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THE PROBLEMS WITH THE APPLICATION OF CONTEMPORARY SOFTWARE FOR THE ANALYSIS OF SHADOWING OF ARCHITECTURAL OBJECTS

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Abstract
The article deals with the issue of the application of modern shading analysis methods using computer software. Obtaining the optimal exposure of buildings in the urban context, issues related to insolation of rooms and meeting other requirements regarding access to natural light are an extremely important element of design work. Despite the high rank of the above issues, in practice designers rarely have the opportunity to verify their theoretical analyses with the results obtained *in situ* during and after the construction of the facility. The need for this type of verification can be imagined in the case of claims by users. However, it is not easy to implement, because in reality the measurement would have to take place on specific days of the year and under favourable weather conditions. This article summarises the results of sample tests, generated with the most commonly used programmes and field tests in nature using simple observational research methods. The obtained data revealed significant measurement discrepancies. The comparative analysis of the obtained results clearly indicates the need for a more critical look at the effects of using modern tools in the work of architects. This article is the result of the initial stage of the author's research, ultimately aimed at the use of a wider spectrum of methods on a larger scale, on the examples of real architectural objects.

Streszczenie
W artykule poruszono problematykę zastosowania nowoczesnych metod analizy zacienienia z wykorzystaniem oprogramowania komputerowego. Uzyskanie optymalnej ekspozycji budynków w kontekście miejskim, zagadnienia związane z nasłonecznieniem pomieszczeń oraz spełnieniem innych wymagań dotyczących dostępu do światła naturalnego są niezwykle ważnym elementem prac projektowych. Pomimo wysokiej rangi powyższych zagadnień, w praktyce projektanci rzadko mają możliwość weryfikacji swoich analiz teoretycznych z wynikami uzyskanymi in situ w trakcie i po zakończeniu budowy obiektu. Potrzebę tego typu weryfikacji można sobie wyobrazić w przypadku roszczeń ze strony użytkowników. Nie jest ona jednak łatwa do realizacji, gdyż w rzeczywistości pomiary musiałyby odbywać się w określonych dniach roku i w sprzyjających warunkach atmosferycznych. W artykule podsumowano wyniki przykładowych badań, wygenerowanych za pomocą najczęściej stosowanych programów oraz badań terenowych w naturze z wykorzystaniem prostych metod badań obserwacyjnych. Uzyskane dane ujawniły istotne rozbieżności pomiarowe. Analiza porównawcza uzyskanych wyników wyraźnie wskazuje na potrzebę bardziej krytycznego spojrzenia na efekty stosowania nowoczesnych narzędzi w pracy architektów. Niniejszy artykuł jest wynikiem wstępnego etapu badań autora, docelowo zmierzających do wykorzystania szerszego spektrum metod w większej skali, na przykładach rzeczywistych obiektów architektonicznych.

Keywords: shading analysis; architectural software; dense urban fabric

Słowa kluczowe: analiza zacieniania; oprogramowanie architektoniczne; gęsta tkanka miejska

INTRODUCTION

Proper exposure to solar radiation is one of the key elements affecting human functioning, as well as all living organisms. Both deficiency and overexposure to the sun are not beneficial.

In architectural practice, issues related to access to natural light and legal regulations regarding daylighting, insolation of rooms, shading, covering, etc. are one of the basic parameters that designed buil-

dings must meet. These issues are analysed already in the phase of spatial planning on an urban scale, and then they should be the subject of detailed research at further stages of making decisions about the form of buildings, elevations, interior layouts, etc.

Currently, the basic tool of the designer's work is a computer with software to support the entire process. Traditional research methods, such as the line of the sun, described by Mieczysław Twarowski in his book *The Sun in Architecture* in the 1960s [M. Twarowski, 1960], are extremely rarely used in the design practice.

BIM technologies are already becoming a standard displacing more traditional two-dimensional design. These are more and more advanced tools that give a huge range of possibilities, thanks to which architects can enter ever higher levels of awareness of the effects of their work. The research problem undertaken by the author of this article is an attempt to verify the correctness and credibility of the results of shading analyses performed with the use of available computer programmes. Similar issues, but in a more general approach, were presented by the author of the article published in the magazine "Architektura–Murator" [J. Rojek, 2020], which describes the imperfections of individual methods and inaccuracies related to the interpretation of the law in force in Poland.

