

Design guidelines for automated floor plan generation applications – target group survey, results and reflections

Maciej Nisztuk

<https://orcid.org/0000-0001-6520-5128>
maciej.nisztuk@pwr.edu.pl

Jacek Kościuk

<https://orcid.org/0000-0003-0623-8071>
jacek.kosciuk@pwr.edu.pl

Faculty of Architecture, Wrocław University of Science and Technology

Paweł Myszkowski

<https://orcid.org/0000-0003-2861-7240>
pawel.myszkowski@pwr.edu.pl

Faculty of Computer Science and Management, Wrocław University of Science and Technology

Abstract: This article presents the results of a survey regarding architects' expectations towards software for automated floor plan generation (AFPG) and optimisation processes in architectural design. More than 150 practising architects from Poland and abroad took part in the survey. Survey results were then extracted, ordered and interpreted with the use of data mining. The survey structure, methodology and analytical tools used are described in the paper.

Keywords: automated floor plan generation, computer-aided architectural design, optimisation in CAAD, hybrid evolutionary algorithm, optimisation

Introduction. Aim of the study

Nowadays, it is difficult to imagine an architect working without any digital design tool. Digital tools have become an integral part of the design process. Properly used, they not only improve design quality, but also enable safe design experiments [Słyk 2014; Słyk 2019]. Current computer technologies offer much more than just basic CAD software. Optimisation tools have a particularly vital role to play here. They significantly improve design processes, freeing the human mind from complex calculations [Słyk 2015] and allowing the architect to focus on conceptual work. They also accelerate the process of reaching the final, optimal solution.

Previous studies [Nisztuk and Myszkowski 2017] show that the current development of architectural optimisation tools often omits the issues of usability and functionality. The authors also draw attention to the lack of cooperation between architects in the research and development of this type of software. This often results in bypassing the designers' requirements for both the functionality of the software and the workflow preferred by the architects. This paper aims to examine the expectations of architects regarding the usability of software that optimises functional layouts in architectural design, as well as preferences regarding functionality and design workflow.

The essential research tool was a survey conducted on over 150 practising architects. In particular, the survey was designed to find answers to the following fundamental questions:

- Do architects consider optimisation software as a useful and necessary design tool?
- What is the potential scope of application of such tools?
- In which direction should AFPG software development be heading?

The additional aim of this survey was to check the architects' awareness of the possibilities of available architectural tools for AFPG. The survey also helped to establish the requirements of such software regarding the general logical features and possible usage scenarios. Furthermore, the survey was used to find the subgroups of architects particularly interested in the use of such software.

The collected information and resulting conclusions will be used to improve the software for AFPG that was developed as part of Maciej Nisztuk's doctoral dissertation at the Faculty of Architecture, Wrocław University of Science and Technology. The EvoLutionary ArchItectural Aided DeSign (ELISi) application focuses on facilitating the search for optimal functional layouts in terms of their compliance with mandatory functional and design requirements as well as investor's preferences [Nisztuk and Myszowski 2019]. ELISi suggests possible solutions that meet the given criteria but leaves the final selection decision to the architect. The floor plans proposed by the software are evaluated according to various design criteria. At the current stage of ELISi development, the software demonstrates possibilities of optimisation when generating architectural floor plans based on functional programs of single-family houses.

The results of the survey will help the author to further develop the software so that it meets the criteria indicated by the architects and is compatible with guidelines for a human-centred design for interactive systems. Due to this, the survey included questions on the following essential areas:

- optimisation criteria considered useful by architects,
- criteria that should be enabled or disabled by default,
- acceptable waiting time for a design solution,
- user profile.

The last area includes architects' professional experience, office size, software used, type of clients, etc. The survey also asked a question to find architects who were interested in testing the ELISi application.

Survey methodology

The research was carried out using an anonymous online questionnaire that could be completed in not less than 10 minutes. In order to democratise the survey group and keep it diverse, the authors chose two groups of respondents:

- architects working in architectural offices from abroad – the authors prepared a list of 300 architectural offices in the world and contacted them by email. The selection was based on various online architectural office rankings [ArchitectureQuote 2019; Lynch 2017; DesignRulz 2017] that encompassed criteria such as innovation, size, revenue, popularity, etc. The mailing list included all studios from the particular rankings regardless of their score.
- Polish architects – members of the Chamber of Polish Architects were contacted via internal communication channels and by social media.

A total of 152 professional architects took part in the survey: 135 Polish architects (1% of the total number of members of the Chamber), and 17 from abroad (5.6% of the number of invitations sent). Since some survey questions could be left unanswered, the number of answers to some questions was lower than the number of survey participants.

Survey structure and respondents' answers

The survey included three groups of questions about key issues:

- characteristics of survey participants,
- scenarios for applying optimisation tools in the design process,
- features of the AFPG software that were considered important.

The numbers on the diagrams presented below correspond to the number of answers given to individual questions. It should be remembered that most survey respondents were from Poland, so the answers and conclusions cannot be perceived as a providing a global picture.

Characteristics of survey participants

Nearly 70% of respondents had more than ten years of professional experience, and most of them (67.1%) owned a design studio. They worked alone or in small design teams of up to four people. Since the mailing targeted members of the Chamber of Polish Architects and official addresses of design offices abroad, nearly 80% of the respondents held the position of "leading architect (project manager)" or design studio owner. This fact narrowed the spectrum of research by limiting it mostly to participants who were the chief decision-makers in the design process. Nevertheless, the age spread of the study participants (or more precisely the years of their professional practice) was close to normal distribution (Fig. 1). The majority of them (ca. 60%) used 2D CAD software, and only a third used BIM software. The application of algorithmic or parametric design tools was vestigial.

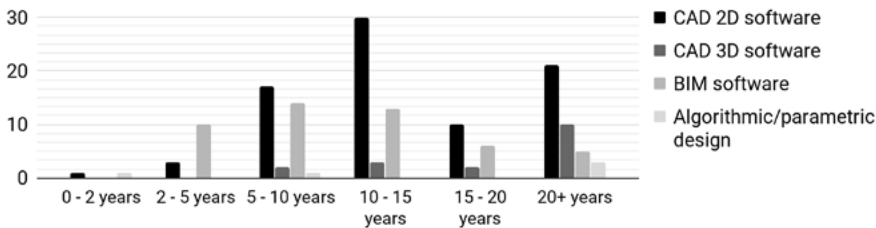


Fig. 1. Type of architectural software used by architects broken down into years of professional experience.

More than two-thirds of the projects the architects were involved in were related to newly designed buildings, and only a third were adaptations, reconstructions or renovations of existing buildings. Customers were individuals and institutional investors in almost equal proportions.

