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Preliminary communication

Continuous Construction Work's Design Quality Monitoring in the Republic of Croatia

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Abstract: The quality of design is an important parameter in achieving requested construction work's quality. The aim of this research is estimation of design quality in the Republic of Croatia based on survey, and proposal of future continuous monitoring as a tool for tracking changes of design quality. Evaluation of the current state of quality of designs was based on first national survey conducted in June 2020 among construction sector professionals: designers and user of designs. The results of the research (a) identified key properties of design quality, (b) established basic reference data on the level of quality of designs in the Republic of Croatia, and (c) profiled a potency for improvement of design quality. Identification of key properties of design quality enabled introduction of design quality indexes. In conclusion, professional community is encouraged to implement activities that improve the key properties of design quality exctracted in current study as an essential part of improving design quality in general. Future continuous monitoring will show the results of these activities and expected improvement of design quality.

Keywords: construction work; design; design quality; quality index; quality property

1 INTRODUCTION

The development of any product is carried out in two main phases: a phase of intellectual creation that results in product design and a phase of physical realization. The quality of a product depends on the success of the implementation of both phases: on the quality of the design and on the effective realization of the product in accordance with the design.

In the area of construction, the product is the *construction work* (term includes both buildings and civil engineering works), the design of the product is a *construction work's design*, and its realization is the *construction process*. Following this analogy, the quality of the construction work will be achieved to the extent that the elements that make up its quality are incorporated into the construction work's design and depending on how much and how these elements were realized during construction process. The quality of compliance with the design will be considered excellent if the construction work fully meets the requirements specified in the design.

However, since the building of construction works differs from the production of other types of products, the question of the quality of designs should take into account not only the suitability of the construction work usage (which is assesed by the end user), but also (a) construction sector legislation, (b) the relations between the participants in construction process, (c) the uniqueness of every single construction work, and (d) the duration of construction process and other construction related specificities.

1.1 Design Quality Problem Determination

During the "Days of the Croatian Chamber of Civil Engineers 2019" it was concluded that (a) undoubtedly, the number of substandard designs is large enough to warrant action from stakeholders, (b) stakeholders should concentrate on collecting data on designs quality in order to gain insight into the situation and review the causes and consequences of substandard designs, (c) investor education would be desirable, but it could only apply to those who frequently act as investors and that the responsibility for designs cannot be transferred to investors. In 2020 the only action taken by institutional stakeholders related to the quality of designs was the adoption of a new Ordinance on the mandatory contents and format of construction work's designs [1]. Unfortunately, the changes implemented in new Ordinance does not constitute any significant progress in terms of improving designs quality and as a first step in design quality problem determination - a survey among participants in the implementation of investment projects - was launched in June 2020.

1.2 Quality of Services and Quality Properties of Construction Work's Designs

Given the long-term and continuous interest of many sectors and industries in quality improvement, the literature on quality is numerous. Quality of services (together with the quality of products part of the total quality management approach [2]) is usually modelled using the SERVQUAL scale, which follows the five dimensions of *service quality* [3]. This scale is frequently used for research on service quality (e.g. [4, 5]), although it is often criticized for theoretical or operational reasons ([6]). In addition to SERVQUAL, various researchers have suggested several different models for evaluating service quality [7-9]. However, the question remains whether and which of these models are suitable for assessing the quality of intellectual and professional services [10] defined as "Services provided by Consultants with outputs of advisory, design, supervision or transfer of know-how nature" [11].

Analysis of the literature on *service quality factors* that refers to the satisfaction of the end user of the construction work, shows that traditional quality dimensions, such as reliabiliy, assurance, responsiveness, communication and empathy, should be supplemented with new dimensions of quality: care in execution of work, quality in aesthetic, innovation and quality of design [12]

By providing a technical solution for a construction work with its specified properties and design, designers graphically and in writing or using some more modern way of providing information [13] enable the contractor to transform designers' concepts and ideas into physical form. The efficiency and effectiveness of this transformation largely depend on the quality of the design [14].

In the literature on design quality, the authors mainly distinguish two aspects: the quality of technical solutions and the quality of the documentation itself [14, 15]. Thus, referring to McGeorge's statement [16] that a good design will be effective (i.e., serve the purpose for which it is intended) and constructible with the best possible economy and safety, these authors find that in order to achieve the "efficiency" of the technical solution, the same must be effectively communicated to the contractor by documentation (blueprints, specifications, etc.). Accordingly, the level of documentation quality can be determined through a number of its properties such as timeliness, accuracy, completeness, alignment, and compliance [17].

It follows that in the phase of realization of construction work, the designs quality is mainly observed through its abovementioned properties while design quality indicators such as location, landscape, finishes or noise that are important for end-user of construction work [18] are rarely indicated. However, the categorization of the importance of design quality properties also depends on the purpose which the design serves as well as on which group of professionals gives an assessment - what is the point of view and position of the participants in the implementation of the investment project [15]. The same diversity and dependance on the position of the participants in the construction process is confirmed by the results of the ranking of quality factors in the management of construction project [19].

From the designer's perspective, the additional important quality properties of technical solutions are also functionality, relevance, innovation, and expressiveness. As for the design documentation, designers consider accuracy and clarity to be important [15].

On the other hand, contractors consider the following design documentation properties important: the possibility of a correct understanding of the technical solution (corresponds to the "clarity" requirement expressed by designers), accuracy, completeness, reliability, relevance, timeliness and alignment of technical solutions provided by different members of design team [20].

Various studies show that designs quality is not an academic issue, but a component of the investment project that significantly affects its implementation. Thus errors and changes of designs are considered to be a fundamental and prominent issue that burdens the implementation of the investment project, which significantly contributes to increasing costs and extending the deadlines [21]. It is shown that design shortcomings, such as faulty technical solutions and incomplete documentation, are the main factors with impact on costs and deadlines because of changes in the scope of the investment project and delays in documentation approvement. Further, irregularities in designs also causes rework costs, construction disputes and conflicts and poor investment project quality in general [22-26].

Additonally important elements are in the focus of the legal requirements for designs: completeness and accuracy of technic for every single technical and/or functional assembly that constitutes construction work, and completeness and mutual alignment of all designs provided by different designers.

