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## Analytical Tools for Functional Assessment of Architectural Layouts

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# Analytical Tools for Functional Assessment of Architectural Layouts

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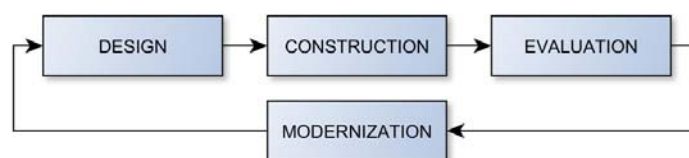
**Abstract.** Functional layout of the building, understood as a layout or set of the facility rooms (or groups of rooms) with a system of internal communication, creates an environment and a place of mutual relations between the occupants of the object. Achieving optimal (from the occupants' point of view) spatial arrangement is possible through activities that often go beyond the stage of architectural design. Adopted in the architectural design, most often during trial and error process or on the basis of previous experience (evidence-based design), functional layout is subject to continuous evaluation and dynamic changing since the beginning of its use. Such verification of the occupancy phase allows to plan future, possible transformations, as well as to develop model solutions for use in other settings. In broader terms, the research hypothesis is to examine whether and how the collected datasets concerning the facility and its utilization can be used to develop methods for assessing functional layout of buildings. In other words, if it is possible to develop an objective method of assessing functional layouts basing on a set of buildings' parameters: technical, technological and functional ones and whether the method allows developing a set of tools enhancing the design methodology of complex functional objects. By linking the design with the construction phase it is possible to build parametric models of functional layouts, especially in the context of sustainable design or lean design in every aspect: ecological (by reducing the property's impact on environment), economic (by optimizing its cost) and social (through the implementation of high-performance work environment). Parameterization of size and functional connections of the facility become part of the analyses, as well as the element of model solutions. The "lean" approach means the process of analysis of the existing scheme and consequently – finding weak points as well as means for eliminating these defects. This approach, supplemented by the method of reverse engineering means that already in the design phase there is essential knowledge about the functioning of the facility. It is far beyond intuitive knowledge, based on the standards and specifications. In the scope of reverse engineering methods, the subject of the research is an audit of the product (i.e. architectural design, especially the built spatial layout) in order to determine exactly how it works. Information gained in this way is to help building a system for supporting decisions for preparing design solutions for future investments as well as the functional analysis itself becomes an essential part of the setting up building information process. The data are presented with graphical methods as networks of different factors between rooms. The direct analytical method for the setting is to determine the functional collision between users' tracks, finding or indication of the shortest paths connecting analyzed rooms and finally to identify the optimal location of these rooms (each according to different factor). The measurement data are supplemented by the results of surveys conducted among users of hospitals, statistics and quantitative medical procedures performed in the test section



of the hospital. The results of research are transferred and integrated with BIM system (building information modelling system), and included in the specifications of the IFC (Industry Foundation Classes), especially at the level of information on the relationship between the individual properties associated with elements (in the case of hospitals it may be information about the necessary connections with other rooms, access times from or to specific rooms, rooms utilization conditions, fire safety protection and conditions and many other). At the level of the BIM specification the model data are integrated at the BIM 6D (an extension of the model data with a range of functional analysis) or even BIM 7D (additional integration with systems used at the stage of operation and maintenance of the facility).

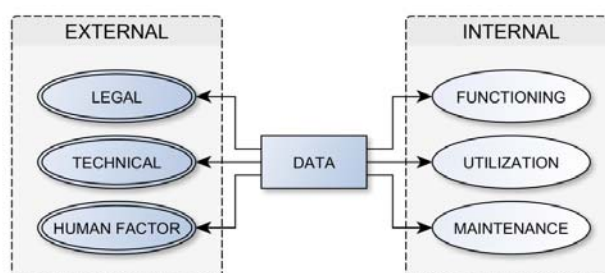
## 1. Introduction

Let's start with a question, what kind of analytical tools do architects need during design process? How did the current design practice go without them or, if they were, to what extent? Is the knowledge and experience of the designer not enough to design a building? The fundamental difference between a traditional and a contemporary design approach is the urgency to include an ever-increasing number of factors and guidelines affecting the final shape of the design and building. They come from the need for growing legal regulations, technological and ergonomic requirements or finally the need to introduce pro-ecological solutions, including energy-saving issues and more. Then, the life cycle of an object, understood as a project and its implementation, is considerably extended, in many cases it is an even iterative repetition, a gradual search for the desired result (figure 1).



