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THE EVALUATION AND JUSTIFICATION OF THE EFFECTIVENESS OF 4D CAD USING MULTI-CRITERIA ANALYSIS

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Abstract. The article presents the results of the analysis focused on the effectiveness of 4D CAD the phenomenon of which has been analysed by foreign scientists considering a number of different aspects. The conducted research differs from prior literature as the objective, in our case, was to evaluate effectiveness and justify results using multi-criteria analysis. Effectiveness has been investigated through the construction experiment observing group performances applying two different types of information – 2D CAD and 4D CAD drawings. Research findings have proved that the efficiency of using the 4D model has been doubled given the same time constraints when the evaluating the completeness of the construction object. Research results have also showed that the use of the 4D model helped with completing the construction of the object much faster. A comparison of the results of the participants of two groups has revealed that the use of the 4D CAD model has twice reduced the occurrence of mistakes in the construction process and helped the participants with faster detecting and fixing the errors they made. TOPSIS, SAW and CORPAS multifunctional solution making methods were employed for 2D and 4D ranking during the experiment on 4D efficiency. The findings confirm that the 4D model is more rational, more convenient and efficient than the 2D model regarding all results of statistical and multi criteria analysis.

Keywords: 4D CAD, 2D CAD, 3D CAD, BIM, effectiveness, multi-criteria analysis, decisions making.

Introduction

Information sharing and proper modelling have always been a challenge in the construction process. The evolvement from the idea in the architect's mind to the completion of the physical building is a complex process. There is a need for better information sharing tools between the participants of various projects that would help with solving problems and improving different skills. 4D CAD design can help with increasing the effectiveness of communication and reducing improper interpretation opportunities in the construction project.

A large number of research projects addressed efficiency issues in construction processes in accordance with the provision that one of the conditions for maintaining efficiency on the construction site was to effectively manage time and material resources. Wang *et al.* (2004) researched 4D application for dynamic construction management and emphasised the importance of the efficient use of resources in the planning process. Maa *et al.* (2005) examined 4D application for planning a dynamic construction management site and construction projects. Jongeling and Olofsson (2007) analysed the possibility of scheduling work flow using two methods such as the process of planning work at a construction site and the 4D CAD model. Tantisevi and Akinci (2006) discussed requirements for the workspace of mobile crane operations to avoid conflicts. Russell *et al.* (2009) introduced the use of 4D CAD for multi-storey building visualization and linear planning. Mahalingam *et al.* (2010) evaluated the applicability of the 4D CAD model for construction design. Turkan *et al.* (2011) were more interested in automated monitoring of the construction process using 4D planning and 3D design technologies. Ku and Taiebat (2011) proved the relevance of 3D, 4D and 5D CAD as well as the need for construction industry by analysing a wide scope of applications of these models in construction industry in the USA.

There are only a few studies on the 4D CAD model in the Lithuanian language. Furthermore, 4D CAD is almost has not been put in practice in Lithuania. The number of items designed using the 4D model is minimal and has been applied only to multi-storey buildings such as the project on the complex of Vilnius city municipality buildings and made by UAB "In Re" which is one of the representatives of the 4D CAD program in Lithuania. The evaluation of the efficiency of 4D CAD has not been properly conducted in Lithuanian construction industry. A new approach to 4D was presented by Liaudanskiene *et al.* (2012) who used this model for studying a possibility of reducing safety issues thus determining not only time but also financial losses. The maximum input, while

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establishing the efficiency of an innovative construction sector and assessment decisions, was made by Migilinskas and Ustinovichius (2006, 2008), Popov *et al.* (2010). The authors were looking for ways to enhance efficiency using computer technologies in design and put an emphasis on the need to use methods for determining which part of the construction process or the actions of influencing factors were the most important.

The purpose of research is to evaluate the effectiveness and justification of 4D CAD using multi-criteria analysis.