Regulations also require the compliance of technical solutions with the requirements and conditions that must be met by construction works as well as formal matters such as a clear division of responsibilities between designers for each part of the design [1, 27]. Civil law regulations show that designs should have properties that enable the construction of a construction work within a certain time and at a certain price [28]

In regard to very definition of design quality, Tilley proposes the definition "the ability to provide the contractor with all the information needed for smooth and efficient construction" [17], while Jaffar et al. state that the legal definition should be "designs should be made with the usual standard of care that exists in the profession", but they immediately add that such a standard does not exist [24]. Regarding the previously mentioned finding that information must be effectively transmitted in order to achieve an effective technical solution, there is an appropriate formulation by Berard et al., who define the quality of the information in the design as "conformance of the design information supplied by the design team to a contractor's specifications for the planning and execution of a construction project" [13]. Such differences in approach show that the definition of design quality is not standardized.

Finally, designs are part of the set of key parameters of the building control system defined by the need for *documentation* to be *appropriate to the risk of the construction work* [29]. Therefore, designs and their quality certainly contribute significantly to the necessary balance between the responsibility of public authorities to manage the risks posed by construction works as well as to conduct appropriate spatial policies and, at the same time, the need to ensure adequate (primarily entrepreneurial) freedoms in relation to construction work [29].

1.3 Research Goals

The aim of this study is to (a) extract key quality properties of design based on literature analysis (b) develop a questionnaire for survey among professionals engaged in different activities related to the implementation of investment projects, in order to collect data on current quality of designs status in the Republic of Croatia (further on: RoC), (c) propose a method and determine current quality level of key design quality properties, and (d) suggest an approach which could improve the quality of designs through continuous and proactive multilateral action by building control system stakeholders - regulators, designers and designs users. The innovativeness of this study is a model which enables long term monitoring and follow up of design quality improvement through direct responses of all stakeholders and in measurable way.

Since monitoring the quality of design from the end user's point of view would be too extensive due to the great diversity of constructions works, this study is limited to the quality of design within the implementation phase of the investment project.

2 METHODS

2.1 Survey Questionnaire

The survey questionaire was prepared based on the research of Tilley and McFallan [15, 20], also including the design quality properties [17] and requirements designs should fulfill according to national regulations [1, 27, 28]. The applied key design properties are (a) the completeness and alignement, (b) accuracy, (c) clarity, (d) relevance and (e) reliability of the designs. Further, the components of the properties (a), (b), (c) and (d) are mutually independent, while the components of property (e) depend on the components of the other four properties. The relations between these properties and their components are shown in Fig. 1.

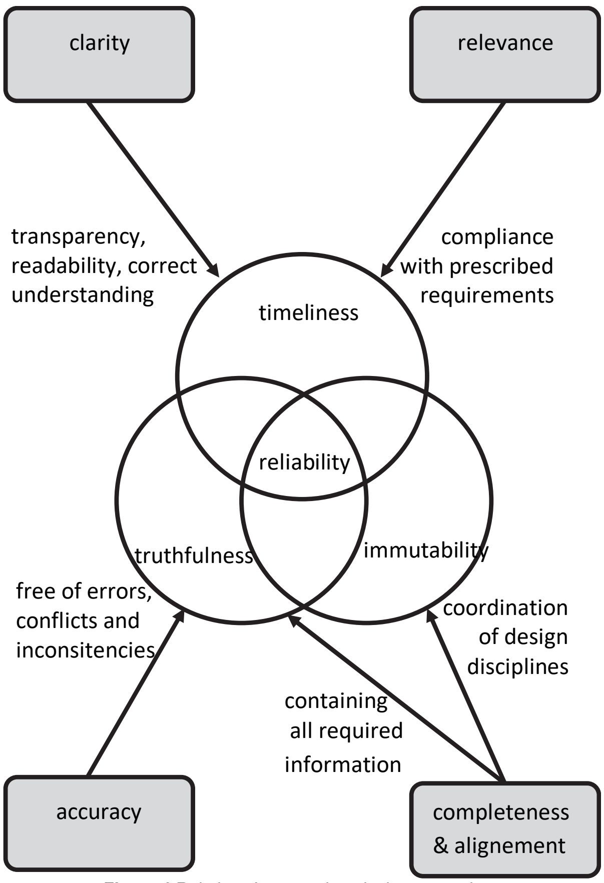

Figure 1 Relations between key design properties

The questions in the survey questionnaire are formulated within the three basic purposes for which the designs are used: (a) to obtain the necessary permits for construction and use of the construction work, (b) for concluding a construction contracts, and (c) for the construction (on site) activities.

Within each of these purposes, a set of questions was developed. Each question is relevant for a certain aspect of design quality and its achieved level of quality, with most questions associated to one or more key quality properties. Questions related to one specific design purpose are composed in the context of design use in accordance with that particular purpose (vertical approach). At the same time, wherever appropriate, each question for one design purpose has a related question within the set of questions for a different purpose but for the same or relevant aspect of design quality (horizontal approach).

In this way, fragmented information on the quality of designs is obtained, assessed through the prism of different design purposes and (due to the diverse professional background of persons participating in the survey) different views of participants, both designers and user of the designs. However, the common theoretical background expressed through key quality properties of designs and relatedness of the questions posed in the context of different design purposes ensure the application of an integrative approach to obtain a multidimensional picture of the quality of projects in RoC as a whole.

The questionnaire includes also a group of questions related to the professional background of the participants in the survey - professionals engaged in various activities related to the implementation of investment projects.

Majority of questions are in the form of claims for which several answers are offered, and participants may choose only one of the answers offered, or have the opportunity to enter their own answer. Participants can also state that they have not had the case described in a particular claim in their practice.

Part of questions were offered in the form of claims for which the participants had to choose answers on a Likert scale (ranging from "strongly agree" to "strongly disagree"), or on a Likert-like scale (ranging from "very satisfied" to "very dissatisfied").

By answering the first set of questions - designs as technical documentation necessary for obtaining permits - the participants provide information about their experiences related to various regulatory requirements regarding mandatory content, elements and properties that designs must meet when used in administrative and similar procedures, namely on: (a) completeness and alignment of designs, (b) compliance of designs (at the general level) with the requirements and on demonstrating the fulfilment of these requirements, and (c) details on the compliance of designs with specific requirements of public law bodies and with location requirements.