**Figure 1.** Investment execution cycle

From a designer's or an architect's point of view, each phase provides enough insights that can lead to adjustments or even deeper changes in the initial design assumptions. The basic data for design guidelines can be divided into two main types: external and internal ones. This first group includes sets of information derived out of a building's own domain – this set contains local legal regulations, technical requirements and specifications or user's demands. The second group is for data that can be obtained directly observing and analysing the object itself; it is data on how the building is used, maintained, and much more (figure 2).



**Figure 2.** The process of analysing and evaluating a building and its reference to data types

For the purposes of this article, aesthetic issues are completely ignored: architecture as such, understood as the art of creating spatial dependencies, the art of composition of the façade, the selection of materials, precludes the precise “mathematical” evaluation criteria. Further reflections will focus on the functional properties of the building, whether and how it can be described, and how to measure it in terms of parametric evaluation. Owing to the multiple and complexity of links and design issues, the general hospital emergency department (ED) has been adopted as a reference.

## 2. The state of research so far

Previous attempts to describe an analytical model have not been fully exhaustive. Of course, there are papers on the subject of analysis and modelling of functional layouts, also including an ED's layout [1, 2, 3]. These works are characterized by a specific approach to the problem: they focus on developing a theoretical model and constructing a description of human behaviour in such a facility. The utilization of a facility, especially a health-care facility, and parameterization of the utility factors cannot be a subject of descriptions, because the processes occurring in the object are not repetitive and are not predictable. It is much more appropriate in this case to observe the real object, and then on the basis of the collected data, develop a statistical model that together with ongoing hospital medical statistics allows describing the most common patterns of the facility usage, indicating actions beyond the margin of standard procedures.

As described by T.W. Kim [4] a usage of space can be defined as an anticipation or prediction how it will be capitalized. However, in fact any analysis is only a description of the existing state but a way of predicting its future change. Certainly, it can provide data to build tools that allow to plan and even anticipate possible changes. However, the building data set itself is just an indication of how it works or is utilized. Only the developed, processed and tested data can be an indication or a pointer what is the way of the functioning of the building – whether it is in daily regular use or under simulated conditions or changes (for example, due to increased user activities or spatial variations). It can be said that the dynamics of spatial planning controlled by a priori assumptions does not lead to any valuable conclusions: it is not possible to predict future behaviour of users based on unknown data (behaviour models, models and ways of space utilization); For this reason, the analysis is purely a pure cognitive tool, describing the present condition and functioning of the object. On the other hand, it is entirely possible to agree with the selection of 4 areas related to the design process (or architectural domains) [4]: (1) architectural programming, (2) post-occupancy evaluation, (3) workplace planning, and (4) operations research for space assignment. The distinguishing seems to be valuable: it is only difficult to call each element an analysis. Such a process can be a continuous iteration, as evidenced by the modernization and adaptation of objects (figure 1).

Another interesting issue raised in the article is the “predictability” of use and the automation of the design process. What is this automatic analysis? And how to prepare a system of artificial intelligence that will conduct such an analysis? Can the self-learning systems actually exist? The analyzer system must not only recognize the spatial layout, but primarily check it for user needs (which are often defined in a very fuzzy, ambiguous manner), as well as assess its compliance with applicable laws and design practices. Doubts also raise the assumption that you can automate the factors influencing design decisions. Practice shows that one cannot automate demographic processes, macro- and microeconomic dependencies, technology development, and so elusive numbers as fashion.

Yet another problem arising from the analysis of the use of space in a building involves prediction, modelling, and subsequent observation of user traffic or behaviour within the designed layout. While some behavioural patterns can be programmed at the design stage and more importantly realized by specific spatial solutions, subsequent observation leads to the conclusion that many spaces at buildings are differently used than originally planned. Investigations and their analysis [5] show that the originally proposed functional layout, especially in terms of communication or open spaces, does not match the expectations and habits of users.