The goals of research cover:

1. Description of the concept of 4D CAD and its application in Lithuanian and foreign scientific literature;

2. Analysis of the 4D CAD model taking into account an academic aspect;

3. Evaluation of the performance of the model comparing modelling tools for 2D and 4D construction;

4. Estimation of the applicability of decision making methods to assessing 4D effectiveness.

Research methods include the analysis of academic literature evaluating 4D CAD application research projects carried out both by foreign scientists – 4D model founders in the field of design (Collier, Fischer 1995) and by examining the evaluation of the latest four-dimensional performance (Mahalingam *et al.* 2010; Turkan *et al.* 2011, etc.). The use of decision-making methods, in terms of 4D effectiveness, was analysed by Migilinskas and Ustinovichius (2006, 2008) and by Popov *et al.* (2010) presenting the results of the study.

1. The process of evaluating an experiment on 4D CAD efficiency

Stage 1. A model of Lego blocks *Apple Tree House* was used as a construction object. A simplified model of the house without eliminated welfare elements (trees, bushes, benches, basketball stand) and additional house elements (satellite antenna, outdoor lamp) was applied. Windows, doors and garage door components supplied to the participants were fully completed and merging into a whole. The model of the house consisted of 330 Lego bricks and was chosen to be employed for several reasons: kits containing Lego blocks are well known, easy to use and need no additional time to become proficient, unlike the use of little-known or complex constructors. Lego blocks are convenient to imitate bricks that are supposed to be one of the basic construction tools. Lego blocks allow creating a realistic image of the house, are easy to assemble and take apart. Parts vary in size, colour, shape and enables participants to distinguish them faster and easier to use as a counterpart of construction elements.

Stage 2. 2D and 4D design software were selected for designing the experimental task. Autodesk Revit 2011 design software, allowing 2D and 4D drawings, were chosen.

Stage 3. 2D and 4D *Apple Tree House* model drawings were created (see Table 1). Graphic drawings were produced in 40 hours.

Stage 4. The participants of the experiment were selected. The respondents were third-year full-time students of civil engineering. Justification for targeted selection was due to knowledge of civil engineering and the ability to understand and use graphical information contained in both 2D (Fig. 1) and 4D CAD (Fig. 2) formats. 28 participants were chosen. They were randomly grouped into 14 groups (2 participants in each group) to set up teamworking. 14 groups of the participants were randomly divided into 2 subgroups. The first 7 groups got 2D CAD drawings and other 7 groups entered the 4D group and got 4D CAD drawings.

Table 1. List of 2D and 4D drawings

2D CAD drawings	4D CAD drawings
Plan of the first floor (Line 1)	4D construction stages (1 & 2)
Plan of the first floor (Line 7)	4D construction stages (3 & 4)
Plan of the second floor (Line 11)	4D construction stages (5 & 6)
Plan of the second floor (eastside of the roof)	4D construction stages (7 & 8)
Plan of the roof	4D construction stages (9 & 10)
East elevation	4D construction stages (11 & 12)
West elevation	4D construction stages (13 & 14)
South elevation	4D construction stages (15 & 16)
North elevation	4D construction stages (17 & 18)
Section 2-2	4D construction stages (19 & 20)
Section 1-1	4D construction stages (21 & 22)
	4D construction stages (23 & 24)
	4D construction stages (25 & 26)
	4D construction stages (27 & 28)

Stage 5. The experiment was performed. The instructions for the experiment were delivered and presented to the participants, including the objective of the carried out investigation, the role of the participants in the experiment and the task to be performed. The participants of the experiment filled the application in the questionnaire indicating the age, practical work experience in the field of construction and completion time for the experiment. The respondents were introduced to CAD drawings applied for the experiment. The 2D subgroup of participants included 2D CAD drawings (see Table 1). The 4D subgroup of participants covered construction drawings of the 4D CAD building model numbered at different stages: the Lego house were divided into 28 stages (see Table 1).

The task of the experiment at the first stage: students were given 5 minutes, including drawing access, debates in groups and discussion of the overall progress of the group.

The task of the experiment at the second stage: construction work on the *Apple Tree House*. The second stage involved building a house consuming the least amount of time and making the fewest amount of mistakes. The maximum allowance of time was set for construction work of the model within 60 minutes. The goal of experimental groups was to complete construction projects within limited time.

