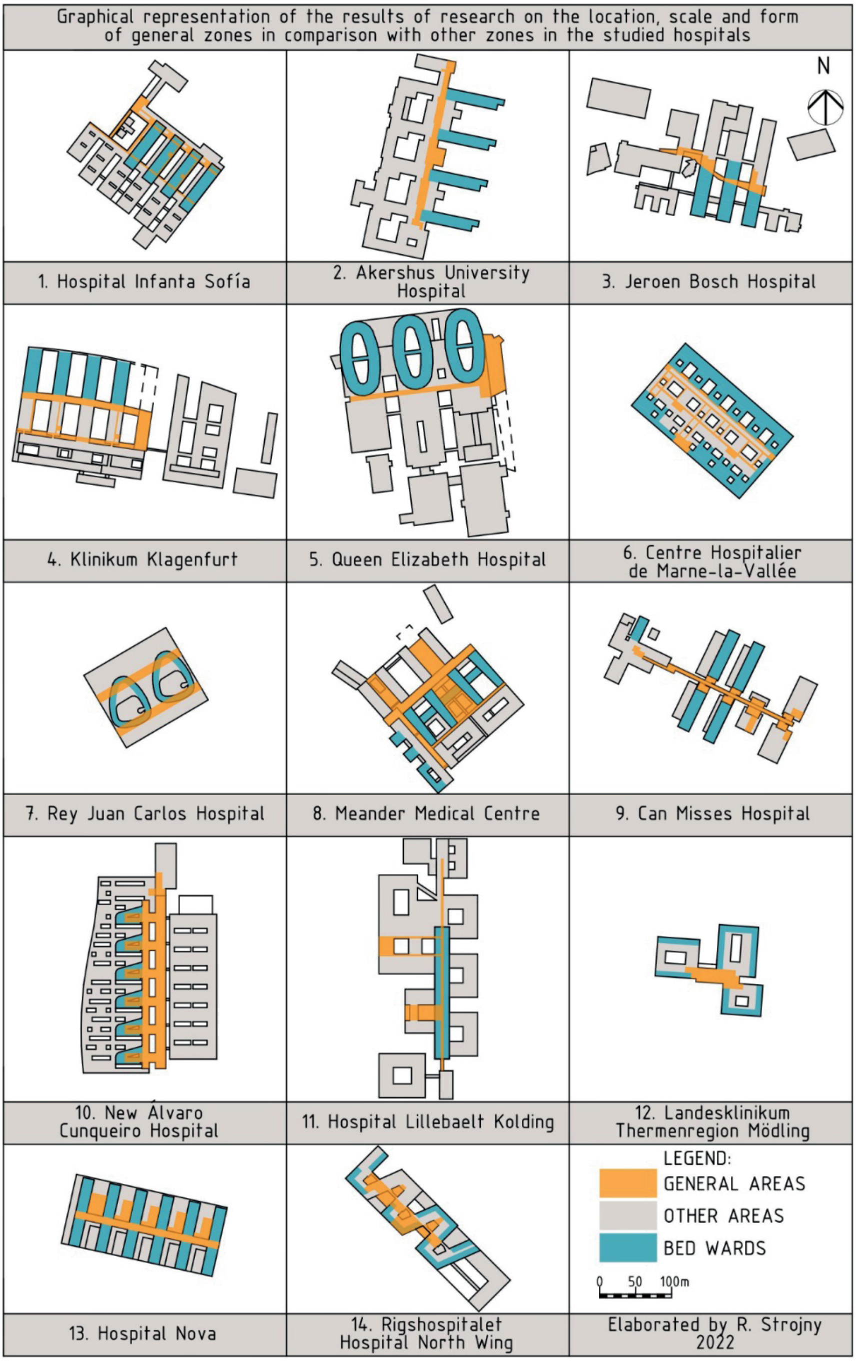

Fig. 2. Graphical representation of the results of research on the location, scale and form of general zones in comparison with other zones in the studied hospitals. The layouts are presented in proportion to each other. *Elaborated by R. Strojny 2022*

4.2. Colour scheme, materials, art elements in general zones

Grey, beige and white colours prevail in the researched facilities. This colour scheme is often broken by blue, green, orange and yellow accents. General zones are usually finished in natural materials such as wood, stone and terrazzo. The general zone in Rey Juan Carlos Hospital is an example of this combination of materials and colours, but it stands out from other hospitals because it is a very elegant space, with simple geometric shapes, austere in form, without embellishment – the main accent is on the material finish and appropriate choice of furniture.