The most common types of designed buildings were respectively single and multi-family residential buildings, commercial or service buildings, and industrial and office buildings (Fig. 2).

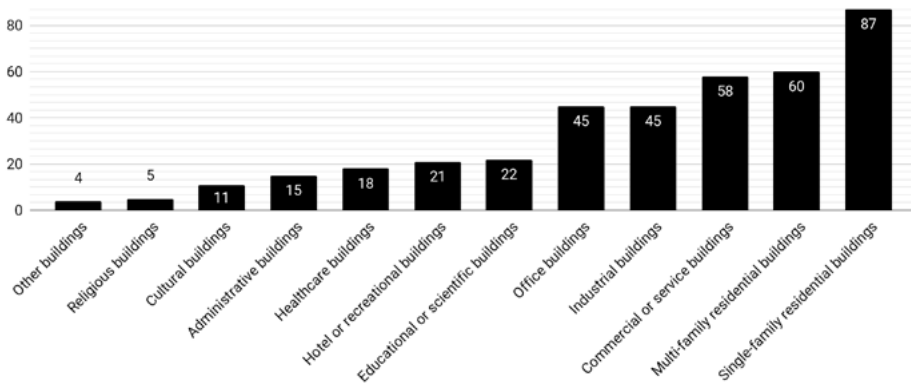


Fig. 2. Most common building types designed by respondents.

Survey participants were also asked if they used an architectural brief – a document containing assumptions and guidelines for architectural design that describes the intentions of the client and clearly defines the most important goals for the project. Three-quarters of respondents used architectural briefs in their design practice, and the majority of them said that the design brief preparation module included in the ELISi application would be useful.

Scenarios for applying optimisation tools in the design process

The most common areas where optimisation was considered useful included *topology* (room connectivity), *length of evacuation routes*, *room location in respect to cardinal directions* and *room area* (Fig. 3).

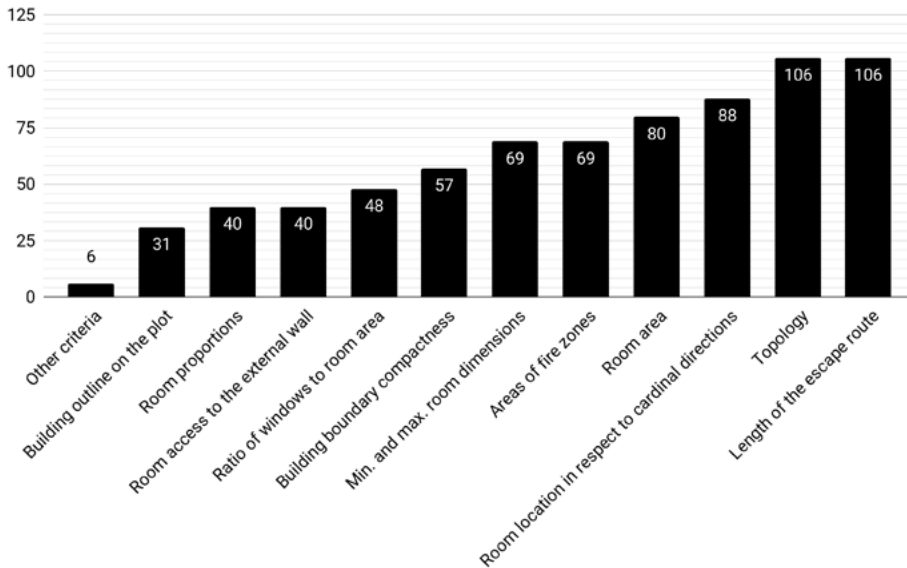


Fig. 3. Areas where design optimisation was considered useful.

A separate question concerned the minimum complexity of the floor plan (expressed by number of rooms) for which the use of optimisation algorithms could be justified. The answers do not give the impression that this question was given careful thought (Fig. 4), so this data should be treated with great caution.

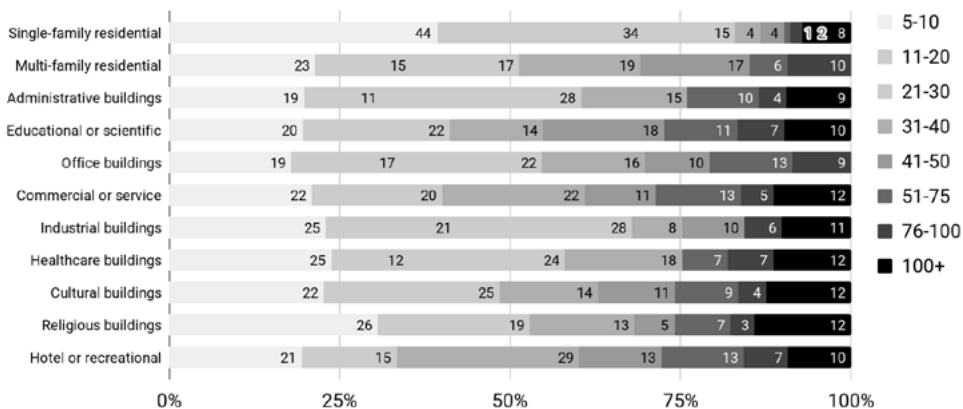


Fig. 4. Complexity (expressed by the number of rooms) of the floor plan required to justify the use of optimisation algorithms. Numbers on graph bars show the number of respondents that selected the given complexity.

Another important question was about optimisation criteria that should have a predefined value. An example may be a *predefined location in relation to cardinal compass directions* for a given type of room, e.g. the preferred orientation of the bedroom – east. As a side note for this particular example, it should be mentioned that these types of preferences might be culturally and climatically conditioned. For example, in the climatic conditions of Italy and Greece, Vitruvius [Vitruvius Pollio and Morgan 1960] suggested that living rooms should be exposed to the south since they will receive more direct sunlight during cold winters and less in hot summer months. In the latitudes of Poland, west-oriented living rooms have been preferred so far. The practice of recent years indicates that due to progressing climate change, some customers are thinking about changing this orientation to the east – less burdensome during hot summers.

The results of the survey indicate that for half of the optimisation criteria, respondents opted for predefined values (Fig. 5). In most cases, these were the requirements imposed by building regulations and safety conditions.