The tools used during the experiment embraced 4D CAD and 2D CAD drawing packages, *Apple Tree House*

Lego blocks, a stopwatch to record time spent by each group to build the house, a video camera to capture the process and a questionnaire for evaluating the completion of the experiment thus noting the time of completion and recording the number of mistakes of the rebuilt blocks.

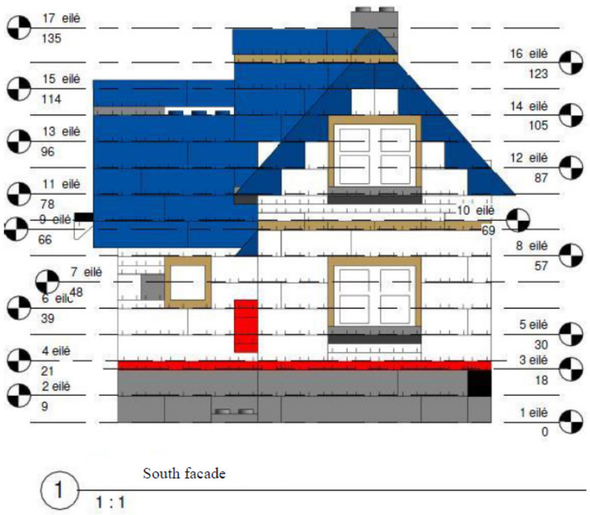

Fig. 1. An example of the 2D group drawing (translation – "eilė" means row)

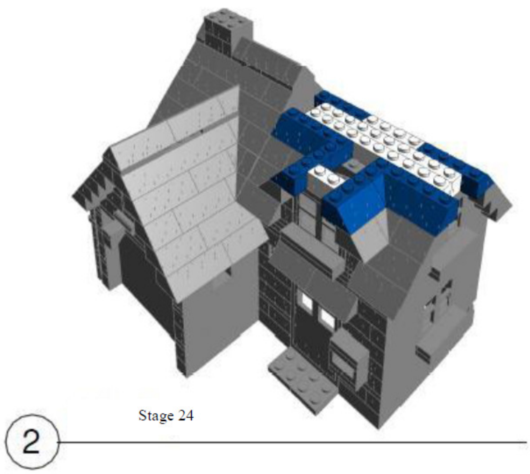

Fig. 2. An example of the 4D group drawing

Stage 6. The evaluation of the experiment. Evaluation criteria.

The participants of the experiment were given a chance to voice their opinion about the time required for task completion.

The construction time of the house model was discussed, in case it was built faster than the given time limit.

The percentage of model completeness was calculated in accordance with the used and unused LEGO bricks:

$$I = \frac{N}{B} \cdot 100\%, \quad (1)$$

where: I – the percentage of model completeness; N – the number of used blocks; B – the total number of blocks.

The number of rebuilt construction elements (Lego pieces) is the actual number of changed or revised elements during the construction process.

The accuracy of the model is calculated by the formula:

$$T = \frac{N}{NK} \cdot 100\%, \quad (2)$$

where: T – the accuracy of the model (in percentage); N – total number of blocks (Lego pieces); C – the number of incorrectly used construction elements (Lego pieces).

Stage 7. Decision-making methods (SAW, COPRAS and TOPSIS) were used for assistance in supplementing and specifying experimental results.

2. Efficiency of the four-dimensional model

Efficiency is the usage rate of manufacturing resources so that to ensure maximum results. Allocative, technological and dynamic efficiency can be achieved through balancing production resources. Allocative efficiency means that resources are distributed for the maximum benefit of production in order to get service delivery results. Technological efficiency covers minimizing losses in the absence of the best use of available resources. Time factor is one of the parameters used for evaluating effectiveness and has been analysed in foreign and Lithuanian scientific literature. The problem of time scarcity and management is the major one faced today. This view is also supported by scientists analyzing the 4D model. Coherent construction planning and the effective use of a building site are important factors in site planning and construction of buildings. Nowadays, complex projects must be planned with plenty of project participants and controlling persons. According to Jongeling and Olofsson (2007) who analysed construction practice in Sweden, only 15–20 per cent of the construction process consists of direct labour time on the site. About 45 per cent of work time, including preparing, instruction and training as well as the management of construction materials, is spent on indirect work. The remaining 35 per cent of time is dedicated towards the correction of errors, downtime and delays qualified as inefficient time in general. Cheng and Teizer (2013) agree that that 4D model helps with minimizing time costs and facilitates the availability of data on real-time resources.