The aim of this work is an attempt to assess the usefulness in terms of measurement precision of modern tools in the hands of architects, with the help of which the requirements for the designed objects should be met. Designers must be sure that the calculation results of the computer programmes they use are fully reliable.

Depending on the geographical location of buildings, the needs of their users change, this should be taken into account when designing them. Not often enough emphasis is placed on these aspects in architectural education. Also in professional practice, the vast majority of architects operating on the local market, where there are specific – seemingly constant – requirements, often lack in-depth reflection on this subject. However, the profession of an architect has always been international and in the current, increasingly globalised reality, the involvement of design offices in the implementation of investments in remote places, even in distant locations of our planet, is more often observed. For this reason, the studies presented in this publication have been carried out in different countries in order to obtain more diverse results.

The author of this article observed with great interest the fundamental differences in the functional arrangement of rooms in relation to cardinal directions during his first stay in another hemisphere. In March 2020, during a trip to Bolivia in South America, with full awareness of geographical differences, the position of the sun at noon and the related consequences in the surrounding space aroused considerable surprise. All the rules and habits regarding the functional layout of buildings, learned from education at a European faculty of architecture, and then through years of practice only in the northern hemisphere, should be 'filtered' there, as it were, through a mirror reflection. It was then that the idea of expanding knowledge in this area and empirically checking the seemingly obvious facts resulting from the changing conditions of insolation in various locations was born.

The issues mentioned above indicate the need not only for in-depth reflection on the proper use of insulation and natural light, but also for taking conscious actions using the available resources. In our dynamically changing reality, it is worth paying more attention to these problems.

1. REQUIREMENTS, STANDARDS, LEGISLATION

Design standards and legal conditions related to insolation, shading, etc. vary from country to country. In this article, the author briefly describes the requirements applicable in Polish conditions. Due to the geographical location, the problem of the inhabitants of this part of Europe is much more often the lack of natural light than its excess.[1] Design standards and trends in Poland still largely focus on the maximum exposure of rooms to the sun. Also in legal regulations we can find requirements relating only to minimum values, on the principle 'the more sun, the better'.

It looks different in other countries (even with similar climatic conditions), where design guides from the 1930s contain information about the nuisance associated with excessive exposure to sunlight, and thus about overheating of rooms, and effective methods of reducing these phenomena [E. Neufert, 2011, p. 501].

Several decades ago, the negative aspects of excessive insolation were almost completely margina-

[1] Statistically, the number of sunny days in Poland is 66 per year, and the number of sunny hours on these days is estimated at about 7 hours. Source: https://www.weatheronline.pl/weather/maps/city?WMO=12375&CONT=plpl&LAND=PL&ART=SON&LEVEL=162&MOD=tab (Access 2022.12.10)

lised. Only the healing and pro-health effect of sunlight on living organisms was indicated [M. Twarowski, 1960, pp. 7-8]. It was only in the 1980s that the topic of the growing ozone depletion, responsible for the increase in the intensity of harmful UV radiation, the increase in the concentration of carbon dioxide in the atmosphere, and thus the global increase in temperatures, appeared in the public and scientific discourse. The currently observed increase in the number of skin cancer cases is alarming. Social awareness of the need to protect against the sun is clearly growing, even in temperate climate zones.

Today, the problem of excessive increase in interior temperatures in summer periods is increasingly being pointed out, which is associated with the installation of costly and energy-intensive air conditioning systems. However, there is a whole arsenal of proven architectural solutions and interior design elements operating on the principle of passive protection against the sun (shading screens, vegetation, shielding pergolas, awnings, sun glasses, blinds, curtains, etc.), the use of which in combination with the proper orientation of the building, properly selected thermal insulation and optimisation of the size of window openings can significantly reduce the effect of overheating of rooms. These solutions are more and more often consciously implemented in architectural designs and appear in completed buildings.

In Poland, the current regulations governing the issues related to the shading of buildings and insolation of rooms are set out in the Regulation of the Minister of Infrastructure of April 12, 2002. on the technical conditions to be met by buildings and their location [Polish Journal of Laws of 2022, item 1225].