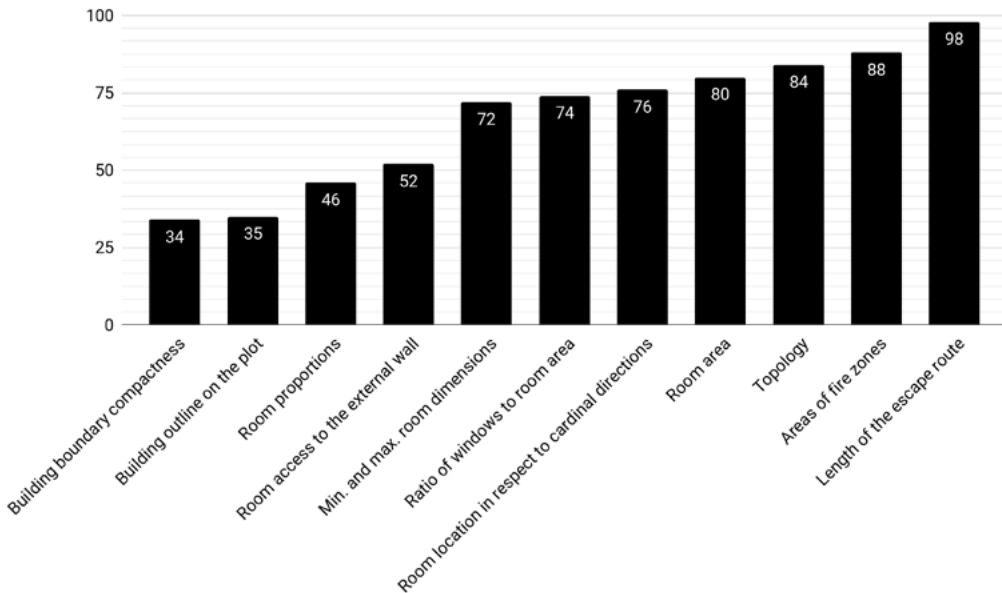


Fig. 5. Design optimisation criteria where predefined values were considered useful.

Important features of the AFPG software

The last section of the survey concerns the features of the AFPG software that were considered significant. Among them, the time necessary to generate floor plans was particularly important. The provided answers were generally in line with expectations – the higher the complexity of the plan, the longer the acceptable time for the generation of the results of the optimisation process. Thus, most of the respondents indicated 30 minutes as the maximum acceptable time for plans covering up to 20 rooms, 50 minutes for floor plans containing between 20 and 50 rooms, and even up to 5 hours for floor plans encompassing between 50 and 100 rooms.

Another question important from the point of view of optimising the software itself concerned the relationship between the introduction of additional criteria and the acceptable waiting time for the final solution. Over 80% of respondents would accept twice as long a waiting time if three additional criteria were introduced. If one compares the last data with the answers to the previous question, it can be concluded that the waiting time for the final solution was not a critical parameter for respondents.

The survey concludes with a question about interest in testing the ELISI software for AFPG, as developed by Maciej Nisztuk for his doctoral dissertation. Since two-thirds of respondents answered positively, this may indicate a potentially great interest among architects in this type of design tool.

The methodology of survey results analysis

Analysis of the survey was conducted using the “R” software environment [R Core Team 2019] and the Waikato Environment for Knowledge Analysis (WEKA) data mining software [Hall et al. 2009; Witten et al. 2016]. The obtained data were processed, taking into account the following:

- since some answers to open questions that had the option of choosing “other answer”, in fact, matched already defined answers, these responses were assigned to respective defined answers,
- multiple choice questions were translated into a set of true/false answers. Each question was broken down into a set of “sub-queries”.

A typical set of data analysis methods with their standard parameters (settings) for particular search methods was implemented. This data was used for the following analysis:

- correlation coefficients. The correlation coefficient describes the relationship between questions. It indicates whether a relationship exists and is statistically significant. Cramér’s V correlation measure method [Mangiafico 2016] calculated in the “R” software environment [R Core Team 2019] was used.
- association rules. Algorithms for association rules find co-occurrences of answers in a studied data set and find patterns of relationships between answers – e.g. the occurrence of answer “A” for one question coincides with the occurrence of answer “C” in another question. Association rules were mined with the Tertius algorithm [Flach and Lachiche 2001], which is part of WEKA software [Hall et al. 2009; Witten et al. 2016].
- decision trees. A decision tree is a graph structure with nodes representing decisions and their consequences. It is a useful graphical tool supporting the decision-making process [Bujak 2008]. The C4.5 algorithm [Quinlan 1993] implemented in WEKA software [Hall et al. 2009; Witten et al. 2016] was used in this case. This method was implemented for profiling architects interested in testing the ELISi software prototype.

Discussion of survey results

The discussion of the results will be divided into three parts corresponding to the analytical tools used, i.e., correlation analysis, association analysis, and decision tree analysis. This division goes hand in hand with an increasing degree of detail in analysis and inference, as correlation analysis is the most general analysis. Each part will be accompanied by a brief description of the analytical method and a summary of the results and their discussion.

Correlation coefficient analysis

The correlation coefficient describes the relationship between the questions. It indicates whether a relationship exists and is statistically significant. The correlation coefficient has a value between 0 and 1, where 0 indicates no relationship between questions, and 1 indicates a perfect relationship. This way, the value of the correlation coefficient indicates the strength of the relationship between two questions. It is generally assumed that correlation values between 0.1 and 0.3 mean a weak relationship, values between 0.3 to 0.5 point to a moderately strong relationship, and values above 0.5 indicate a strong or very strong relationship. The occurrence of correlations indicates the strength of the relationship between questions, but does not specify the nature of these relationships.

Correlation coefficient analysis unveiled the noisy character of the relationship landscape between particular questions. Correlation strength for the majority of questions did not pass the threshold of 0.3, meaning there was a weak relationship. The full correlation matrix between questions can be found on the project’s webpage [Nisztuk et al. 2019].

A few groups of questions did create “islands” of common relationships [Nisztuk et al. 2019]. Questions about the type of building usually designed by architects showed a strong relationship (correlation value above 0.7) between single-family residential buildings and other types of buildings. Slightly lower correlation values

(above 0.5) were found for the rationality of using optimisation tools at different levels of floor plan complexity for various types of buildings. Particularly strong relationships were found between administrative buildings and educational or scientific buildings, healthcare buildings and cultural buildings, educational or scientific buildings and healthcare buildings, and commercial or service buildings and educational or scientific buildings. The questions about acceptable waiting times for the generation of floor plans of various complexities (from floor plans containing up to 20 rooms to floor plans containing 50–100 rooms) showed moderate to strong internal correlations (values between 0.45 and 0.59).

Mostly moderate correlations (values between 0.39 and 0.58) were discovered between questions pointing to design optimisation criteria considered useful and those which were believed should be enabled by default. The relationships were shared between questions about the same optimisation criteria, e.g. the question *Is topology (room connectivity) suitable for optimisation in architectural design* had a strong correlation with the question *Should the topology (room connectivity) criterion be active by default?* The strongest relationships were between questions about *topology (room connectivity)* – 0.58, *room area* – 0.55, *room access to the external wall* – 0.53, *maximum and minimum room dimensions* – 0.49, *length of escape route* – 0.49, and *compactness of the building's boundary* – 0.49.