Wong and Fan (2012) presented the effectiveness of the building information model (BIM) considering another aspect which is the difference between demand for labour power in the structure of the design process (see Fig. 3). In contrast to the previously mentioned performance on time trials, Wong and Fan (2012) presented the initial design stage (up to the full creation of the 3D model) showing that BIM technology requires significantly more labour resources than the traditional (2D) design model. Preparing separate parts such as sections, elevations and specific parts (heating, ventilation, electricity, etc.) is a breakthrough application the workforce needs.

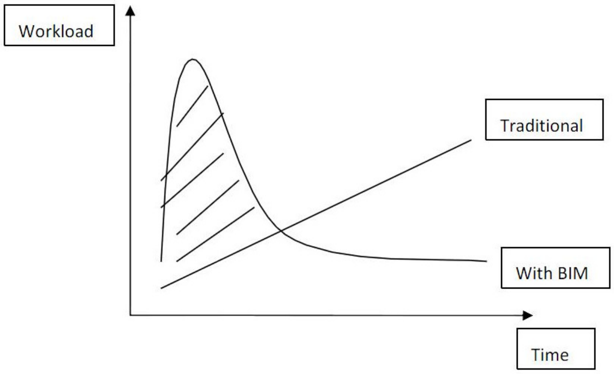

Fig. 3. Workload using traditional and BIM design (Wong, Fan 2012)

According to Chau *et al.* (2005), 4D SMM (four-dimensional site management model) and 4D GCPSU (graphics for construction and site utilization) graphical construction tools for construction and a building site, as 4D model products used in practice, allow improving the efficiency of the construction process. The increased efficiency of construction processes is ensured by: 1) maintaining a possibility of multi-user data exchange and the concept of avoiding conflicts in the integrated system; 2) assessing a possibility of the conflict of construction processes, management functions and structural safety problems; 3) specifying material characteristics of building's elements and indicating loads operating points.

Kang *et al.* (2013), Zhou *et al.* (2013) suggest that 4D model helps in making construction processes more efficient because of the possibility of evaluating risks and preventing safety mistakes.

Dawood and Sikka (2008) analysed the efficiency of the performance of the 4D model accepting time factor as an assumption about an increase in efficiency. The authors used a model for a Lego house for their studies. Time-cycle cost differences achieved by reducing the number of errors, the use of information intensity and correction costs using 2D and 4D design drawings were considered during the experiment when researchers found that the 4D model was more effective for several reasons. 4D information was understood faster and transmitted easier. 4D helps with making decisions faster through a better understanding of logical construction sequence taking into account all participants of the construction process. Dawood and Sikka (2008) were investigating the effectiveness of 4D and found out that perfection was 7 percent higher using the 4D rather than 2D model under the same time limit. The studies also demonstrated that the disclosure form of the 4D model was one of the conditions for efficiency, since information was understood 12 per cent better. Therefore, there was a lesser need for accessing information on the construction project using the 4D rather than 2D model. Error reduction is one of the biggest advantages of the 4D model. Errors decreased by 40 percent at the construction process while employing the four-dimension model compared to the two-dimension one. The researchers found that, to achieve higher efficiency during the construction process, in comparison to the two-dimensional model, the application of the 4D model allows shortening the duration of the construction process by approximately 7 per cent, improving the understanding of the construction process on average by 14 per cent, reducing time for drawing reading on average by 8 percentage and decreasing time for error correction by 67 per cent.

Liaudanskiene *et al.* (2012) pay attention to one 4D efficiency aspect that has been poorly researched in Lithuania as well as by foreign researchers in the context of 4D efficiency. The use of 4D gives an opportunity to minimize structural, technical and safety problems. To solve these problems, the authors offer using a three-stage tree diagram model.