Fig. 3. Summary of selected general zones in the examined hospitals. (1 – Akershus University Hosptial/ C.F. Møller, Phot. Jørgen True/Studie-E, 2 – Jeroen Bosch Hospital/ EGM Architecten, Phot. EGM Architecten, 3 – Queen Elizabeth Hospital/ BDP, Phot. BDP, 4 – Rey Juan Carlos Hospital/ Rafael de La-Hoz, Phot. Alfonso Quiroga, 5 – Meander Medical Center/ atelier PRO architecten, Phot. Dirk Verwoerd, 6 – Hospital Lillebaelt Kolding/ Schmidt Hammer Lassen Architects, Phot. Helene Mikkelsen, 7 – Hospital Nova/ JKMM Architects, Phot. Tuomas Uusheimo). *Illustrations published with the kind permission of the owner*

Many studies on colour and light have revealed their influence on human behaviour, mood and concentration. Cool colours (such as green, blue) promote relaxation and calmer activities, while warm colours (red, orange, yellow) stimulate physical and social activities. In contrast, colours such as beige and grey limit attention. Colour in the public space of a hospital can also be an element facilitating orientation and navigation within the building [14]. In addition to colours, views from different zones are also essential. According to a study by Serbian researchers, it is important to provide views on the outside areas of the hospital, not only for safety, but also psychological reasons. Constant access to the outside world reduces feelings of isolation and claustrophobia [28].

In the facilities created in the last five years, general zones are characterised by the inclusion of art in many forms. These include art installations, the form of lighting, seating and similar elements of small architecture, as well as colourful graphics. Sculptures can also be found in some hospitals. According to research by the curator of art in health care Mary Grehan, art in the hospital should be balanced so that it engages and stimulates users, without being provocative, bearing in mind varying degrees of emotional sensitivity [19].

4.3. Formation of general zones and functional links with other parts of the hospital

Furthermore, hospital public spaces are often embellished with greenery (e.g. trees in pots), which fosters cosiness in a given zone. Greenery has a positive effect on stress management, especially when spending time in hospital – for patients, visitors and staff alike [12]. Seats arranged in rows are rarely used. Today, they are often individually designed for a specific hospital. This is illustrated by the seats at the Hospital Nova, being wooden benches with comfortable oval-shaped backs. Wooden sculptural compositions and the shape of lighting provide additional accents in that hospital. In the Rigshospitalet Hospital North Wing, art comes in the form of a spiral staircase and colourful ornaments beneath some flights of steps.

Despite the large scale of the hospital and its general zone, such architectural and design solutions often make the space cosier and more friendly for patients and other users. They also make a facility seem less of an institution, which was one of the main features of 20th century hospitals. Most contemporary general zones of large hospitals do not resemble a hospital interior, but look more like the inside of a gallery or hotel lobby. These spaces often can resemble shopping arcades with cafés, restaurants, shops (e.g. grocery shops), florists, kiosks and even exhibition spaces. These areas play a very important role as places where people can meet and socialise, and as such there are many clusters of seats there, not only in waiting areas. Besides, information desks and waiting areas can be found around this zone. Nearby, chapels and prayer rooms are located too. In some hospitals built in recent years, chapels are divided into zones for different faith communities, for example at Jeroen Bosch Hospital (The Netherlands, 2010) and Queen Elizabeth Hospital Birmingham (UK, 2010).

The growing importance of public spaces in hospitals is linked to the desire for integration with urban structures. These spaces are shaped as shopping arcades offering services. They can also take the form of squares. In the case of outdoor spaces, these are most often gardens and courtyards with art elements. Adequate lighting of the public zones influences hospital forms, resulting in more fragmented hospital layouts with fewer storeys [16]. General zones in hospitals usually begin with a spacious reception hall. The linear general zone may also be divided into one or more places by glazed atria. This is noticeable in the Meander Medical Center, among others, with its clearly accentuated main entrance and generous glazing. This large-scale space contains many clusters offering various places to sit. It is also a kind of communication hub for the entire establishment. A similar entrance hall can be found at Queen Elizabeth Hospital, with mainly white and blue accents. The high entrance hall distinguishes also Lillebaelt Kolding Hospital, where the atmosphere is additionally invigorated by big flower pots with trees surrounded by seats.