Rather strong correlations (values between 0.48 and 0.59) were identified between questions about the optimisation criteria that should have predefined values or that should be enabled by default. The relationships were shared between questions about the same optimisation criteria. The strongest relationships were between questions about *room access to the external wall* – 0.59, *maximum and minimum room dimensions* – 0.59, *percentage ratio of window area to room area* – 0.56; *topology (room connectivity)* – 0.51, and *room area* – 0.48.

Furthermore, the analysis showed particularly strong relationships between various criteria inside the *pre-defined values of optimisation criteria* questions: *length of the escape route* with *areas of fire zones* – 0.79, *building outline on the plot* with *compactness of the building's boundary* – 0.64, *room location in respect to cardinal directions* with *room access to the external wall* – 0.56, *proportion of width to length of room* with *room access to the external wall* – 0.52, *compactness of the building's boundary* with *proportion of width to length of room* – 0.52, and *percentage ratio of window area to room area* with *length of the escape route* – 0.5.

In addition, the analysis identified mostly moderate to strong relationships between various criteria inside the *should the optimisation criterion be active by default* questions: *length of the escape route* with *areas of fire zones* – 0.69, *maximum and minimum room dimensions* with *proportion of width to length of room* – 0.57, *room location in respect to cardinal directions* with *proportion of width to length of room* – 0.51, *compactness of the building's boundary* with *proportion of width to length of room* – 0.51, *building outline on the plot* with *proportion of width to length of room* – 0.5, *percentage ratio of window area to room area* with *proportion of width to length of room* – 0.44, and *length of the escape route* with *percentage ratio of window area to room area* – 0.44.

There were also some predictable relationships between optimisation criteria. The analysis, for example, detected relationships between *building outline on the plot* and *compactness of the building's boundary*, and *areas of fire zones* and *length of the escape route*.

On this basis, it can be concluded that the optimisation criteria described above were particularly important for respondents and should be implemented in the AFPG software. Although correlation analysis did not reveal particularly striking results, they brought useful data for the further development of the ELISi software prototype – particularly in relation to architects' opinions on optimisation criteria that should be enabled by default together with their predefined values. In order to find and describe more specific links between collected data, the association rules between answers to survey questions were examined.

Analysis of association rules between survey answers

This section contains the description and interpretation of two sets of association rules:

- association rules occurring in the entire data set,
- association rules between selected group of questions.

Association rules are a data testing method used in data mining. This method involves the analysis of a set of variables to find the recurring dependency. An example of applying this technique is the analysis of customer

transactions in a grocery store. Based on information about purchased food products, association rules connecting the purchase of individual products can be found, e.g. the purchase of bread and butter leads to the purchase of tomatoes. In this article, the basic difference between analysis of correlation coefficients and association is the level of detail. Correlation coefficients indicate a relationship between questions, while association rules find relationships between individual answers.

Association rules were mined using the Tertius algorithm [Flach and Lachiche 2001], which is part of WEKA [Hall et al. 2009; Witten et al. 2016] software for data analysis and knowledge exploration. The mined association rules are indications of relationships occurring between answers in the data set; therefore cannot be interpreted as a pure causal relationship that is always correct.

Attempts to conduct associative analysis based on the entire data set proved to be of limited use. Although some interesting information about the architect profession in general was mined the general association rules proved to be too noisy and complex to interpret. Therefore, further data evaluation was narrowed to mining association rules only in specific groups of topics defined for extracting focused data:

- the internal relationship between various questions concerning participants' profiles,
- participants' profiles in relation to the level of floor plan complexity justifying the use of optimisation tools,
- participants' profiles in relation to design optimisation criteria considered useful,
- participants' profiles in relation to acceptable waiting times for final optimisation solutions at various levels of floor plan complexity,
- participants' profiles in relation to the number of additional optimisation criteria that would make doubling the calculation time acceptable.

Association rules were also examined between groups, each containing two categories of questions:

- the level of floor plan complexity justifying the use of optimisation tools and design optimisation criteria considered useful in relation to acceptable waiting time for optimisation solutions at various levels of floor plan complexity and number of additional optimisation criteria that would make doubling the calculation time acceptable.

Association rules occurring in the general data set

A set of interesting general association rules common for the entire survey data set were found:

1. If the user selected the shortest waiting time for a given floor plan complexity, (s)he was likely to select the same option for other complexities.
2. If the user selected the simplest level of floor plan complexity as justification for the use of optimisation tools for a given building, (s)he was likely to select the same option for other building types.
3. If the architect designed single-family residential buildings, (s)he likely did not design public buildings (administration buildings, cultural buildings, scientific or educational buildings, office buildings, or health care buildings), industrial buildings or religious buildings. (S)he was likely to design commercial and service buildings or multi-family residential buildings.
4. Single-family residential buildings were most commonly designed by architects working alone.
5. If the investor was an individual client, the architect was likely to design single-family residential buildings or commercial and service buildings. Usually, these were newly designed buildings.
6. An architect working for an institutional client was probably working on the reconstruction or adaptation of existing buildings.
7. The architect working as the lead architect (project manager) was likely to design educational or scientific buildings.
8. The criterion for the maximum and minimum dimensions of the room was likely to be used by architects with 10–15 years of experience. However, it was not frequently considered useful by architects with 20+ years of experience.
9. Architects designing multi-family residential buildings rarely selected room area as the first optimisation criterion.

Conclusions from detailed association rules

This section contains association rules between a selected group of questions. Narrowing the search field allowed a much larger number of interesting association rules to be found.