The second group of questions - designs as the basis for contracting construction - provides insight into the experiences of participants regarding those aspects of designs quality that have an impact on the success of contracting construction: (a) causes that have the most significant impact on designs quality, (b) sufficiency of the main design as the basis for contracting, and its accuracy, (c) introduction of standard cost estimates, and (d) mutual alignment of designs.

The third group of questions - designs as the basis for on site construction process - covers the experience of participants regarding design properties that are particularly important for the successful carrying out of works on the construction site: (a) evaluation of designs in relation to the need to ask additional questions and/or clarifications, (b) shortcomings of designs by technical and/or functional assemblies or different protection areas, (c) assessment of cost estimates in relation to the need to ask additional questions and/or clarifications and additional works not covered in cost estimates, (d) cooperation of construction participants regarding possible poor quality of designs, and (e) litigation caused by substandard designs.

The fourth group of questions collects data on participants and includes: (a) type of professional work that the participant has mostly done in the past five years, (b) type of construction work (buildings, infrastructure construction works, purpose of the construction work) and type of intervention (new construction work, reconstructions) on which the participant has worked predominantly in the past five years, (c) work experience in the profession and participant's place of employment, and (d) participant's preferences regarding the proposal for the definition of design quality.

The questionnaire is distributed in the form of Excel electronic records via e-mail to members of professional chambers in the construction sector, chamber of commerce/crafts, persons employed in building authorities and in public and state-owned enterprises acting as investors/project managers/builders. A total of 250 participants submitted their response.

2.2 Analysis of Survey Data

In order to get survey results at this stage of the research, (a) a frequency analysis by aggregating common responses is conducted, (b) a degree of consensus for items evaluated on a Likert scale is calculated, and (c) a method to calculate the quality index for certain key quality properties of designs is proposed.

The frequency analysis is based on a breakdown of survey results for each answer offered, indicating the number and share (expressed as a percentage) of participants who opted for it. After that, if the question is of such type, the responses are grouped by common characteristics of a positive or negative assessment of the certain quality property of design for which the question is relevant. In this way, a design quality assessment is obtained for the narrow quality segment to which the answer relates, as well as the overall design quality regarding the certain quality properties to which the question relates. Responses that are ambiguous are excluded from the analysis.

The described method of analyzing the frequency of responses regarding the quality properties of design is also appropriately applied to the analysis of data on participants characteristics (e.g. in relation to experience in the profession, tasks, etc.), which gives their assessment of a narrow segment of a particular characteristic, and a complete insight into the groups of participants that share particular characteristic.

Statements assessed on a standard Likert scale or a Likert-like scale, are analysed by a measure of dispersion [30] as an indicator of participants' agreement (consensus) or disagreement (dissention). The measure of dispersion applied is based on Shannon's entropy. Using distribution probability and editing category rankings on the ordinal scale of the distribution allows for values limited to a unit interval. This measure, which is always within limits of 0 and 1, is applied when collecting and analyzing data on the Likert scale with the aim of determining the degree of agreement or disagreement (consensus or dissention) between ordinally ranked categories i.e. it determines the proximity of ordinal data to agreement or disagreement defined in relation to the degree of proximity of the distribution frequency on the measure.

Each attribute of the Likert scale is assigned a numeric value ("strongly agree" = 1, "partially agree" = 2, "neither agree nor disagree" = 3, "partially disagree" = 4 and "strongly disagree" = 5), so *that* $X = \{1, 2, 3, 4, 5\}$ and $X_1 = 1$, $X_2 = 2$, etc. where d_x (width of X) = $X_{\max} - X_{\min}$, => $d_x = 5 - 1 = 4$. The expected value of X is the mean that is calculated using this expression:

$$E(X) = \sum_{i=1}^{n} p_i X_i = \mu_x \tag{1}$$

Consensus - $Cns(X)$ is defined as [31, 32]:

$$Cns(X) = 1 + \sum_{i=1}^{n} p_i \log_2\left(1 - \frac{|X_i - \mu_x|}{d_x}\right) \tag{2}$$

where: X - Likert scale; X_i - a particular Likert attribute, i.e. individual answer to a question in a questionnaire; p_i - probability or frequency associated with each X_i (relative number of participants who gave a specific answer); d_x - width of X, and μ_x - mean value of X.

Disagreement is defined as:

$$Dns(X) = 1 - Cns(X) \tag{3}$$

A quality index is introduced as a measure to assess the achieved level of quality of certain independent key quality property of designs. The quality index is usually a measure compiled from several items that assess key dimensions of work and service quality, and may include different measurement data [33]. For the purposes of this research, the quality index is calculated on the basis of the total number of participants who answered a survey question and the proportion of participants who answered this question with a positive assessment of the quality property to which the survey question refers. The calculation of the quality index includes all the questions that are associated to particular key quality property.

The quality index of a certain design key quality property is calculated, including questions relevant for a particular property of design quality, using this expression:

$$QI_s = \frac{\left(r_1^+ \times O_1\right) + \left(r_2^+ \times O_2\right) + \cdots + \left(r_n^+ \times O_n\right)}{\left(O_1 + O_2 + \cdots + O_n\right)} \tag{4}$$

where: QI_s - quality index of an individual property of design quality; r_1^+, r_2^+, ..., r_n^+ - share (percentage) of the participants who answered positively to a particular relevant question (1, 2, ..., n) regarding the observed quality property to which the survey question refers; O_1, O_2, ..., O_n - the number of participants for a particular relevant question (1, 2, ..., n) whose answers are included in the calculation (excluding persons who have not responded or have given more than one answer).

3 RESULTS

3.1 Participants in Survey

Participants who completed the questionnaire perform various tasks within the building control system established in the RoC.

Data on their professional experience (Tab. 1) show that over 3/4 of the participants have ten or more years of experience, which significantly contributes to the credibility of their answers.

In order to estimate impact of duration of professional experience, answers of participants who have up to ten years of professional experience were compared with those who gave the answer "I have not had such a case". The purpose of this analysis was to determine whether responses are in correlation with less experience in the profession.