Pursuant to §13, the distance of the building with rooms intended for people to stay from other objects should allow natural lighting of these rooms. In the following expansion, the section describes the rules for determining the distance between buildings depending on their height and location in relation to each other and other elements, based on geometric relationships between the obscuring and obscured objects. The legislator states that adapting to the given rules will allow meeting the requirements regarding the provision of 'natural lighting'. In the light of the regulations, however, this is not the same as 'insolation'.

Another provision concerning 'daylighting' in this legal act is §57, stating that a room intended for people should be provided with daylighting, adapted to its purpose, shape and size, and specifying the minimum area of windows to the floor surface.

The requirements for the minimum time of direct access to the sun in rooms intended for people are regulated by §60, according to which at least 3 hours of sunlight should be provided at specific times on the days of the equinoxes. In multi-room apartments (and the vast majority of them are), it is enough that this condition is met in one room. In downtown buildings, these requirements are reduced by half (i.e. to 1.5 hours), and in relation to one-room apartments in such a location, the time of insolation is not specified at all.

It should be stated that these provisions are not perfect and contain many inaccuracies, which in turn leads to discrepancies in interpretation. The genesis of this form of legislation and its critical analysis can be found in many scientific publications. However, this is not the subject or purpose of this article and requires separate research.

2. ARCHITECTURAL PRACTICE

The creation of space is usually the result of a compromise between the investor's expectations, budget possibilities, planning constraints, etc. In most cases, economic reasons come to the fore. Real estate prices and the capital associated with them force designers to find solutions that are primarily profitable in terms of investment, and land absorption analyses maximising PUM[2] indicators are usually the basic design guideline. With this type of initial assumptions, a very compact architecture is usually created (which is sometimes a positive effect) with maximum building intensity parameters. In such a 'compact' space, there is no room for a little breath, for 'unnecessary' square meters, both inside and outside. There is no room for flexibility there. Ensuring proper insulation parameters in such a compact development is a difficult task given the current, imprecise regulations, especially in the case of buildings with complex forms.

As mentioned above, issues related to the proper insolation of architectural objects[3] are an extremely important aspect in design work. Along with technological progress, the tools of work change. Computers in the work of architects began to be used in the 1980s. However, only the development of three-dimensional BIM software made it possible to perform realistic spa-

[2] PUM - Polish abbreviation for Usable Residential Area, which is the most important indicator for most modern developers, determining the level of investment profits.
[3] It is not only about buildings, but also small architecture objects, greenery, etc.

tial models, and then multi-criteria analyses, including the impact of natural and artificial light on the designed forms.

Before obtaining a building permit, designers must prove in the documentation that the planned investment meets all legal requirements. One of the elements is the analysis of shading and insolation. Already at the investment planning stage, these issues can be a source of conflicts, especially in the case of 'densifying' the already existing buildings. In order to ensure that the architectural administration body meets the requirements set out in the regulations, reliable analyses must be included in the design documentation. It should be noted that there is no single method for calculating the legal period of sunshine. An architect should be 100% sure of the unconditional credibility of the effects of his work using specific tools. Hence, there exist questions and doubts about the reliability of the results generated by computer programmes. Errors at the design stage are extremely difficult to fix at the later implementation stage.

The impact of the issues analysed in the article on architectural practice may turn out to be enormous. In addition to the already mentioned aspects related to the proper insolation of rooms, there are also other issues, e.g. related to the effective use of devices in the designed facilities producing renewable energy. In order to obtain sunlight as an effective power source, designers must have precise tools to support accurate spatial simulations. The effects of inaccurate assumptions regarding solar exposure at the design stage may not only have an economic dimension, but also legal consequences related to failure to achieve the assumed parameters in the actual operation of buildings.

3. RESEARCH METHOD

The author's study was based on simple observational techniques, the results of which became the basis for several-stage comparative analyses. The research material was the measurements documented with photographs obtained by the research team consisting of people who had no contact with each other.