The examined general zones usually constitute a hospital's central public axis of communication around which public functions are concentrated. In this hierarchy, they are followed by diagnostic areas, the ED and outpatient clinics, which have separate passageways accessed from the general zone and require undergoing access control. Only after passing through the general zone and then the internal passageway can one reach the hospital's medical facilities such as diagnostics, outpatient clinics etc. In addition to the services and public functions directly linked to the general zones, the space on the ground floor usually provides access to outpatient care, diagnostics, rehabilitation etc. At certain intervals, the general zone has access to vertical communication that connects it to upper floors where bed wards, operating theatres and the administrative area tend to be located (Fig. 4).

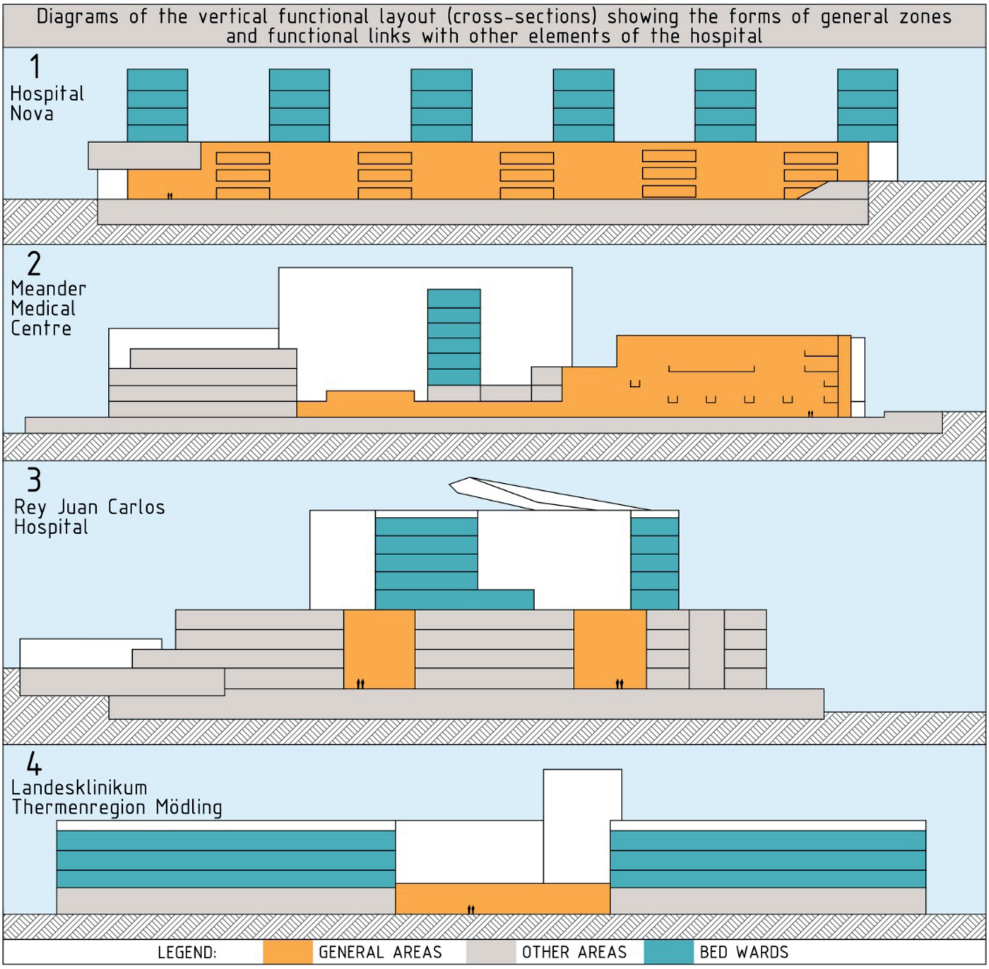

Fig. 4. Diagrams of the vertical functional layout (cross-sections) showing the forms of general zones and functional links with other elements of the hospital. *Elaborated by R. Strojny in 2022*