Table 1 Shares of participants in relation to professional experience

professional experience	participants N	share	groups
less than 5 years	21	9%	22%
5 years to less than 10 years	33	13%	
10 years to less than 15 years	32	13%	76%
15 years to less than 20 years	45	18%	
20 years or more	113	45%	
did not declare	6	2%	2%

The analysis shows that these participants with up to ten years od professional experience:

- constitute 20.1% to 26.9% (23.2% on average) of responses confirming that they have had experience with some of the described cases of substandard designs, and
- constitute 14.7% to 30.6% (21.0% on average) of responses declaring "I have not had such a case".

Such shares, which correspond well with the share of participants with up to ten years of work experience in the profession in the total number of participants (22%), indicate that the work experience of this group of participants has no impact on the survey results, i.e. that the answer "I have not had such a case" is not related to less experience in the profession.

The answers of the participants to the question about the tasks they mostly performed in the past 5 years, were analyzed in relation to whether they are involved in design creation or they are the user of designs. The distribution is shown in Tab. 2.

According to the survey results, the share of those participants who only create designs (32%) and those who only use them (35%) is approximately the same, as is the share of participants who perform a combination of those or other tasks (32%). Such a distribution of participants by tasks they have mostly done for the past 5 years also has a positive effect on the credibility of the results of this research.

Table 2 Distribution of participants by tasks

tasks	participants N	share	groups
only design	80	32%	32%
only professional supervision	29	12%	35%
only management of works	30	12%	
only project management	28	11%	
combination of the four above	58	23%	32%
other tasks	23	9%	
did not declare	2	1%	1%

Table 3 Distribution of participants by types of construction work

types of construction work	participants N	share
residential and non-residential buildings	79	32%
buildings for production purposes	9	4%
industrial and similar installations	23	9%
roads	33	13%
water engineering facilities	15	6%
combination of construction works 1-5	72	29%
other types of construction work	12	5%
did not declare	7	3%

The distribution of participants by types of construction work on which they worked in the past 5 years is shown in Tab. 3, and by the types of interventions on the construction works on which they worked is shown in Tab. 4.

Table 4 Distribution of participants by types of interventions

types of interventions	participants N	share
new construction work only	65	26%
reconstructions	37	15%
combination of the two above	143	57%
did not declare	5	2%

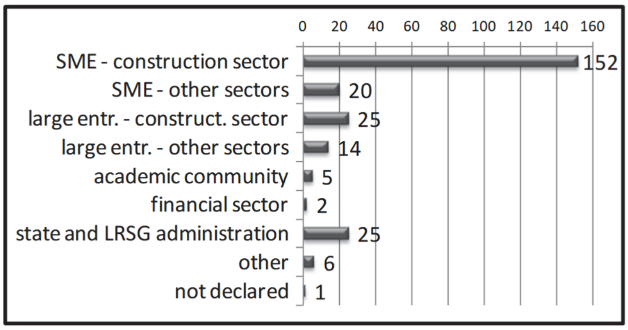

Figure 2 Distribution of the size of entrepreneurs and economic sector

Distribution of the size of the entrepreneur and the economic sector in which the participants carry out their work is shown in Fig. 2.

3.2 Designs as the Basis for Permits

The answers to the questions from the group related to designs as the basis for issuing permits relevant to the stated requirements of the building control system, show that approximately 2/3 of the answers indicate the shortcomings of designs regarding their:

- completeness and mutual alignment (Tab. 5: a total of 66% of participants confirm that designs are incomplete and/or not aligned and/or both), and
- compliance with the requirements for the conditions that construction works have to meet (Tab. 6: a total of 70% of responses indicate some form of non-compliance).

Table 5 Distribution of results on completeness/alignment of designs

completeness/alignment of designs	participants N	share	groups
predominantly incomplete	37	16%	66%
predominantly unaligned	52	22%	
equally the two above	64	28%	
I have not had such a case	79	34%	34%

Table 6 Distribution of results regarding compliance with prescribed requirements and conditions

predominantly non-compliant with	participants N	share	groups
technical regulations	33	14%	70%
accessibility requirements	3	1%	
spatial requirements	32	14%	
location requirements	33	14%	
equally the four above	53	23%	
something else	8	4%	
I have not had such a case	68	30%	30%

Furthermore, according to the partipants, in 17% of building permit procedures it can be expected that the building authority will not accept designs due to incompleteness and inaccurate evidence of compliance with the basic requirements and other conditions that a construction work must meet. The same survey result is also obtained for the misalignment between the main and the detailed design, which is established in the procedures for issuing the use permit.

However, the particular issue of proving compliance with the basic requirement of mechanical resistance and stability, for which the proof is checked through institute of main design control before applying for the building permit, gives different information regarding meeting this requirement of the building control system. Namely: (a) 27% of participants replied that the design control report has been issued without the need to revise or modify the design, (b) 47% of participants answered that the design control report has been issued only after the project is revised or modified, and (c) 26% of participants answered that none of the above cases prevailed, i.e. that they occur with the same frequency.

It follows that the share of cases in which proof of compliance with mechanical resistance and stability must first be revised or modified to issue a positive report by a certified auditor is 60% (47 + 26/2), while the share of those for which the report is issued without the need for revision or modification is 40% (27 + 26/2).

When asked which area leads in terms of non-compliance with special requirements set for construction work (Tab. 7), by far the largest number of responses (39%) relates to the area of fire safety. Responses about other areas (different types of installations, sanitary conditions, occupational safety) were less frequent.

Table 7 Distribution of replies on non-compliance with special requirements

special conditions	participants N	share	groups
for plumbing installations	6	2%	66%
for sewer installation	4	2%	
for sanitary conditions	4	2%	
for electrical installations	9	4%	
fire safety	90	39%	
occupational safety	3	1%	
for gas installations	9	4%	
other requirements	28	12%	
I have not had a case	79	34%	34%

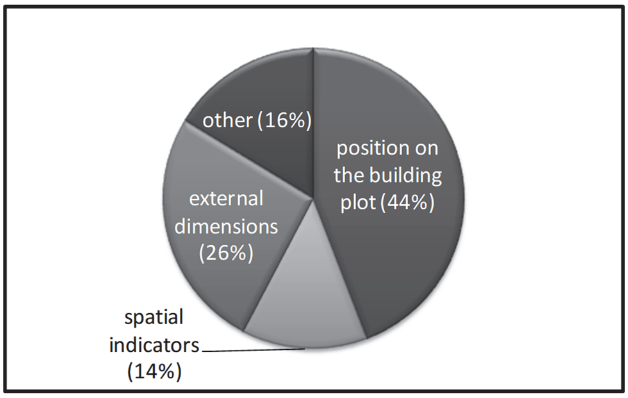

Figure 3 Distribution of deviations from location requirements

As regards the non-compliance of the design with the location requirements, more than half of the participants (57%) stated that they have not had such a case, while the rest stated that they most often deviate from the permitted position of the construction work on the building plot, followed by permitted spatial indicators, while external dimensions or other reasons for deviation are almost equal (Fig. 3).