The author invited volunteers living in various places around the world to conduct research, giving identical instructions for completing the task. The participants were asked to measure the length of the shadow cast on a horizontal plane by a straight vertical pole one meter long and the angle of this shadow from the north direction.[4] The date of the study was selected on June 21, the day of the summer solstice, at 12:00 local time and at astronomical noon (different time for different latitudes).

Satisfactory research material was obtained from the following locations: Poland - Białystok; Spain - Logroño, La Rioja; Kosovo - Gjakova; Canada–Toronto; Bolivia-Cochabamba; USA - Piermont, NY; Brazil - Curitiba.

Due to unfavourable local weather conditions, the task could not be carried out in all planned locations. On a specific test day, in Russia (Moscow and St. Petersburg), Australia (Sydney), the sky was completely cloudy on that day. For various reasons, not all collected materials were subjected to the next stages of research. The effects of the measurements were recorded using photographs.

The quality of the photographs received from individual participants varied, but it was possible to select for further analysis good enough shots from most of the locations covered by the study.

In the next stage, the collected photographic material was digitally processed, as a result of which the angular values between the north direction and the shadow cast by the pole, as well as the shadow length readings were obtained.

The next step was to conduct the above study in virtual space by means of popular computer programmes used by architects. Students of the Faculty of Architecture at Bialystok University of Technology, fluent in using the indicated tools, were asked to perform the exercise. The selected programmes were: Sketchup, Archicad and Revit. They all have a built-in shading analysis module. With the assumption of identical output parameters, simple three-dimensional models were built, and then measurements of the length of the shadow cast by the pole and its deviation from the north direction were made, independently in each of the programmes. During the exercise, the students did not contact each other, they did not have the opportunity to compare their results with others.

4. VERIFICATION OF RESULTS

The collected research material was grouped according to the location and time of the research, and then the results obtained with the use of individual tools were summarised in the form of a table presented below.

[4] This is a simplification for the purposes of researching the concepts:
'azimuth' – the angle between the projection of the direction of the sun's ray on the plane of the horizon and the direction of the south, and 'altitude' – the angle between the direction of the sun's ray and the horizontal plane.

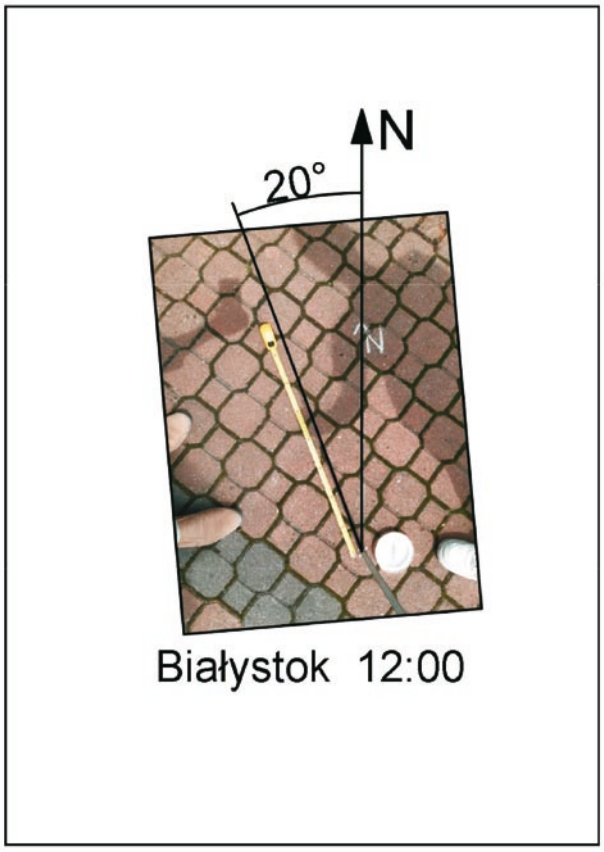

Fig. 1. Shadow measurement in Białystok, Poland at 12:00; source: photo by the author, 2020.06.21