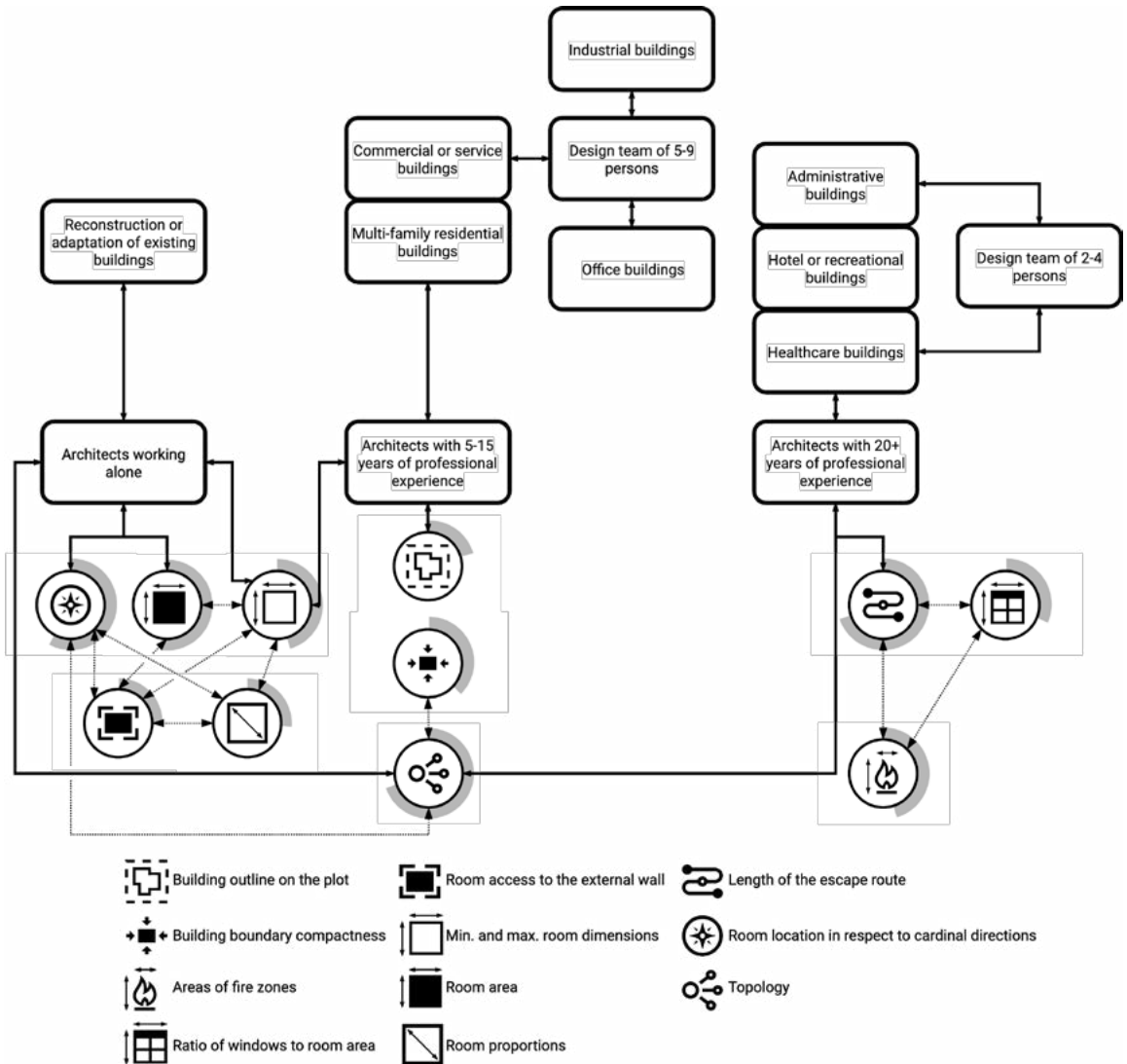


Fig. 6. The relationship between architect profiles, types of buildings, optimisation criteria considered useful and design team size. Grey rings around icons symbolising individual optimisation criteria show the percentage of indications.

Analysis of the survey data brought the most comprehensive results regarding relationships between architect profiles, types of buildings, optimisation criteria considered useful and design team size (Fig. 6). Three groups of architects emerged from this analysis:

- architects working alone,
- architects with 5–15 years of professional experience,
- architects with 20+ years of professional experience.

Although the first group typically worked on reconstructing and adapting existing buildings, the analysis also showed that this group worked on single-family houses as an alternative. For this group, the optimisation criteria considered most useful were the following:

- *room location in respect to cardinal directions,*
- *room area,*
- *minimal and maximal room dimensions,*
- *topology.*















Further relationships also point to *room proportions,* their *access to the external wall* and *the building boundary compactness.*

For the second group of architects, those with 5–15 years of professional experience, the most typical design tasks were multi-family residential houses and commercial and service buildings. They worked in teams between five and nine persons and also designed office and industrial buildings. The optimisation criteria they considered useful were *building outline on the plot* and *minimal and maximal room dimensions.* The last criterion is further associated with the whole group of optimisation criteria typical for architects working alone.

The last group – the most experienced architects – dealt mainly with the design of healthcare buildings, hotel and recreational buildings, and administrative buildings. Surprisingly, they seemed to work in smaller design teams of between two and four persons. The design optimisation criteria considered most useful were *topology* and *length of the escape route.* The first was further associated with *building boundary compactness,* while the choice of the second criterion typically accompanied choosing the *area of fire zone* and *ratio of window to room area* as important optimisation factors.














The analysis of relationships between the three main groups of architects and the most important optimisation design criteria show that architects working alone chose the largest number of criteria (Table 1). Another interesting observation is that each group of architects indicated different criteria as the most important. The only common choice was that of *room topology.*





















Table 1. Main groups of optimisation design criteria considered useful.

	Optimisation design criteria						
Group 1 (architects working alone)							
Group 2 (architects with 5–15 years of professional experience)							
Group 3 (architects with 20+ years of professional experience)							

Analysis of mutual relationships between the optimisation design criteria indicated by survey participants as the most important is also interesting (Table 2). This analysis should be understood as an indication of the relationships between the choices of individual criteria. For example, an indication of an essential criterion *room access to the external wall* was often accompanied by choosing *minimal and maximal room dimensions,* *room location in respect to cardinal directions,* *room area,* and *room proportion* as additional criteria.

Table 2. Mutual relationships between optimisation design criteria considered useful.

											
	—										
		—			X	X		X			X

											
			—				X			X	
				—					X		
		X			—			X			X
		X				—		X			X
			X				—			X	
		X			X			—			
				X		X			—		
			X				X			—	
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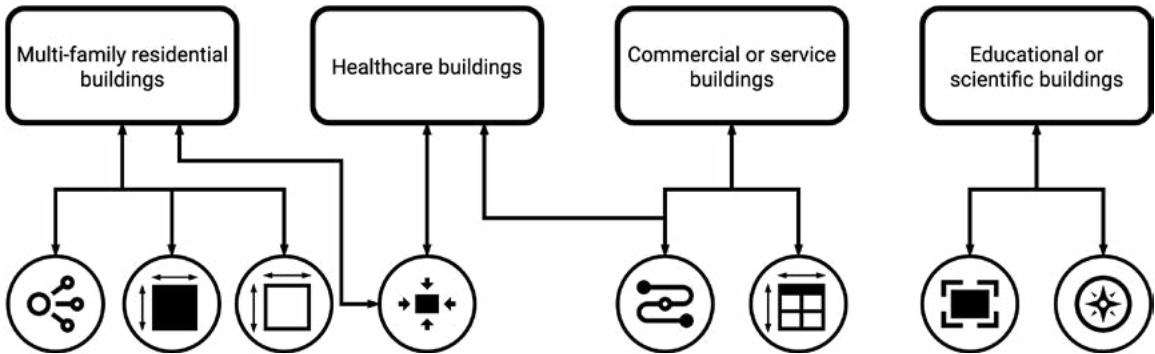


Fig. 7. Relationship between the type of designed building and the most important optimisation criteria indicated by the respondents.