As mentioned above, the academic analysis and practical use of the 4D model is a relatively new area of interest. This comes from the opinion that 4D design is suitable for the construction of complex objects such as multi-story buildings. Doner *et al.* (2011) represents another alternative to using the 4D model, which is geodesic design. Following the analysis of 4D application to the projects for geodetic purposes, the authors have based the design of an appropriate method and the need for increasing the complexity of land-use projects in the Netherlands.

The model of 4D design creates listed conditions for the effectiveness of the tools presented in the program. Xu *et al.* (2010) made comparisons of popular CAD programs with reference to the introduced different options (see Table 2).

Table 2. Most popular CAD programs

File format	Program	Information contained	Generality
DXF	AutoCAD	Geometry, colour.	Good
3DS	3DSMAX	Geometry, material, texture, lightening, animation, camera.	Much better
FLT	Multigen	Geometry, material, texture, lightening, animation, camera.	Much better
OBJ	Wavefront	Geometry, material, texture.	Common
WRL	VRML	Geometry, material, texture, lightening.	Better

Despite the effectiveness of the 4D model, comparing to the previous ones, it is not applied as often as it could be. And one of the reasons for the rare use of the 4D model is updating it in the construction process (Kim *et al.* 2013).

Migilinskas and Ustinovicius (2008) put emphasis on the benefits of 4D in the construction process, but point out that one of the most important problems encountered is uncertainty. According to investigators, it is very complicated to exclude a few similar factors that increase risk and uncertainty for the construction process each of which is unique in its nature and should be assessed individually by determining its inherent risks and uncertainties at different stages of the construction process. Turskis *et al.* (2009) state that the construction process is influenced by a variety of external factors difficult to quantify. In this case, the researchers recommend using multiple analysis models that should be applied at the construction stage and assessing planned decisions with the help of multiple criteria analysis techniques that can be chosen from a great variety of options. Turskis *et al.* (2009) recommend the LEVI 4 model. Professor Zavadskas (Vilnius Gediminas Technical University, Lithuania) a pioneer and developer of multi-criteria analysis agrees it is unlikely there is only one of the best multi-criteria evaluation models, and therefore recommends using several models (Podvezko 2011). One of the proposed options on analysis was the SAW (Simple Additive Weighting) method that is one of the most popular approaches due to its ease of use. While using the SAW method, the minimum values of the defined criteria must be evaluated before employing it and converting to the maximum value by the application of appropriate formulas. This disadvantage is eliminated using the COPRAS method developed by professors Zavadskas and Kaklauskas (1996).

To sum up, the 4D model creates conditions for planning demand for the best resources and the need to organize them in the construction process. Four-dimensional models help with reducing the number of errors. Time cost required for error reconstruction increases efficiency.

3. Evaluation of the efficiency of 4D CAD

For assessing the effectiveness of 4D, a similar experiment using Lego bricks was made by Dawood and Sikka (2008). The strong similarity of the conducted experiments is assessing the effectiveness of 4D. However, the main difference between the carried out experiments is that Dawood and Sikka (2008) focused on communication between the participants of the construction process with limited access to information during the experiment and on the evaluation of the ability of the participants involved in the experiment to restore the provided information in different formats.

The study on the efficiency of 4D suggests that the made experiment and the obtained results were evaluated based with reference to several key aspects: model completeness in percentage, time consumption, the number of unused building elements (bricks), the number of incorrectly used construction elements (bricks) and the number of rebuilt building elements (bricks). Experimental results could be affected by a large amount of subjective factors related to the participants such as age, work experience in the construction field, personal characteristics that help in faster obtaining and applying information presented in drawings, communication, group work skills, etc. In order to avoid subjective differences, the couples of the participants involved in the experiment were of similar age and had the same education. The difference taken into account was a criterion for experience in the construction field that may have an impact on the results.