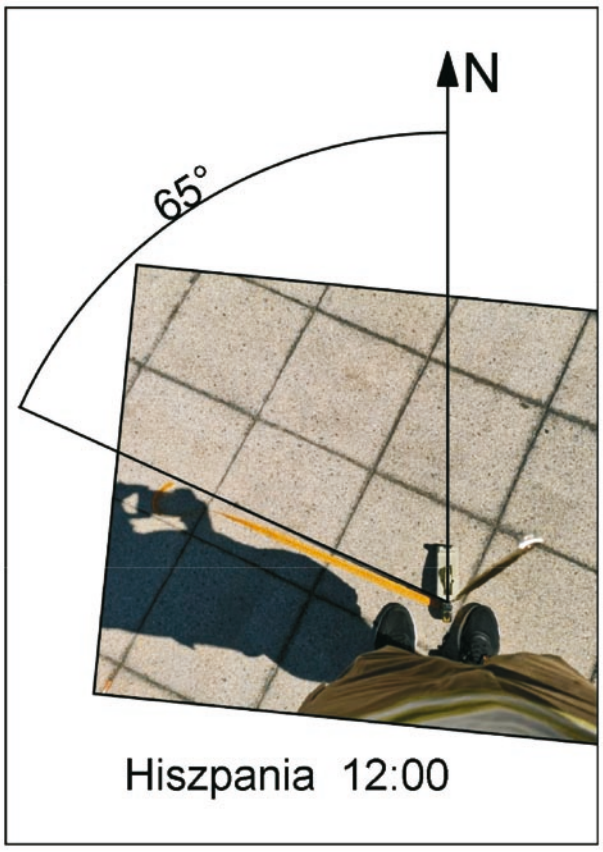

Fig. 2. Shadow in Logroño, La Rioja, Spain at 12:00; source: photo by J. Angel, 2020.06.21

Fig. 3. Shadow measurement in Toronto, Canada at 13:19 (astronomical noon) ; source: photo by J. Maliszewski, 2020.06.21

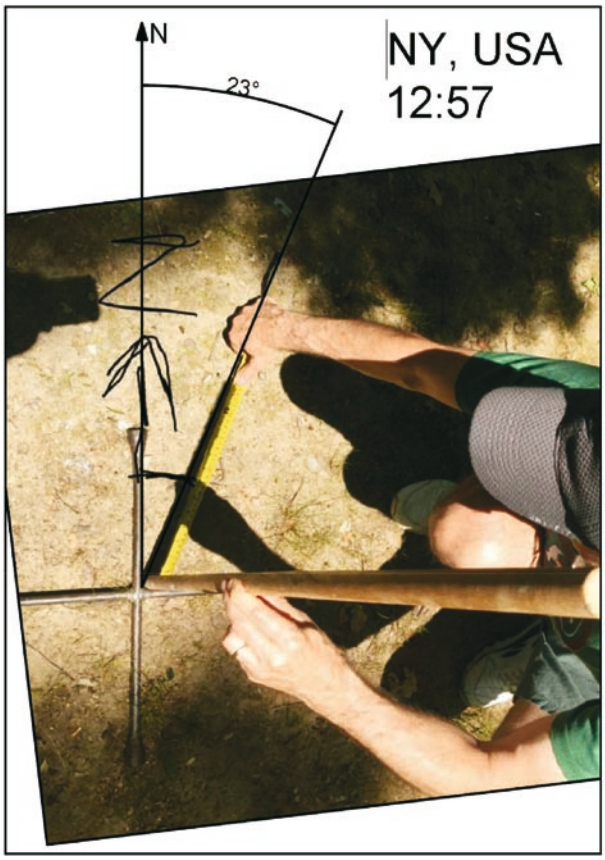

Fig. 4. Shadow measurement in Piermont, NY, USA at 12:57 (astronomical noon); source: photo L. Wiszowaty, 2020.06.21