## 3. Descriptive model of functional layout

Designing as an iterative process involves introducing solutions that will force the user to take the desired action: these can be properly designed communication lines (including gradation of traffic routes and access control to dedicated zones), as well as interconnections between rooms and many others, taking its origins from processes undergoing in the building. The methods and analytical tools used in the every-day design work can be labelled as designer-oriented, allowing, for example, the visual evaluation of the proposed solutions, thereby shifting most of the analytical works involved in the verification (possibly quantitative and other numerical data) into conformity with applicable or

accepted regulations. The basic problem is to distinguish the items that are analysed into fields and areas of interest, and to create a tool whose complexity will be hidden and will leave the design interaction only in the direct designer relationship to the basic input set.

Assuming that an architectural design of a building is, in a sense, a “research hypothesis”, a set of accepted assumptions on how a building works, one can ask here how it is verified. This verification is made by developing a spatial model of the selected unit, where – for the given quantitative and utility parameters – the spatial relationships are optimized. Optimization includes, among others, the shortening of access to key rooms, the removal of collision points (for example at the intersection of sensitive roads), the ergonomic designation (from the point of view of procedures) of technological lines.

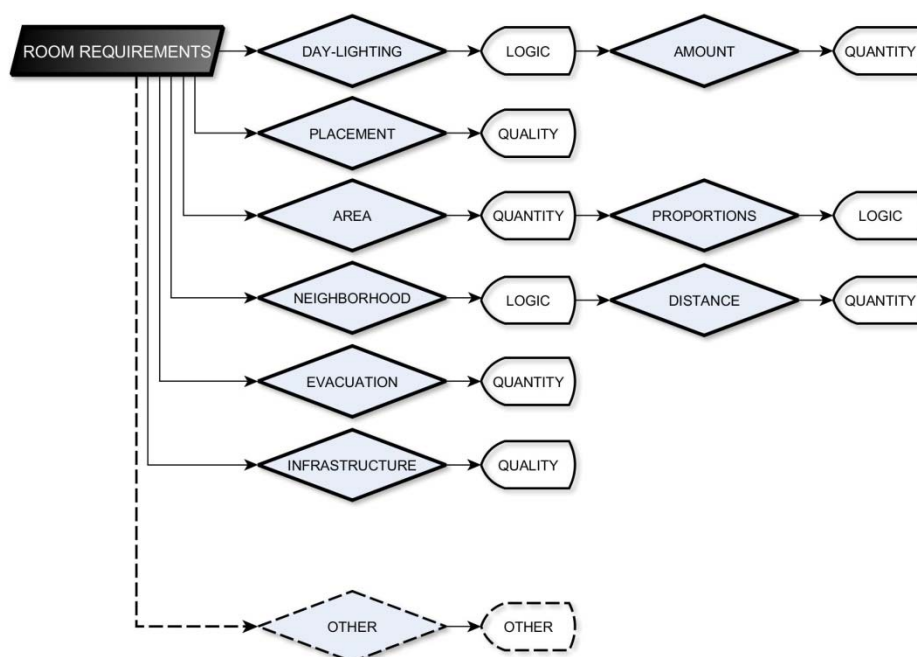
In addition to apportionment of the indices into internal / external ones, they can be further subdivided into several groups related to the scope of the issues described. Geometric and technical data can be used as construction parameters: the shape and dimensions of the construction and installation grid, the illumination of the building track, the horizontal and vertical communication system (including communication as part of the fire protection system), the system of distribution of the installation. Appropriate parameters can be set up as relationships between rooms or facilities, especially system and production lines (technological) that demonstrate the ergonomics of the adopted solutions; functional grouping of rooms; quality and legibility of the internal communication system.

The functional system of a building, especially one with complex functional, internal connections between rooms or premises, is assessed at each stage of the project (design, construction and evaluation). The final rating is the user’s assessment, and although it takes place in the post-construction phase of the “technical life” of the building, i.e. in the exploitation phase, it is the most important test of correctness of chosen solutions.

Data on the functioning of a building can be divided into 3 basic categories:

- Logical data – describing simple outputs for meeting the query conditions, such as whether the room has access to natural lighting, or if there is another room in its immediate vicinity (according to technology or ergonomics requirements), whether the proportion / width of a room is sufficient to set up the apparatus or the technological line etc.
- Qualitative data – describing more complex spatial relationships, for example whether a group of rooms creates a coherent and consistent spatial layout (on basis of characteristics or properties inheritance and distribution as sub-classes), or access to rooms is assured according to technology requirements (sequence of rooms in relation to established input point) and so on.
- Quantitative data – describing dependencies in simple, numerical way, for example as a list of distances between rooms and length of access to a special purpose room, numerical description of fire escape routes (their width and distance from rooms to escape exits, width in relation to the assumed number of users).