The main differences between 2D and 4D models, from the perspective of the user, are the form of information and the ease of use. The experiment confirmed that information on the 4D model allowed executing construction processes faster because of the method that assisted in an easier understanding of information. The participants who used information on the 2D form completed less than a half of the constructed object. The constructed objects, among the participants of the 2D experiment, were only partially completed and ranged from at least 33 to 57 per cent at most. As regards the participants of the 2D experiment, the average completeness of an object is less than a half and makes 48.2 per cent. The participants of the 4D group of the experiment completed on average 99.1 per cent of the object. The least completed object reached 98.8 per cent. The best result, according to the analysed criteria, among the participants of the 4D group, made 99.4 per cent of the whole completion. Comparing the final completion of building between the participants of groups that worked on 2D and 4D models, it can be concluded that the use of the 4D model allowed achieving almost double productivity under the limited period of time. A comparison of the experimental results of the two groups of participants shows that those of the 4D group achieved a higher level of project completion (48.6 per cent) than the ones who used 2 D.

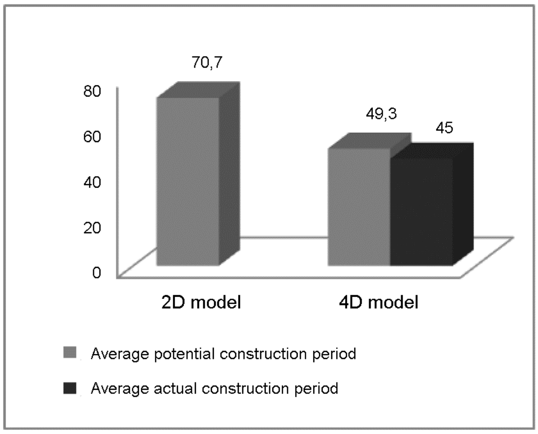

Fig. 4. The average potential and average actual construction period (min) in groups 2D and 4D

The performed experiment included asking participants about the identification of the potential construction period (see Fig. 4). The participants of group 4D predicted lower time cost than those of 2D. The minimum duration of the planned construction was 30 minutes while the maximum was predicted to last 60 minutes. The shortest predicted construction time among the participants of group 2D was 50 minutes and the longest – 100 minutes. The duration of the designed construction, if compared different groups of participants, shows that the participants using the 2D model are planning to spend more time (62.1 per cent) for the construction of the object than the participants using the 4D model.

The experiment evaluated the amount of time for completing the construction object considering the groups of participants using different models.

The experiment shows that none of the participant couples who used the 2D model has completed the construction. The average time spent for the construction object by participant couples who used the 4D model was 45 minutes, which is more than 4 minutes less than the predicted one. Among the participants dealing with the 4D model, the construction object was completed within 36 minutes. The maximum time spent for the construction of the object covered 59 minutes.

Having evaluated the completion and time costs of the building object, time costs were estimated according to seconds per one element of construction. The lowest time cost among the participants of group 2D per construction element was 19.1 seconds while the highest one – 33 seconds. The assessment of the results of the participants of group 4D shows that the lowest time cost per item is 6.5 seconds, whereas the highest one – 10.8 seconds. The average time required for the construction of one element using the 2D model during the experiment was 24.8 seconds, and using the 4D model – 8.2 seconds. To sum up experimental results, the employment of 4D accelerates construction processes up to 3 times.

The carried out experiment showed that information on the 4D model makes preconditions for speeding up the construction process. The obtained results showed that the couples of the participants who used the 4D model did not refer to only 3 building elements. The majority of unused building elements among the participants who preferred the 4D model were 5 pcs, and the lowest number of unused building elements – 1 pcs. The average of unused construction elements among the participants of group 2D is 171. The highest number of unused building elements is 221 pcs, whereas the lowest one – 142 pcs. To sum up research results, according to the number of unused building elements employing different models, the application of the 4D model helps with completing the object of construction faster.