A slightly different picture of the associations emerges if one analyses only the direct relationship between the type of designed building and the most important optimisation criteria indicated by the respondents (Fig. 7). Many of the relationships found are puzzling. For example, there is no sensible explanation for the strong relationship between the design of commercial or service buildings and the *ratio of window to the room area*. On the other hand, in the case of designing multi-family residential buildings, the lack of a strong relationship between *room location in respect to cardinal directions* and *room access to the external wall* criteria is striking. Therefore, there are doubts about whether the respondents always gave answers entirely consistent with their professional experience. Thus, this part of the analysis should be treated very cautiously.

		ARCHITECT SPECIALISATION						
		Single-family residential buildings	Multi-family residential buildings	Office buildings	Commercial or service buildings	Industrial buildings	Cultural buildings	Hotel or recreational buildings
BUILDING TYPE	Single-family residential buildings	LOW				HIGH		
	Administrative buildings	LOW				HIGH		
	Healthcare buildings	LOW						
	Cultural buildings	MEDIUM	LOW	MEDIUM		MEDIUM	MEDIUM	LOW
	Hotel or recreational buildings	MEDIUM	LOW		MEDIUM			

Fig. 8. The level of complexity justifying the use of optimisation tools in relation to the type of buildings of the architect's specialisation.

Similar doubts could arise when analysing the answers of architects specialising in the design of particular types of buildings to the question regarding the level of complexity justifying the use of optimisation tools (Fig. 8). However, the results of the analysis should be considered while taking into account different levels of difficulties in the design of particular types of buildings. For example, in the case of industrial buildings, a high level of complexity was needed to justify the use of optimisation tools, and this is due to the usually low degree of functional complication of such buildings – the use of optimisation is justified for a large number of rooms with different functions. Moreover, contrarily, in the case of hotels, a low level of complexity was needed to justify the use of optimisation tools, and this results from the high level of functional complication, so optimisation already makes sense with fewer functions and rooms.

In general, it can be said that the level of complexity justifying the use of optimisation tools is inversely proportional to the level of difficulty characteristic for particular types of buildings.

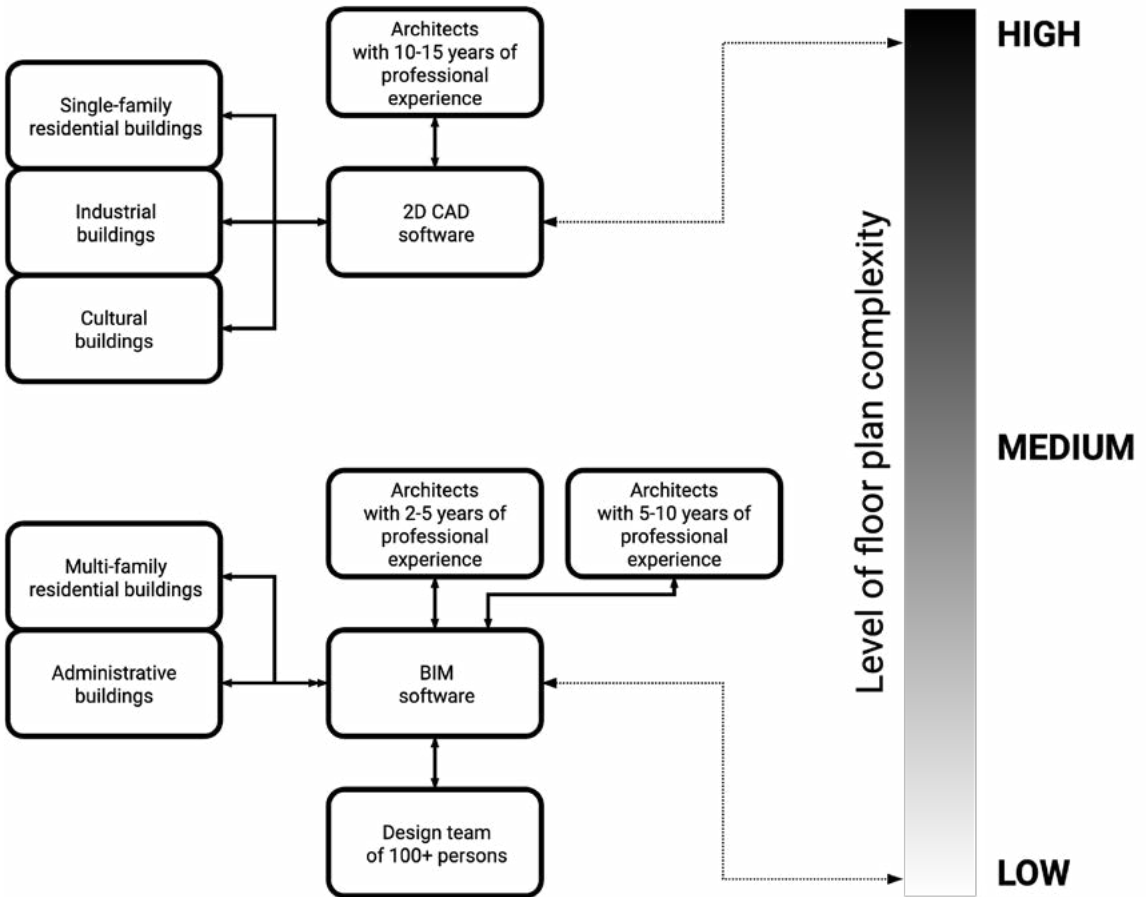


Fig. 9. The level of complexity justifying the use of optimisation tools in relation to software being used, architects' experience and type of designed buildings.

The level of complexity justifying the use of optimisation tools can also be analysed from the point of view of the software being used (Fig. 9). Users of 2D CAD systems set this level very high, while architects using BIM software would use optimisation tools even at low levels of design complexity. In the opinion of the authors of the study, this may indicate that in contemporary BIM software, there is still a lack of sufficient connection between the conceptual design phase and the stage of building information modelling. This deficiency can be a significant obstacle to the full implementation of BIM technology, which should also include the earliest conceptual design phases. From this, one can conclude the potential usefulness of tools optimising functional layout (and at the same time allowing control over the form of the building), resulting in a simplified 3D model.