**Figure 3.** Data types to be collected and evaluated in the process of acquiring object information

Figure 3 shows a diagram of the assignment of the query sequences and the transmission of the obtained data for further processing. The result of the data processing can be graphical representation of the relationships (in the form of a graph, distance map), sets of numerical data (data sheets or tables containing basic geometric values and many others).

While the first group of data can produce a zero-one representation, the remaining groups need to adopt more complex ways to present the results of analysis, a more complex model and a more complex mathematical description. For many queries a graph is the most suitable way to describe and represent dependencies that can be established. The same set of graph vertices can be combined using different sets of edges; different weights can be assigned to the edges depending on the characteristics of the system being considered. Internal communication is investigated as a set of graph edges connecting the object's rooms (considered as vertices of the graph). For current analyses, the graph trees are expanded in such a way that each intersection of communication axes is marked with an additional vertex. In this way, the mathematical model of the functional layout is built – as in the real object – on the skeleton of the communication system. This procedure allows to divide segments (graph edges) used by different groups of users and define additional parameters: traffic collision, traffic volume on precisely selected and defined sectors and time periods. Rooms of the facility are the vertices of thus prepared graph and it is acceptable simplification for analyses at the description level for the entire spatial layout of the facility. Additional data is directly attributed to the room and, with few exceptions, does not affect the description of the overall system image.

At the evaluation stage the methodology is provided through collecting utility data by using the object's functional statistics and using direct measurement as one of the possible and direct way to conduct a functional analysis of an object. The scientific method is based on observational studies, in particular on the collection of quantitative data on how selected rooms in selected departments of hospitals are used. The frequency of use (taken as number of entering and exiting the key rooms, time spent there – with the indication of essential user groups). It is assumed that users are divided into two basic groups: staff and patients. The first group is divided into three subgroups (doctors / nurses / support staff). Such data is used to determine the “map” of the ergonomic connections between individual rooms (room assemblies).

Linking the project with the as-built phase (project realization) enables the construction of parametric models of functional systems, especially in the context of a “sustainable design” or “lean design” in every aspect: ecological (by reducing the impact of the object on the environment), economic (by optimizing its implementation costs) and social (by implementing a high-class work environment). Parameterization of the size and functional associations of rooms and their assemblies becomes an element on the one hand, analysis, on the other, of functional model solutions. In the case of a lean approach, this means analysing an existing process or scheme and, consequently, finding weak spots and ways to eliminate defects. This approach, supplemented with reverse engineering methods, means that it is crucial at the design stage to have knowledge of how the system works. Intuitive or even based on technical standards and specifications, knowledge does not always give an answer to the question of how a building works. Within the scope of accepted reverse engineering methods, it is assumed to carry out a product testing process (that is, an architectural project including a spatial layout) to determine exactly how it works. The information obtained in this way allows for the construction of a system supporting the design of spatial design decisions for subsequent investments, and the functional analysis itself becomes part of the building information process.

#### 4. Results and discussions

The “building the knowledge base” function takes input from the architectural design, user profiles, and the external database to provide the knowledge base for a specific project as an output. Building a knowledge base is a fundamental task required by every analytical tool. It seems that implementation of the building information model methods (BIM) is a good solution and a good platform for knowledge sharing at every stage of both design and construction and use of the facility. First and foremost, it allows for the construction of an open system accessible to users at every stage of the building’s technical life [6].