The carried out research calculated errors made and fixed within the construction process. Among the participants of the group dealing with the 2D model, the lowest number of incorrectly used and rebuilt items is 9 pcs while the highest one – 34 pcs. The assessment of the results of the participants of the group focused on the 4D model, according to the analyzed criteria, provides that the lowest number of incorrectly used and rebuilt elements is 7 pcs and the highest is 13 pcs. A comparison of two groups of participants indicates that those involved in the group working with the 4D model in the construction process can reduce the possibilities of making mistakes comparing with the group of the 2D model. The group of the 4D model reconstructed 10.3 pieces, and that of the 2D model rebuilt on average 19.6 pieces. The reconstruction number of the group working with the 4D model is 90.3 per cent less than the situation in the group of the 2D model. The summary of the experimental results displays that use of the 4D model provides a possibility of reducing likelihood mistakes in the construction process and helps with detecting and removing them faster.

The conducted experiment illustrates the number of errors that occur during construction and are inconspicuous using the 2D or 4D model. The minimum number of incorrectly used pieces in the group of the 2D model is 1 pcs and the maximum – 18 pcs. One group of the participants involved in the experiment on 4D did not make any mistakes while building a physical model. The biggest amount of mistakes in the group of the 4D model is 3 pcs, which was placing in a wrong place. Following the conducted experiment, it can be accepted that the use of 4D CAD drawings offers a possibility of reducing mistakes almost three times.

The experiment showed that the participants were characterized by a subjective indication that could affect the outcome results of the experiment – the experience of practical work in the construction field. The evaluation of the relationship between model completion and construction experience showed that the couples of the participants involved in the group of the 2D model and having longer practical experience in the field of construction reached higher completion of the model. The participants with practical work experience of more than half a year in the field of construction built by 7.7 per cent more of a physical model than those having no experience. Upon the evaluation of the impact of the existing practical experience gained by the participants of the experiment in the field of construction on the completeness of the composed model, the received results showed that those having a higher degree of completeness also had 5–6 months and higher than 7 months work experience in the construction sector. It was noticed, that the participants having the experience of 3–4 months achieved completeness that was 0.3 per cent lower than the respondents having the experience of 0–2 months only. A comparison of the relationship between work experience and model completion using 2D CAD and 4D CAD drawings indicates the linear correlation method showed the existing statistical dependency. When assessing the relationship between practical experience in the construction sector of the participants involved in the experiment and model completion, 2D model linear correlation coefficient is 0.51, while for the 4D model participants it is up to 0.62 and confirms a direct connection.

4. Comparison of 2D and 4D models using statistical analysis

Several groups of 7 couples of students having the pads of 2D and 4D models were chosen to evaluate 2D and 4D models. The couples were assessed with reference to certain indicators: forecasted construction time in minutes, the number of unused Lego pieces, the number of rebuild pieces, the number of incorrectly used pieces, the compilation of the model in percentage, the total amount of used pieces and the average time for one piece to use. The averages of the experimental results of the groups of 2D and 4D models are presented in Table 3.

The means of the results of 2D and 4D models are very similar; nonetheless, standard deflections are obvious. Thus, in order to evaluate the results of these two initiates, the standardization of the introduced initiates goes next. For example, for evaluating the results of the 2D model, initiates are marked as $x_1, x_2, ..., x_7$, and for evaluating the results of the 4D model, initiates are marked as $y_1, y_2, ..., y_7$.

Table 3. Averages of experimental results (group of the 2D model and group of the 4D model)

Index	2D model	4D model
Forecasted construction time in minutes	70.7	49.3
The number of unused pieces	171.0	3.0
The number of reused pieces	19.6	10.3
The number of incorrectly used pieces	7.4	2.6
The compilation of the model in percentage	48.2	99.1
The total amount of used pieces	159.0	327.4
The average time for one piece to use	23.3	8.2

The initiates will be standardized using the following formula:

$$z_{xi} = \frac{x_i - \overline{x}}{s_x}; \quad (3)$$

and

$$z_{yi} = \frac{y_i - \overline{y}}{s_y}, \quad (4)$$

where: $\overline{x}$ is the empirical average of the 2D models' parameters values; s_x – experiential standard deflection; $\overline{y}$ – the empirical average of the 4D models' parameters values and s_y experiential standard deflection. Experiential standard means are shown in Table 4.