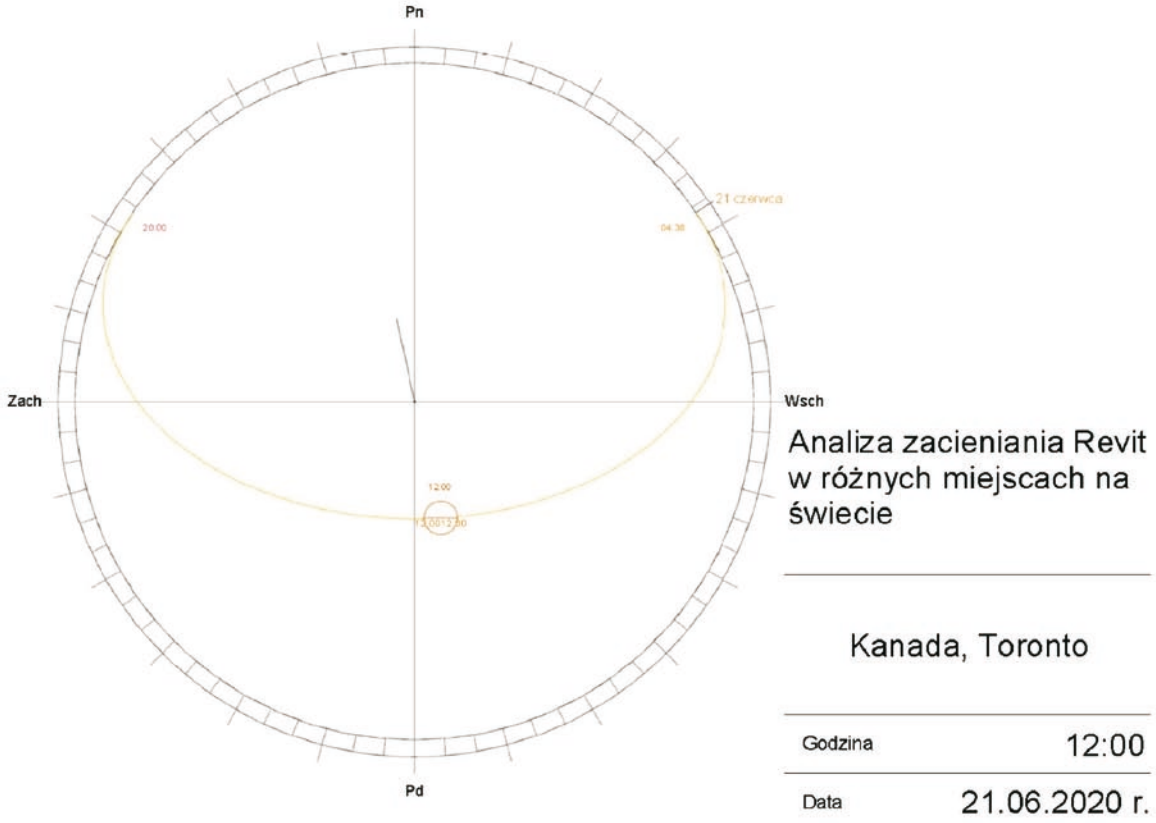

Fig. 5. One of the results of exercise with students of Faculty of Architecture BUT.

Differences between the results obtained with the use of individual tools were found in all the locations studied. Particularly large discrepancies were noted in the measurements of angular values. In the case of the tested lengths of the shadow cast on the horizontal plane by a one meter pole, it was assumed that deviations of values not exceeding 5 cm are acceptable[5] - these results are marked in the table by bold and underlined fonts. It should be realised, however, that with such a margin of error, with the height of a real building 10 meters high, it would give differences in results of about 50 cm.

Interpretation of length results

It is difficult to clearly indicate the most reliable tool, although the statistics show that the number of similar results obtained using SketchUp and Archicad programmes is the largest. The value of the shadow length measured physically during the experiment in nature should be quite accurate. This is due to the simplicity of the test and the nature of the components that affect the result.

In view of the above facts, it can be assumed that the measurements of the actual length of the shadow in specific locations using 'natural' readings are correct and can provide a reference to the results obtained using computer programmes. It is found that the number of divergent results is significant.

Interpretation of angular value results

The results of the study of the angle of the shadow's deviation from the north direction are quite difficult to interpret. In contrast to the field studies relating to the length of the shadow, if the correct angular value is determined, the results may be subject to more errors. It could be problematic to precisely determine the direction of north. Individual participants of the experiment used different tools to indicate cardinal directions. During field research, not all participants had the opportunity to determine the angular value. This measurement was carried out by analysing photographs during subsequent digital processing using the AutoCAD programme.