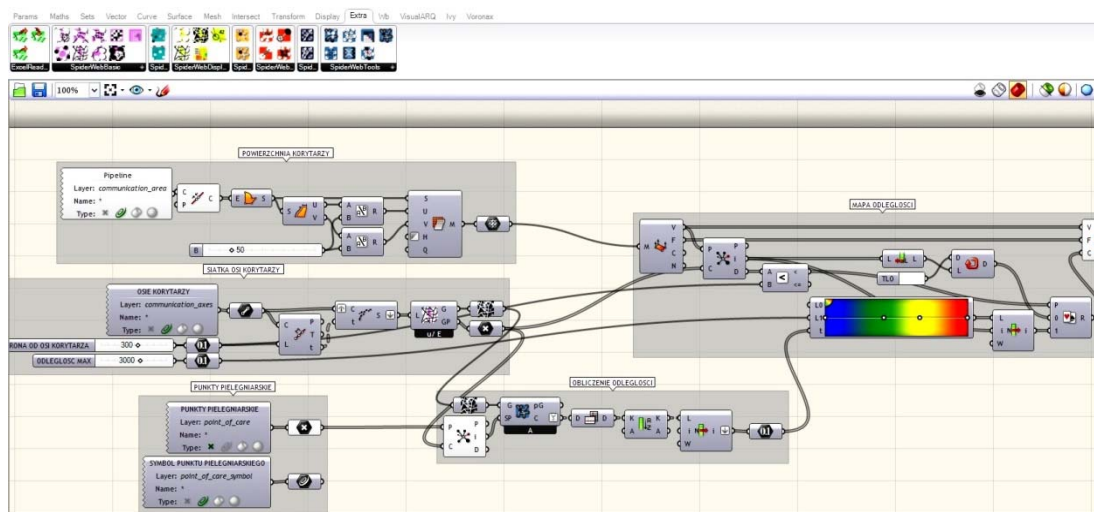
In addition to the normative knowledge base and knowledge gained directly from the observation of the facility and its operation, it is supplemented by the results of surveys conducted among the direct users and the hospital’s quantitative statistics of medical procedures performed in a department being tested. User opinions are important that, depending on the hospital department administration model, an optimal solution for one facility does not have to be the same for another. This is due to the different management models used in each case, as well as the habits and working methods of individual users. Statistical data on performed medical procedures allow bringing measurement data to the dimension of concrete actions in the basic function of the facility. While a specific event may not appear (or will appear in excess) during the observation period, annual medical statistics allow averaging of results and inclusion of exceptional events.

The results of the research are transferred and integrated into the BIM systems and in the IFC (Industry Foundation Classes) specifications, particularly at the level of interdependency information or attributes assigned to the components (for hospitals, this may include information on necessary links to other rooms, arrival time from other facilities, service conditions, fire protection conditions). As far as the dimension of the model is concerned, the data is integrated at the BIM 6D level (extension of the model data for functional analysis) or even BIM 7D (additional integration with the systems used at the stage of operation of the facility). The software platform is an integrated platform consisting of Rhinoceros (spatial modelling, technical drawing, and work environment) + VisualARQ (BIM) + Grasshopper (analytical tool and parametric modelling).



**Figure 4.** Visual representation of the access time analysis for nursing points. Emergency department of the Voivodship (Provincial) Hospital in Elbląg. A fragment of the 1st floor plan. Design: A. Kohnke, J. Bąkowski, 2014

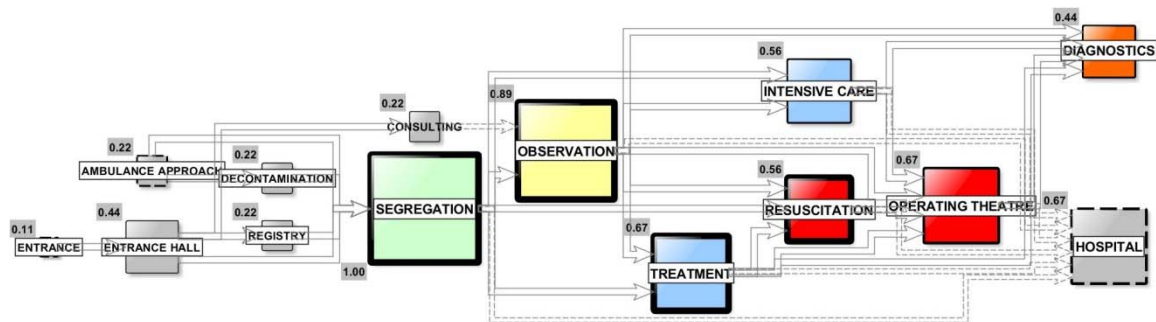
Figure 4 shows one of the many variants of performed analyses related to the efficiency of the communication system in the emergency department of the Voivodship (Provincial) Hospital in Elbląg, Poland as a part of the modernization project. Several analyses of this type have been carried out, examining the distances from the basic rooms of the ED facility to other points within this department as well as those related to the functioning of the whole building. In the latter case, these were primarily fire escape access points, but also a connection to the so-called “main street” of the hospital (this refers to the hospital’s main artery, leading from the main entrances, both acute and regular, to the departments or wards entries and further to all other hospital facilities; in addition to the main corridor the main street consists of a set of vertical communication elements, in this case 5 elevators and 2 main stairwells).