3.3 Designs as the Basis for Contracting

Responding to the question of what most affects the quality of designs, participants mostly chose the low cost of designs (32%). This is followed by the answer about the lack of possibility of gaining proper designing experience (20%), short deadlines (14%), followed by less frequent causes such as poor design tasks (12%) public procurement system, and other causes (11% each). As many as 18 answers to this question are excluded from further consideration because the participants cite more than one cause, mainly claiming that it is not possible to pick a single cause as the most common.

The question in which the participants declare their agreement (i.e. disagreement) with the statement "the main design is sufficient to conclude a contract with the contractor and ensures minimal financial corrections of the investment", as a result has a measure of disagreement (dissention) $Dns = 0.53$ (Eq. (3)), i.e. the participnts declare that they disagree more than agree with the claim.

Regarding the question of whether professional chambers should prepare standard cost estimates, the opinion of the participants was divided (54% for, 42% against, 4% other). However, the analysis of the answers of those who chose the option "other" are mainly in favour of a certain form of standardization of cost estimates.

Regarding the impact of design misalignment on the success of the implementation of the construction contract, the participants find that this impact will be unfavourable for 48%, i.e. for every other investment project. Another question regarding the misalignment of designs used for contracting shows that just under a third of participants find that designs are mostly aligned, while two thirds find that designs are partially or wholly unaligned (Tab. 8).

Table 8 Distribution of results regarding mutual alignment of designs

alignment of designs	participants N	share	groups
mostly aligned	78	31%	31%
only partially aligned	116	47%	67%
mostly unaligned	49	20%	
other	5	2%	2%

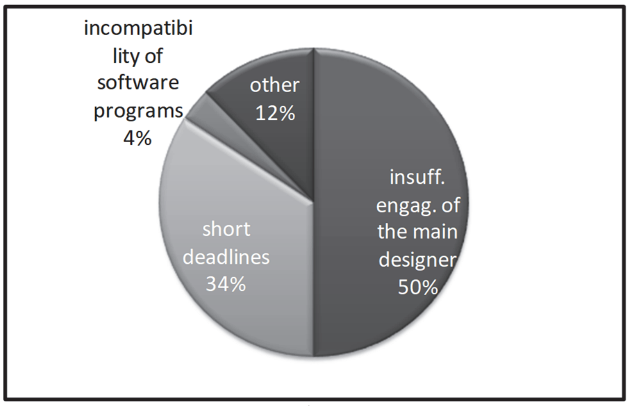

Figure 4 Main reason for designs misalignment

When asked about the main reason why designs are unaligned, half of the participants find that this is due to insufficient engagement of the main designer, while approximately one third attribute the non-alignment to the short design development deadlines. The remaining participants declare that it is due to the incompatibility of software programs or other reasons (Fig. 4). In the analysis on this question, 10 responses were excluded because the participants cited more than one cause.

3.4 Designs as the Basis for the Execution of Works

Regarding the question in which design quality descriptions are ranked from "excellent designs for which no additional questions are asked" to "poor designs, not suitable to perform works", the replies of the participants (Tab. 9) show that just under one third (29%) find that designs are good enough, while others (71%) consider the designs unclear or poor quality.

Table 9 Distribution of responses about design quality

description of design quality	participants *N*	share	groups
excellent; additional questions are never asked	0	0%	29%
good; additional questions are rarely asked	67	29%	
unclear; additional questions are often asked	116	50%	71%
bad; they almost always need to be revised	46	20%	
bad; they cannot be used to execute works	2	1%	

Very similar results are found in relation to questions about the quality of cost estimates (Tab. 10). The question about the frequency of works not included in the cost estimates can be linked to this, and the results of the survey show that additional works can be expected in practically any project (Fig. 5), with significant defects (frequent and very frequent works not included in cost estimates) occurring in 39% + 42% = 81% of cases.

Table 10 Distribution of responses on the quality of cost estimates

description of the quality of cost estimates	participants *N*	share	groups
excellent; additional questions are never asked	0	0%	26%
good; additional questions are rarely asked	62	26%	
unclear; additional questions are often asked	121	52%	74%
bad; they almost always need to be revised	50	22%	
bad; they cannot be used to execute works	0	0%	

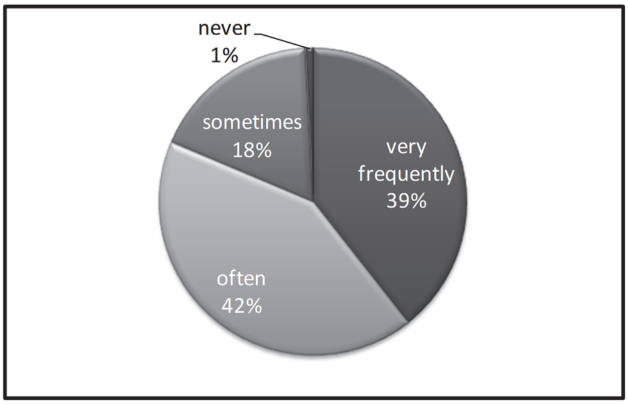

Figure 5 Frequency of works not included in cost estimates

Technical and/or functional assemblies that most often have flaws in the designs (Tab. 11) are mostly geomechanical or foundation designs (19%) followed by designs of the load bearing structure (15%) and technical solutions regarding fire safety (11%), while other assemblies have a share of less than 10%. However, what is significant is that the incidence of designs deficiencies in the total number of responses is high (77%), as only 23% of participants reported that they had no cases of such design shortcomings.

Regarding the question which technical and/or functional assembly designs usually lack a technical solution or the technical solution is not sufficiently elaborated, none of the assemblies particularly emerged. However, it is important to point out that 63% of the participants state that there are technical and/or functional assemblies for which there is no technical solution in the design, and 66% that there are assemblies for which the technical solution is not sufficiently elaborated in the design. Descriptions of deficiencies indicate mainly the need to develop a detailed design. In this case, it is assumed that the remaining participants who do not state that there are design deficiencies thus declare that they have not had such a case.