[5] It is a subjective assessment adopted by the author, enabling the creation of a set of similar results. This discrepancy is not acceptable in practice, especially when referring to buildings of considerable height.

Table 1. The results of the study of the length of the shadow and the angle of deviation from the north direction using the experiment in nature and comparison with the results generated by computer programmes.

Country	City	Geographical coordinates		Hour of test (local time)	Reading from nature		Revit results		SketchUp results		Archicad results	
		Latitude	Longitude		Length of shadow [cm]	Azimuth	Length of shadow [cm]	Azimuth	Length of shadow [cm]	Azimuth	Length of shadow [cm]	Azimuth
Poland	Białystok	53.15	23.12	12:00	58	20	58.5	14	58.2	13.4	58.15	14
				12:29	61	8	62	27	57	0.1	61.72	13.2
Spain	Logroño, La Rioja	42.46	-2.42	12:00	73	65	37	306	60.8	3.8	81.08	82.39
				14:11	31	24	34	48	24	0.8	28.71	36.28
Kosovo	Gjakova	42.38	20.42	12:00	41	16	35.5	14	37.8	26.9	35.31	13.48
				12:40	37	18	42	38	34.3	0.1	41.5	38.19
Canada	Toronto	43.76	-79.41	12:00	41	22	37.5	348	48.9	45.4	37.74	12.42
				13:19	36	332	44	36	36.9	0.5	43.69	35.94
Bolivia	Cochabamba	-17.39	-66.14	12:00	88	154	103.5	208	88	9.3	87.8	188.89
				12:26	86	167	94.5	200	86.4	0.2	86.29	180
USA	Piermont, NY NY State	41.03	-73.91	12:00	44	34	31	2	39.1	38.9	32.10	2.2
				12:57	35	337	39.5	40	31.7	0.5	39.51	39.64
Brazil	Curitiba	-25.44	50.58	12:00	122	176	130	203	123.8	7.2	115.40	185.4
				12:19	119	N/A	123.5	198	122.3	1.6	114.67	179

Source: prepared by the author

However, the results obtained using computer programmes alone are also significantly different. Even when using fieldwork as a benchmark, there is a surprising amount of discrepancy.

It is stated that the scale of discrepancies is significant. The obtained research results should be a source of reflection on the credibility of the results obtained with the use of various tools.

Obviously, the possibility of human error cannot be overlooked. Despite the diligence and reliability of the work of the students invited to conduct the research, it is impossible to rule out possible irregularities in the use of selected computer programmes.

However, it is indisputable that a vast majority of the compared research results indicate a discrepancy between the obtained values. The author of the article has not encountered similar attempts made using several tools in his previous scientific work and professional practice. Typically, architectural offices use one selected software. The purpose of the experiment was not to select and indicate the most reliable tool, but to objectively compare the results of the research and attempt to draw conclusions.

CONCLUSIONS

The research results presented in this article indicate that there is a clear dissonance between the theoretical assumptions based on computer calculations and the results in nature. This is a worrying phenomenon, as it leaves room for interpretation. There are questions about the scope of responsibility of software developers for possible discrepancies between the design made using specific tools and their subsequent verification on the completed facility.

As a result, it may turn out that it is not possible to actually meet the stringent requirements precisely defined in the law. This is particularly important in the light of the current trend of high intensification of development density, where there is no room for the so-called 'margin of error' or 'safety factor' protecting the designer and securing the interests of recipients of architectural space. Parameters specified in local legislation are usually used to the maximum, and even through their 'creative' interpretation, they are significantly exceeded, in order to 'optimise' economically. This usually happens at a loss for the quality of space and the comfort of future users.

The issues of measurement inaccuracies go beyond the field of architecture. In everyday life, differences can often be encountered in the readings of various parameters and results. An example may be temperature or weight measurements using modern electronic measuring devices. Interestingly, more confidence is usually rested in analogue meters, and incorrect indications of the above parameters can have negative consequences for human health.

The issues raised by the author are broader than the scope described in this article, hence further research on the issue presented in this text is planned. This publication is an introduction to further, in-depth studies based on specific cases of real buildings on a larger scale, carefully surveyed, which will allow for more precise results and the use of a wider spectrum of available tools.

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