**Figure 5.** The application written in the Grasshopper environment, operating as a Rhinoceros CAD system extension. The application output shown in figures 4 and 8.

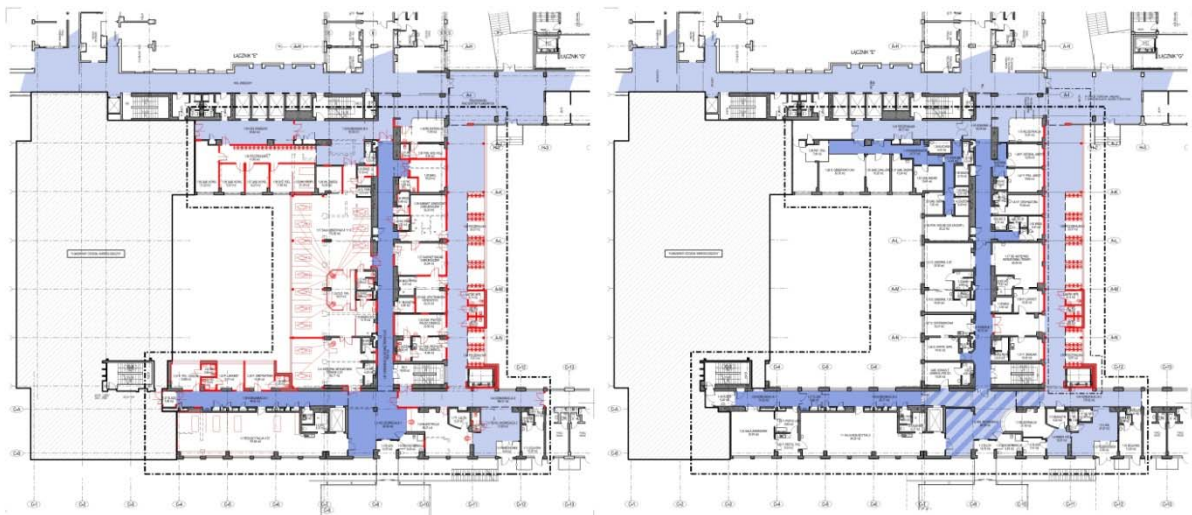


The next step was to prepare diagrams showing in a simplified way the interrelation and dependencies between the ED rooms. The advantage of such a visualization of the functional layout is that it is clearly legible for anyone, even for those who don't have much experience in working on a technical drawing. It is important that at this stage there is a first check-out of the connections between the ED rooms at the level of the future user. The description of planned changes must be legible for all participants in the design process. Figure 6 shows one way to visualize user-generated data on quantitative relationships (patient flow between ED rooms).



**Figure 6.** Relationships between ED rooms as a weighted graph – the room access frequency as the weight of its edges

Obviously, the course of the design process ends up with the preparation and delivering of the documentation, primarily agreed with the direct user of the facility, but also due to the formal and legal agreement of all necessary authorities (figure 7).