Table 11 Distribution of responses on deficiencies in assembly designs

assembly	participants *N*	share	groups
geomechanics, foundation	41	19%	77%
structure	32	15%	
water supply	0	0%	
sewage	7	3%	
electrical installations	5	2%	
electrical facilities	0	0%	
mech.eng. installations	13	6%	
mech. eng. facilities	8	4%	
fire safety solutions	24	11%	
occupational safety solutions	4	2%	
another assembly	32	15%	
I have not had such a case	49	23%	23%

When asked about satisfaction with the cooperation of contractors and supervising engineers in cases where designs are not of satisfactory quality, it can be calculated that, regarding cooperation satisfaction, there is an agreement (consensus) between the participants (Eq. (2)) $Cns = 0.69$. One separate answer (which was filtered out), however, indicates the following phenomenon: the participant is satisfied with the cooperation in the case when the supervising engineer is independent of the designer, but when the supervising engineer and the designer are the same person, this cooperation is not satisfactory.

Similarly, regarding the satisfaction with the designer's cooperation with the contractor in the case when the designs are not of satisfactory quality, five participants declared that they had no such experiences. For other participants, a slightly lower degree of satisfaction was calculated than in the case of the contractor-supervising engineer: the agreement (consensus) on this satisfaction is (Eq. (2)) $Cns = 0.64$.

Finally, the survey shows that due to substandard designs, one lawsuit can be expected per 6% of investment projects.

3.5 Definition of Design Quality

Finally, the participants are offered three possible definitions of design quality, with the additional opportunity to make their own proposal.

The following definition: "a quality design is one that successfully balances the investor's needs and requirements of regulations and provides sufficient and accurate data and information necessary for the building of the construction work" is accepted by 68% of participants while 19% accepted definition: "a quality design is one according to which a contractor of average capabilities can build a construction work without having to consult with a designer". Few participants (7%) find the following definition acceptable "a quality design is one that does not contain errors that prevent and/or significantly slow down the issuance of the necessary permits and/or building of the construction work." Most of the remaining 6% of participants suggest some combination of the provided definitions.

3.6 Calculation of the Quality Indexes

By combining the share of positive answers per question relevant to each of the independent key quality property of the design and the number of participants whose answers were taken into account in the analysis per question acording to the quality indexes for completeness and alignement ($QI_{\mathrm{c+a}}$), accuracy (QI_{acc}), clarity (QI_{clr}) and relevance (QI_{rlv}) according to Eq. (4) are calculated (Fig. 6).

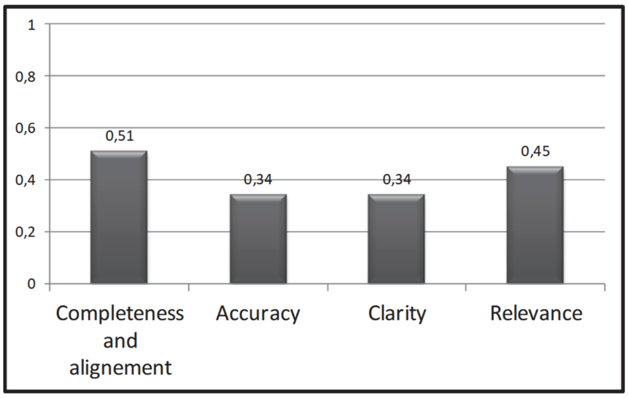

Figure 6 Quality indexes for key quality properties

4 DISCUSSION

The added value of this study is that the quality of the designs in the RoC has been quantified. This enabled the objectification of the phenomenon, which has not been systematically monitored so far, but was recognized only anecdotally in cases where the difficulties of the investment project outgrew the interest of directly interested parties and became known to the wider professional and other public.

According to the building control system of the RoC, designs (as a result of the design service) are commissioned by the investor from the designer [27]. In this regard, the principles followed by literature and standardization documents on quality management [2] are fully applicable because there is a service provider (designer) and a client or service user (investor). However, in practice on the user side there are three parties: (a) building control authority whose role is to certify that the design is produced in accordance with the prescribed requirements [27], (b) investor, who, on the basis of the design, contracts the building of the construction work [28], and (c) contractor, who undertakes to carry out the construction work as provided for in the design [28].

In this context, a certified design auditor and a supervising engineer are not considered as special design users, as the design auditor performs design control for the needs of the building authority and the supervising engineer carries out professional supervision for the benefit of the investor [27].

Taking into account the position, tasks and objectives of these parties, it can be concluded that: (a) the interest of building authorities regarding the quality of designs is limited only to the compliance of the construction work with the prescribed requirements and conditions, (b) the investor interest includes compliance with the prescribed requirements and extends to issues of quality and functionality of the construction work, and (c) the interest of the contractor is to fulfill the obligations undertaken by the construction contract in (from his point of wiev) business-friendly way. Accordingly, expectations regarding the quality of design of these three parties in the implementation of the investment project can be incompatible, and in some cases even contradictory [15, 17]. Thus, the question of defining the design quality and recognizing whether a design is of proper quality becomes more complex.

In relation to the *design completeness and alignment*, a key quality property of drawings and other documents to contain all the information required and to be thoroughly coordinated between design disciplines [15, 20], from the results of the survey it can be concluded that one of the very widespread problems of design quality in the RoC is the issue of completeness and alignment. Namely, both in the group of issues related to designs as the basis for issuing permits and in the group of issues related to contracting, the prevailing view of the participants is that the projects are mutually unaligned/incomplete (66% of permitting issues, Tab. 5; 67% of contracting issues, Tab. 8). In addition, the participants find that the non-alignment of the project will adversely affect the implementation of construction contracts in 48% of cases, i.e. in almost every second investment project. According to the findings of previous research on importance of design documentation properties [17, 20], and on the impact of incomplete documentation such widespread irregularity regarding completeness and alignement of designs should have negative influence - increasing of costs and delays [22, 25], rework costs [23], construction disputes [24] and poor investment project quality [25] - on realisation of large number of investment projects in the RoC.