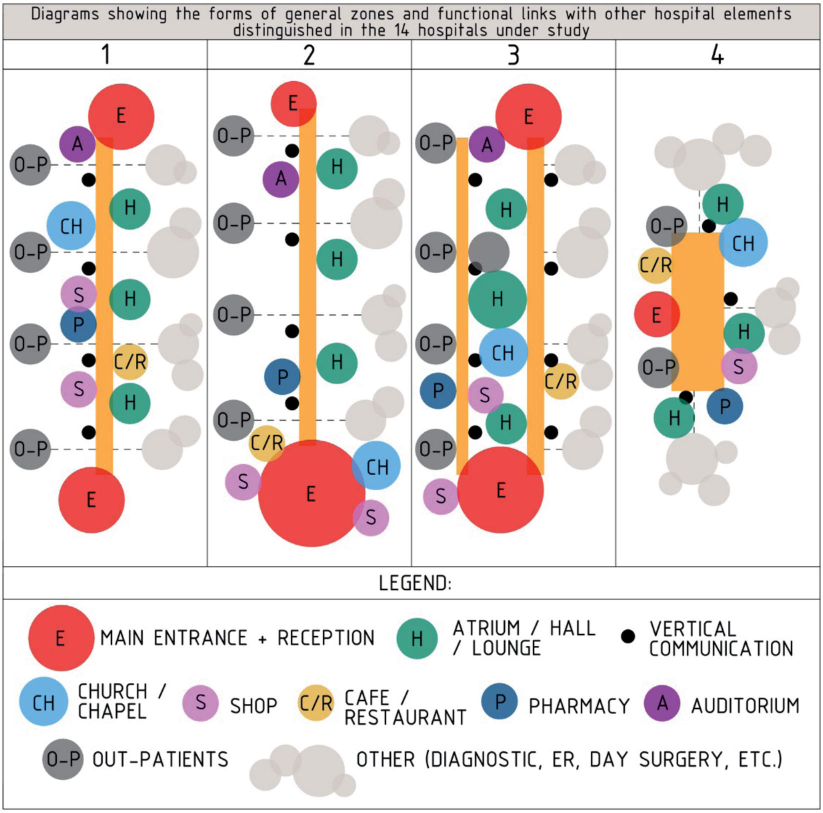

Fig. 5. Diagrams showing the forms of general zones and functional links with other hospital elements distinguished in the 14 hospitals under study. *Elaborated by R. Strojny in 2022*

Regarding the form of general zones and their links with individual functions of the facility, four solutions were distinguished among the 14 hospitals researched (Fig. 5). The first three solutions are clearly linear. In the first layout, the general zone begins and ends with a similar-sized entrance hall with a reception area. Along the general zone are the previously mentioned public functions (shops, café, etc.) and vertical communication. Perpendicular to the main axis of the general zone, there are passages to specific parts of the establishment. Most often, one side of the axis leads to zones for outpatient care, while the other side to zones for the ED, diagnostics, rehabilitation etc. Vertical communication provides access from the general zone to the higher parts of the facility with bed wards, operating theatre, administration etc. This is the layout of Akershus University Hospital in Oslo, among others (Fig. 6).

The second layout of the general zone differs from the first in that the proportions of the entrance areas at both ends are different. In this case, there is one main hall, much larger than the other one, and also much larger than the entire passageway that makes up the whole general zone. It can assume the form of a tall glazed atrium. The third layout consists of at least two passageways between which are located both public functions and services such as ambulatory care etc. This type of solution is most often found in clearly horizontal hospitals with a low-rise structure. As well as vertical communication, spacious green atriums are arranged along the general zones in order to maximise light.

The last layout differs considerably from the above in that it is not clearly linear and can be found in slightly smaller hospitals. In this case, public functions are located around a central general zone. It is linked in several places to other parts of the complex.

Fig. 6. Simplified ground floor plan of Akershus University Hospital in Oslo presenting how the general zone connects with other parts of the hospital and a section through the entrance area showing its proportions. *Compiled by the author from material on Akershus University Hospital from C.F. Møller's website 2022*

4.4. Features of modern general zones

Compared to hospitals of the 20th century, modern general zones in large multispeciality hospitals differ significantly. Above all, in contemporary developments, proportions, human scale and the key role of daylight have transformed the aura of these spaces. This also applies to the form of the "hospital street", which can now resemble a shopping arcade or a hotel lobby. The perception of this space has changed in particular with a much bolder approach to the extensive use of natural materials such as wood and stone. Greenery can also be found increasingly often, not only outside in the atriums, but also inside the building. How the general zones are arranged, apart from the materials, the role of daylight and greenery, also involves well-chosen colours and art elements that make it easier to navigate the building.