This analysis (Fig. 9) also brings interesting observations regarding the relationships between the software used, the length of architects' professional experience, and type of buildings designed. BIM software is still a relatively new technology and therefore is rather used by younger architects who have encountered this design technology in the early stages of their careers. The older generation still prefers 2D CAD software.

Apparent differences can also be seen in the type of designed buildings. 2D CAD is preferably used for single-family residential buildings and cultural and industrial buildings. The last observation is a bit worrying since generally, BIM technology has found its most extensive and most complete application in the design of industrial buildings. Perhaps, therefore, the issues of the software used and the type of buildings designed should be interpreted separately.

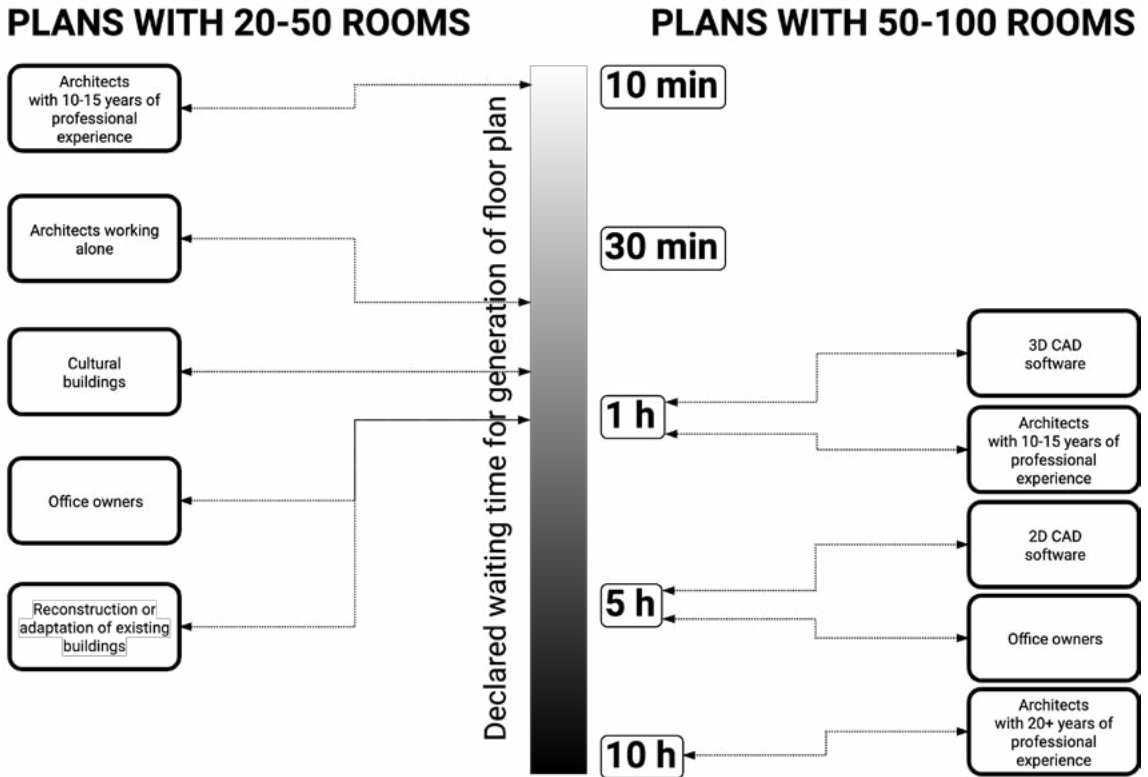


Fig. 10. Acceptable waiting time for the optimisation solution in relation to the complexity of the floor plan.

Important from the point of view of ELISi performance were questions regarding acceptable waiting time for the optimisation solution in relation to the complexity of the floor plan. The obtained answers set the boundary values expected by the respondents – from 10 minutes by architects with 10–15 years of experience for plans with 20–50 rooms, up to 10 hours by the most experienced architects for plans with 50–100 rooms. The acceptable waiting time also depended on the type of software, type of building and architect’s position.

Table 3. Acceptable waiting time for the optimisation solution in relation to the complexity of the floor plan and building type.

Acceptable waiting time for generation of floor plan with 20–50 rooms	Complexity of floor plan based on building type
10 minutes	Multi-family residential buildings = 41–50 rooms
30 minutes	Healthcare buildings = 41–50 rooms
100 minutes	Hotel or recreational buildings = 100+ rooms
	Industrial buildings = 100+ rooms
	Healthcare buildings = 100+ rooms
	Multi-family residential buildings = 100+ rooms

More detailed relationships can be found when analysing only acceptable waiting time and level of plan complexity from which the use of optimisation algorithms might be justified (Table 3). In this case, the respondents pointed to much more stringent requirements in relation to the speed of solving optimisation tasks. For plans with 100+ rooms, regardless of the type of building, the acceptable waiting time for the optimisation solution was in the range of 100 minutes. This shows a lack of consistency with the responses shown in Fig. 10.

The last of the analyses concerned the relationship between the number of additional optimisation criteria that would make doubling the calculation time acceptable and the respondent’s profile (Table 4).

Table 4. Number of additional optimisation criteria that would make doubling the calculation time acceptable in relation to participants' profiles.

Number of additional optimisation criteria that would make doubling the calculation time acceptable	Participants' profile
1	Working in a design team of 10–19 persons
	Lead architect (project manager)
2	Architects with 15–20 years of professional experience
3	Architects holding their current position in the design team for 0–2 years
	Designers of multi-family residential buildings
6	Working in a design team of 2–4 persons
	Office owners

The owners of design offices and members of small (2–4 persons) project teams were the most restrictive here. They would accept a doubling of the time only after introducing as many as six additional criteria.

Decision tree analysis

In order to understand the interest of respondents in testing the ELISi software for AFPG, the authors used decision tree analysis for this survey question. This type of analysis creates a graph structure with nodes representing decisions (responses indicated in the survey) and their consequences. The C4.5 algorithm [Quinlan 1993] implemented in WEKA software [Hall et al. 2009; Witten et al. 2016] was used for this. Analysis was done in two contexts:

- interest in testing ELISi based on architect characteristics,
- interest in testing ELISi based on potential software properties (suitable optimisation criteria and waiting times for automatic generation of floor plans).