A more favourable survey result regarding statutory [27] and contractor's [20] requirement on alignment of main and detailed designs (establishing non-alignment in 17% of the procedures for issuing the use permit), indicates that the shortcoming of the design completeness and alignment are primarily a "horizontal" problem (mismatch between designs provided by different members of design team), and much less a "vertical" problem (non-alignment between designs of different levels of elaboration).

Regarding key quality property *accuracy* of *designs*, ie that the drawings and other documents are free of errors, conflicts and inconsistencies [15, 20] in the part of the use of designs for issuing permits, answers related to the prescribed requirement regarding fulfilment of location requirements [27] are stressed. Although the total number of participants who replied that they did not have the case where designs deviated from location requirements is more than half (57%), it is significant that the remaining 43% of the answers indicate some inaccuracy of the design (Fig. 2): ranging from the deviation of the position of the construction work on the building plot, to spatial indicators, to external dimensions or other reasons. As location requirements are fairly simple demands of a geometric nature, the notable proportion of these inaccuracies/deviations could indicate potentially significant design inaccuracies of technical solutions where accuracy depends on assumed or less reliable properties of the material (e.g. foundation soil) or on mechanisms for which it is necessary to apply complex mathematical and/or physical models (load-bearing structures, pressure vessels, ...). As a result of such inaccuracies (both location-vise and technical solutions-vise) increasing costs and extending deadlines [22, 24-26], rework costs [23], conflicts and construction disputes [24] can be expected. Also, in most cases the alteration of manner, means, situation, or the conditions of the construction process will take place [24].

The accuracy of designs when used for contracting may be assessed through the absence of consensus of the participants regarding the sufficiency of the main design for contracting. Namely, as the claim referred to "ensuring a minimum financial correction of the investment", it follows from the measure of disagreement of the participants with this claim (Dns = 0.53) that the participants generally disagree with this statement. This would mean that main designs often contain a number of inaccuracies that can result in significant financial corrections of investments.

Regarding designs as the basis for construction (on site activities), answers to questions related to the quality of cost estimates and additional works not included in cost estimates provide information related to (in)accuracies in designs. As many as 74% of participants (Tab. 10) consider the cost estimates to be unclear or bad, and as many as 81% (Fig. 4) expect "very frequent" and "frequent" additional works not included in cost estimates, which indicates that there are frequent inaccuracies in this part of the documentation, which is often an integral part of the design. Such a frequency of this type of design error in the RoC indicates that frequent cases of cost increases can be expected [22-24].

To sum up results of this survey, the level of quality [17] of *accuracy of designs* in RoC is low which confirm also the quality index (QI_{acc} = 0.34) and absence of the consensus (Dns = 0.53) regarding indicators on minimum financial corrections.

The state of key quality property *design clarity*, i.e. its transparency, readability and the possibility of correct understanding of the technical solution [15, 20] is reflected in the participants' answers to the question related to standard cost estimates and a number of questions related to the use of designs for the execution of works.

As only slightly more than half of the participants (57%) replied that it would be necessary to prepare standard items descriptions for cost estimates, it could be concluded that cost estimates are not considered to be a particular cause of design ambiguity. However, the frequency of answers to the question about the quality of cost estimates indicates that they are very often unclear (74%, Tab. 10). As the clarity of design is considered to be important quality property both for designers [15] and for contractors [20], further research should therefore determine which cost estimate standardization measure is appropriate. Namely, the fact that a relatively large number of participants is against standardization may arise from doubts about its effectiveness due to the uniqueness of each construction work. This could be eliminated by an appropriate way of standardizing cost estimates.

Results of ranking design quality from "excellent, no additional questions" to "bad, not for execution", which serve to evaluate the quality of designs at a general level, indicated that clarity of designs is not at a remarkable level (71% of the answers indicate that designs are "unclear" or "bad", Tab. 9).

Questions about designs that lack or do not have sufficiently elaborated technical solutions show that the clarity of designs is relatively low: 63% of participants said that technical solutions were missing, and 66% that they were not sufficiently elaborated.

Findings of this survey, as well as quality index of this designs property (QI_{clr} = 0.34) show low level of quality [17] of the *clarity of designs.* Thus, increasing costs and delays [22, 25, 26], rework costs [23], conflicts and construction disputes [24] are to be expected in the RoC.

Concerning *design relevance*, a key quality property related to the content of designs that ensures the compliance of the designed construction work with the prescribed requirements [15, 17], the survey results at a general level (level that does not depend on the type of compliance area), show a relatively high degree (70%, Tab. 6) of non-compliance with the requirements. At a more detailed level of elaboration, the survey results show that even when it is statutory required that designs must comply with special requirements [27], here is a high level of non-compliance - 66% of participants (Tab.7) declared that they had such a case. Despite the somewhat better situation on regulatory obligation regarding the compliance of designs with location requirements [27] (participants stated that non-compliance with location requirements occurred in 43% of cases, Fig. 2), it can be concluded that there are many shortcomings of designs regarding the prescribed requirements.

A specific topic is the quality of designs in terms of (in)completeness and (in)validity of the, regulatory required [27], evidence of compliance with the basic requirements and other conditions that construction works must meet. Namely, according to the experience of the participants, the building control authority would not accept designs for these reasons in 17% of the building permitting procedures. On the other hand, 60% of the participants who had the opportunity to work with designs subject to the control of a certified auditor, indicate that designs first need to be revised in order to get a positive audit report. A relatively high percentage of designs that are incomplete or have invalid evidence of compliance with the basic requirement of mechanical resistance and stability should be observed together with a generally high proportion of designs that do not meet other prescribed requirements (specific requirements, location requirements). When these three properties of design quality are compared with the low share (17%) of designs that are not accepted by the building control authority due to incompleteness and invalidity of evidence of compliance with the basic requirements and other conditions, the question arises if this low share is related to the lack of adequate verification of validity of evidence by the building control authority [34]. The possible answer that the designs are still extremely good in this respect is unlikely, given all the other questionable findings on the quality of designs from this aspect, and taking into account that the frequency of invalid proofs of compliance with the basic requirement of mechanical resistance and stability occurs in about 2/3 of cases, as does the mutual non-alignment of designs and their non-compliance with the regulations.