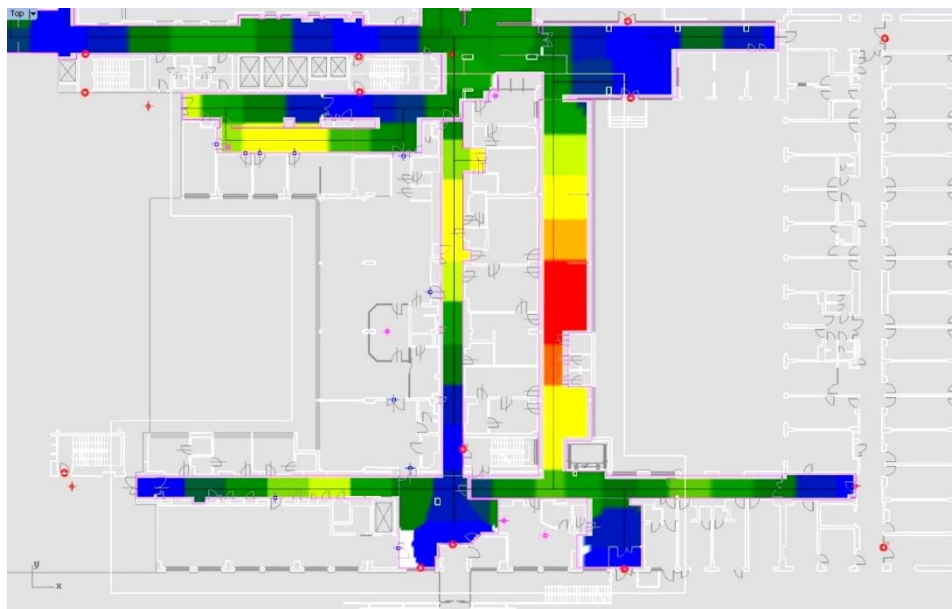


**Figure 7.** Possible transformations of the ED at the Voivodship (Provincial) Hospital in Elbląg; 2 variants of communication core transformations. Design: A. Kohnke, J. Bąkowski, 2014

At every stage of the design work, any number of partial analyses concerning the correctness of the implemented solutions can be made. Such analyses allow for an experimental validation of variant solutions. Depending on accepted or developed analytical methods, these analyses can be done on the fly, using the simple and quick technique of changing selected quantitative parameters or even by “dragging and dropping” the key elements to the desired position. The architect’s work on the spatial



and functional layout solutions thus is greatly simplified, as changing the parameters allows for quick and direct observation and evaluation of possible resolutions.



**Figure 8.** Visual representation of the access time analysis for nursing points, a modified layout. Emergency department of the Voivodship (Provincial) Hospital in Elbląg. A fragment of the 1st floor plan. Design: A. Kohnke, J. Bąkowski, 2014

Figure 8 shows the effect of analyses in a modified ED environment for the same assumptions and using the same data parameters as the analysis shown in Figure 4. Changing the location of the selected rooms (and crucial from the point of view of the ED function) and the deep reconstruction of the general hospital communication system as well as the ED one caused visible relocation of areas of inferior service to nursing points. The general communication led through the ED (which was not in accordance with legal regulations) has been spatially separated, which simplified the access to the ED rooms together with simultaneous functional zoning.

## 5. Future research

All the activities described above took place at the level and in the scope of the basic architectural design. To fully assess the proposed solutions and analytical tools, one further step is needed: the evaluation of the finished, modernized facility utilization. This task still waits for implementation; the work is under its way on the preparation and implementation of the measurement methodology.

The necessary data will be collected by a test apparatus (a gauge) in the form of an RFID system (radio-frequency identification system) based on set of antennas / UHF readers. The system allows for unattended registration of users' movement, actions and behaviour. Basing on the collected data, the map of users' activities within the zone of the ED can be prepared, together with the length of stay in rooms, which – in conjunction with the hospital statistical data – will allow to estimate the utilization of the ED, including staff and patients flow through the ED, the volume of medical procedures conducted at the ward and utilization of specific rooms. One of the research problems of this approach is adoption of easy and accurate method of gaining data, as it seems that one of the main problems may be the human factor – the hospital staff preparedness and willingness to participate in the study.

## 6. Conclusions

The choice of creative and analytical tools is the individual choice of any designer. Each tool has its advantages and disadvantages, practically every design task can be done with any tool. The same choice of a form of presentation of analysis and insights depends on the will and skill of the designer. For interactions with a future user of the facility, the clear and legible methods should be chosen, allowing flexible use, manipulation and presentation of data. In design practice, analysis is an important stage, but it is only one of the stages of the creation process, supporting the whole course of the design actions, it is not the purpose itself. Transferring computations and functional analyzes into the CAD environment, in particular incorporating them into the BIM methods and classes – allowing interaction and collaboration with other representatives of the investment process at every stage – this approach seems to be the most optimal solution.

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