Table 4. Experiential standard means

Index	2D model	4D model
Forecasted construction time in minutes	–0.01	–0.19
The number of unused pieces	1.48	–0.58
The number of reused pieces	–0.77	–0.52
The number of incorrectly used pieces	–0.95	–0.58
The compilation of the model in percentage	–0.34	0.23
The total amount of used pieces	1.30	2.16
The total amount of used pieces	1.30	2.16

Both experiential standard means can be applied for comparing 2D and 4D indexes. Statistically, the construction time used in 4D model case as well as the number of unused pads is lower than those of 2D models. For comparing all other indexes such as the number of reused pieces, the number of incorrectly used pieces, compilation percentage, the total number of used pieces and the average time for one pieces use, the means of 4D models are much higher than those of 2D models.

5. Evaluation of the efficiency of 2D and 4D using the multipurpose solution method

Multifunctional analysis was used for evaluating the efficiency of 2D and 4D models. TOPSIS, SAW and CORPAS multifunctional solution making methods were applied along with alternatives – 2D and 4D methods. The alternatives have been evaluated with reference to seven indexes: forecasted construction time in months (R1), the number of unused pieces (R2), the number of reused Lego pieces (R3) (see Table 5), the number of incorrectly used pieces (R4), the compilation of the model in percentage, (R5), the total amount of used Lego pieces (R6) and the average time for one piece to use (R7) (see Table 6).

Table 5. Initial decision-making matrix

Indexes Alternatives	R1	R2	R3
2D	70.71	171.00	19.57
4D	49.29	3.00	10.29
min/max	*min*	*min*	*max*
The integrated values	0.180	0.143	0.201

Table 6. Initial decision-making matrix

Indexes Alternatives	R4	R5	R6	R7
2D	7.43	48.17	159.00	23.33
4D	2.57	99.10	327.43	8.23
min/max	*min*	*max*	*max*	*min*
The integrated values	0.131	0.144	0.102	0.099

Table 7. Ranking alternatives to the results of 2D and 4D models using TOPSIS, SAW and COPRAS methods

Method Alternatives	Methods		
	TOPSIS	SAW	COPRAS
2D	0.3004	0.529	0.212175
4D	0.6996	0.905	0.234825

Table 8. Ranking alternatives to the results of 2D and 4D models using TOPSIS, SAW and COPRAS methods

Method Alternatives	Rank		
	TOPSIS	SAW	COPRAS
2D	2	2	2
4D	1	1	1

It is obvious that 4D is more rational in all seven index meanings (results of ranking different alternatives can be seen in Tables 7 and 8).

Conclusions

The analysis of scientific literature has showed that the 4D model gives the opportunity to manage the need and makes the reasonable use of recourses during construction. Efficiency is evident at the reduced number of mistakes and time for fixing them. The 4D model gives the opportunity to advance construction applying the 2D model (under the same time limit). While employing the 4D model, the need for double-check of information on the construction project is by 12 per cent less; therefore, a chance of mistakes decreases by 40 per cent. Time used for the construction process decreases by 7 per cent only because the average increase in understanding the project progresses by 14 per cent (at all stages of construction). Time for reading a project sketch reduces by 8 per cent and time for fixing construction mistakes decreases by 67 per cent.

The execution of the experiment on the practical effectiveness of 4D demonstrates that the use of the 4D model allows achieving almost twice higher efficiency under the limited resources of time. While employing the 4D model, a possibility of reducing construction time by 1/3 arises.

A summary of the results of the conducted experiment, with reference to the number of unused building elements and different models, provides that the application of the 4D model helps with completing the construction of the object much faster.

A comparison of the results of the participants of two groups shows that the respondents involved in the 4D construction process can reduce the possibilities of making mistakes compared to the group of the 2D model. The employment of the 4D CAD model can reduce mistakes twice in the construction process and help with detecting and fixing them faster.

While comparing the relationship between the existing labour practices and the completion of model construction using 2D and 4D models, the linear correlation method shows the existing statistical dependency.

TOPSIS, SAW and CORPAS multifunctional solution making methods have been used for ranking 2D and 4D models during the experiment on 4D efficiency. In all meanings, the 4D model is more rational. Considering all statistical and multi criteria results of the carried out analysis, the 4D model is more convenient and efficient than the 2D one.

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