The results of the survey concerning the question of shortcomings in the design of technical and/or functional assemblies on the basis of which the construction work is carried out show that designs often have deficiencies that can adversely affect the requirements of functionality, as well as other requirements for the implementation of the investment project. Namely, 78% of the participants declared that there are shortcomings (of all types) in particular assembly designs (Tab. 11). This result indicates that in the realization of investment projects in the RoC there is a strong possibility of rework costs [23].

Design relevance is according to previous research [15, 17, 20] important quality property and that lack of the same in RoC is proven by this research and by quality index QI_{rlv} = 0.45. Therefore, delays in documentation approvement [22] as well as reducing the quality of whole construction process [25] can be expected.

The degree of the key property *reliability of design*, i.e. property that allows (primarily the contractor) to be able to rely on the timeliness, truthfulness and immutability of the information contained in the design [15, 20], is certainly the result of synergistic interaction of other quality properties: completeness, alignment, accuracy, clarity and relevance. In this sense, regardless of the fact that the degree of synergy of these properties and their combined final impact on the reliability of designs is yet to be investigated, based on individual calculated quality indices ($QI_{\mathrm{c+a}}$ = 0.51; QI_{acc} = 0.34; QI_{clr} = 0.34; QI_{rlv} = 0.45) it can be concluded that the acceptability level of the reliability property of designs is also questionable.

As the investment project is "... an undertaking consisting of a series of interconnected activities..." [35], another parameter that can provide information on the reliability of designs is cooperation between construction participants needed due to the substandard design quality.

Although the group of questions related to designs in the context of permitting does not contain a direct question about the cooperation of different designers (at this stage of implementation of the investment project, the designer does not yet have - as a rule - the need to cooperate with the contractor and the supervising engineer), the impact of (non-)cooperation on the quality of designs can be considered in the context of the responses about design alignment. Namely, the assessment that a number of designs (66%, Tab. 5) are incomplete/unaligned indicates that the cooperation between designers is insufficient. Understandably, since the main designer is obligated to ensure the completeness and mutual alignment of the design, the degree of cooperation of the designer will depend primarily on the success of fulfilling this obligation by the main designer.

Appropriate conclusions on the non-cooperation of designers may also be reached by analyzing the responses related to the alignment of designs when they are used for contracting: 67% of the participants find that designs are partially or mainly unaligned (Tab. 8).

It is only during the construction process that the full scope of cooperation between different participants in the construction is shown when it comes to eliminating problems that may be caused by substandard designs. As expected, this cooperation is more pronounced in the relationship between the contractor and the supervising engineer (measure of agreement, consensus Cns = 0.69) than between the contractor and the designer. Namely, contractors and supervisory engineers are participants who are simultaneously engaged to work on the same construction work, and consequently cooperate more closely. In the case of contractors and designers (measure of agreement, consensus Cns = 0.64), they are participants in the construction where there is a "time shift". For the designer, the construction work that is being built is something that he/she designed a few months back, and at the time of construction he/she is (most often) engaged in a new design project, so he/she can devote less time to problems on the construction site. It can be assumed that the more successful cooperation between contractors and supervising engineers is influenced by their (as a rule) richer on-site experience.

It could be concluded that the (un)reliability of designs entered at the design stage due to insufficient cooperation of the members of design team is eliminated by the relatively successful cooperation of the participants in the construction during the on site activities.

However, as *design reliability* is recognized in previous research [20] as important for the contractors, taking into account low level of this quality property (derived from the low level of quality properties that constitute *design reilability*) can cause various obstacles such as incresing of costs and delays [22, 23, 25, 26] frequent change orders [23] as well as contruction disputes and conflicts [24] in relization of investment projects in the RoC.

Discussing the results of answers to questions not directly related to the assessment of abovementioned design quality properties may shed further light on some of the circumstances related to design quality.

Regarding the causes of the quality of designs, the diverse answers to the question of what cause has the strongest impact on the quality of designs indicate the complexity of this phenomenon, and confirms the findings of earlier research [14]. Namely, it is significant that a very large number of participants opted for more than one cause, making it clear that not only one cause can be considered crucial. This is confirmed by other responses in which the participants opted for only one answer: the distribution of selected answers is such that it shows that none of the causes can be considered dominant to such an extent that other causes can be ignored (Fig. 6).

The subject of litigation over design shortcomings, according to the survey results, is not particularly frequent - which does not fit with other indicators of the number of substandard designs. It is safe to assume that the cause of the low number of lawsuits is the duration of court proceedings that discourages the injured party from using this method of resolving the dispute.

Finally, the definition of design quality by different authors is not equal (e.g. [13, 17, 24]). Such a result does not come as a surprise as the views and responsibilities of the persons who make or use designs in the context of the implementation of an investment project may significantly differ [15, 20], and due to diversity of the legal, business and social framework of construction in which the authors operate.

However, the results of the survey on defining the quality of designs show that in due course one can expect to reach an agreement (consensus) on the very definition of design quality to be used for the purposes of further research activities. In the context of the objective to monitor the quality of designs (and even ultimately succeed in efforts to improve design quality), a valid definition plays a key role, which then serves as a benchmark against which design requirements can be set and the extent to which those requirements have been met can be assessed.

5 CONCLUSION

Current study developed detailed questionnaire for estimation of design quality in construction sector. Additionally, the survey established the method and basic reference data on the level of quality of designs in the RoC in 2020 represented by quality indexes of key design quality propreties: design completeness and alignement with quality index QI_{c+a} = 0.51, design accuracy with quality index QI_{acc} = 0.34, design clarity with quality index QI_{clr} = 0.34, design relevance with quality index QI_{rlv} = 0.45. Collected data and method for calculating level of quality indexes enable introduction of continuous national annual surveys providing insight into the dynamic of designs quality. If adjusted, both questionnaire and method, can exceed national relevance and be applied on European level.

Current state of design quality in construction sector in the RoCindicates significant space for improvement. The estimation of quality index threshold, which could be used as a measure of acceptable level of design quality, determination of quality index for key property reliability of designs and very definition of quality of designs, is the topic of further research. It is expected that such quantification of design quality will be recognised by designers within their business interests.

The results of the survey, confirming the existence of problems of insufficient design quality in the RoC, are expected to encourage stakeholders of the professional community and the building control system: regulators, designers and design users to act multilaterally, continuously and proactively to improve key quality properties of designs.

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