The height of these zones ranges between one and four storeys so that their scale is not too overwhelming. The linearity of general zones does not mean, however, that they are always simple long passages. Contemporary general zones can also have undulating forms or change their width and height throughout, depending on functional and compositional factors.

Table 2. Main features of the general zones in the hospitals researched

No./ source	Hospital name	General zone characteristic
1 [32]-[34]	Hospital Infanta Sofía	4-storey linear general zone, well-lit, predominance of the white colour, natural materials: wood, stone, plaster
2 [35]-[37]	Akershus University Hosptial	6-storey linear general zone, well-lit, predominance of white and wood tones, natural materials: wood, terrazzo, plaster
3 [38]-[40]	Jeroen Bosch Hospital	2- storey curved linear general zone, well-it, mainly white and wood tones, coloured accents (yellow, orange), views of green courtyards, main materials: plaster, terrazzo, wood
4 [41]-[45]	Klinikum Klagenfurt	1-2 storey linear general zone, well-lit, colourful accents, views of green courtyards, predominant materials: plaster, PVC flooring, glass
5 [46]-[47]	Queen Elizabeth Hospital	3-storey general linear zone, well-lit, mainly white with coloured accents (green, blue), materials: plaster, terracotta, steel elements
6 [48]-[49]	Centre Hospitalier de Marne-la-Vallée	1-storey extended linear general zone, mainly white with coloured accents, materials: glass, resin flooring, PVC lining, steel elements
7 [50]-[51]	Rey Juan Carlos Hospital	4-storey linear general zone, well-lit, predominance of grey and brown tones, main materials: stone, glass, wood
8 [52]-[53]	Meander Medical Center	2-6 storey extended linear general zone with glazed atria, well-lit, predominance of white and wood tones, coloured accents, main materials: wood, terracotta, glass
9 [54]-[56]	Can Misses Hospital	1-storey linear general zone, well-lit, predominance of white with coloured accents, main materials: glass, stone, steel elements
10 [57]-[58]	New Álvaro Cunque-iro Hospital	1-2 storey linear general zone, well-lit, mainly white and wood tones, main materials: plaster, wood, stone, glass
11 [59]-[61]	Hospital Lillebaelt Kolding	1-2 storey linear general zone with glazed entrance atrium, well-lit, predominance of white and wood tones, main materials: glass, terra-cotta, wood, steel elements
12 [62]-[64]	Landesklinikum Ther-menregion Mödling	1-storey centralised general zone, well-lit, predominance of white with coloured accents, main materials: glass, terrazzo, wood
13 [65]-[67]	Hospital Nova	3-storey linear general zone with local atria, well-lit, mainly grey and wood tones, coloured accents, main materials: terrazzo, wood, glass, art elements (wooden installations, form of lighting and seating)
14 [68]-[70]	Rigshospitalet Hospital North Wing	3-storey linear general zone, well-lit, mainly white with coloured accents, main materials: plaster, stone, wood, steel elements, art elements (art installations, coloured graphics)

5. Conclusions

The conducted research revealed a trend towards a linear structure for general zones in large multispeciality hospitals in Europe. This arrangement is related to a change in the shape of hospitals in the 21st century – from vertical (popular in the late 20th century) to horizontal forms today. General zones occupy almost 1/10 of the total hospital area. This is the primary area which, in addition to its communication role, provides space for reception, information, interpersonal contact and other services.

Regardless of the hospital's form, the general zone in large complexes is linear. Moreover, the materials used to finish contemporary hospitals have undergone an observable change, especially in the general zones. A large proportion of natural materials, such as wood or stone, can be noticed there. Elements of greenery, which humanise the hospital interior, are increasingly popular. Artistic elements play an important role both in general zones and wards, which is particularly evident in hospitals built during the last five years. The architectural solutions and interior design of the examined zones illustrate the evolution in the approach taken by European hospitals from the 20th-century form of "machines for treating the sick" to hospitals that are patient-friendly, adapted to a more human scale and prioritising patients' not only physical but also psychological comfort, as evidenced by art in hospitals and the increasing role played by greenery.

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