In terms of architect characteristics, the major factor that influenced the decision to test the ELISi software was if office buildings were being designed. In this case, the respondent was likely to test. If not the case, the next condition was if a religious building was being designed. If so, the respondent was again likely to test. If not designing a religious building, the final condition was the size of the team. Architects working in teams of 2–4 or 5–9 persons were likely to test.

In terms of the potential software properties, the major factor that influenced the decision to test the ELISi software was the waiting times for the automatic generation of a floor plan containing between 20 and 50 rooms. Respondents willing to test can be divided into three groups:

- those who thought 20, 60, 70 or 100 minutes were acceptable waiting times,
- those who accepted a waiting time of 30 minutes and also considered the optimisation criterion of *building's boundary compactness* as useful.
- those willing to wait for 40 minutes and also considered the additional optimisation criterion of *topology* as useful.

The results of this part of the survey analysis should be treated with caution – they might be accidental since the patterns found were supported by very low statistical values.

Conclusion

The information contained in the results of the survey is an important source of knowledge for those creating computational tools for architectural design – software for AFPG in particular. Because only a few sources of similar information are available, e.g. [Cichocka et al. 2017; Wortmann 2019], access to the survey data is provided freely online [Nisztuk et al. 2019], as this might be helpful for other developers of this type of application.

The analysis discovered interesting relationships between the answers, which went some way to reveal the contemporary state of the discipline of architecture. The important information received from the survey is in particular, that architects are eager to use AFPG software in the design process. Furthermore, the research allowed usage scenarios and the target audience of such software to be recognised. It also helped to identify the points where using computational tools is beneficial for the design process. In addition, the survey showed factors that are important for the development of AFPG software. The research showed that such software should support many types of buildings and identified the most desired building typologies. Moreover, it allowed the number and types of optimisation criteria for AFPG problems considered as useful by architects to be clarified. Over and above that, the study found that computation time and floor plan complexities supported by AFPG software are considered the most crucial factors.

A few participants expressed concern regarding the destructive potential of AFPG technology: the possible replacement of the architect with a computer and eventual architect profession degradation. In general though, the idea of AFPG was well received by survey participants. In the final section of the survey where participants could leave a comment, the authors received a lot of support and encouragement.

The authors believe the structure of the survey fitted its designed role. Although some questions were not fully answered, the survey gave valuable information about the contemporary perception of AFPG technology by architects.

Limitations

In the survey, 152 architects participated. Although the survey reached a wide group of respondents, the quantity of participants could have been even higher. Three hundred international architectural offices were invited to participate, and the Chamber of Polish Architects has 12500 (in 2019) members. Invitation to participate in the survey sent by email to worldwide architectural offices proved to be ineffective. Because the internal communication channels of the Chamber of Polish Architects performed better, the survey is overrepresented by Polish architects.

Analysis indicated dependencies and relationships occurring between survey answers but did not always provide their clear interpretation. Because of that, some discovered relationships were trivial or hard to explain.

The authors believe that the quality of the survey could be improved. Firstly, the surveyed group could be wider and represent architects from a larger variety of countries. In order to achieve this, a more direct and informal form of research invitation should be used. Despite this, the online form of collecting data proved to be efficient. It allowed fast data collection, a wide survey reach and easier data analysis.

In order to improve research data quality, the authors believe that the survey should contain only clearly defined questions, without open or multiple-choice questions. The best type of question for the analysis performed in this study was a question with closed binary answers.

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References

- [1] ArchitectureQuote. 2019. 100 Best Architecture Firms in the World [2019]. *ArchitectureQuote*. <https://architecturequote.com/blog/100-best-architecture-firms-in-the-world/>.
- [2] Bujak, Ł. 2008. *Drzewa decyzyjne*. Toruń: Wyd. UMK.
- [3] Cichocka, J., Browne, W., and Rodriguez Ramirez, E. 2017. Optimization in the architectural practice. An International Survey. *Protocols, Flows and Glitches, Proceedings of the 22nd International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2017*, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), 387–397.
- [4] DesignRulz. 2017. Top 100 Most Innovative Architecture Firms to Work For. *DesignRulz*. <https://www.designrulz.com/best-architecture-firms/>.
- [5] Flach, P.A. and Lachiche, N. 2001. Confirmation-Guided Discovery of First-Order Rules with Tertius. *Machine Learning* 42, 1, 61–95.
- [6] Hall, M., Frank, E., Holmes, G., Pfahringer, B., Reutemann, P., and Witten, I.H. 2009. The WEKA Data Mining Software: An Update. *SIGKDD Explor. Newsl.* 11, 1, 10–18.
- [7] Lynch, P. 2017. These are the Top 300 Architecture Firms in the US for 2017. *ArchDaily*. <http://www.archdaily.com/876808/these-are-the-top-300-architecture-firms-in-the-us-for-2017>.
- [8] Mangiafico, S.S. 2016. R Handbook: Measures of Association for Nominal Variables. *rcompanion.org*. https://rcompanion.org/handbook/H_10.html.
- [9] Nisztuk, M., Kościuk, J., and Myszkowski, P.B. 2019. The survey data and correlation graphics. http://elisi.pl/wp-content/uploads/2020/01/survey_answers_nominal_values.zip.
- [10] Nisztuk, M. and Myszkowski, P.B. 2017. Usability of contemporary tools for the computational design of architectural objects: Review, features evaluation and reflection. *International Journal of Architectural Computing*, 58–84.
- [11] Nisztuk, M. and Myszkowski, P.B. 2019. Hybrid Evolutionary Algorithm applied to Automated Floor Plan Generation. *International Journal of Architectural Computing*.
- [12] Quinlan, J.R. 1993. *C4.5: Programs for Machine Learning*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.
- [13] R Core Team. 2019. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.
- [14] Słyk, J. 2014. Eksperyment, symulacja-techniki projektowe i wyzwania edukacyjne. *Kwartalnik Architektury i Urbanistyki* 59, 2, 11–24.
- [15] Słyk, J. 2015. Methodology of architectural design and rules of cooperation in the digital environment. Augmented space as a field of research and alternative environment for architectural creation. *Architecture Civil Engineering Environment* 4, 11–18.
- [16] Słyk, J. 2019. Architektura Eksperymentalna? *Rzut Kwartalnik Architektoniczny* 3, 1.
- [17] Vitruvius Pollio and Morgan, M.H. 1960. *Vitruvius: the ten books on architecture*. Dover Publications, New York.
- [18] Witten, I.H., Frank, E., Hall, M.A., and Pal, C.J. 2016. *Data Mining, Fourth Edition: Practical Machine Learning Tools and Techniques*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.
- [19] Wortmann, T. 2019. Architectural Design Optimization – Results from a User Survey. *KnE Social Sciences*, 473–483.