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RESEARCH ARTICLE

Investigating the building commissioning practices in Turkey

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Abstract

Advances in technology give rise to buildings with complicated systems and components. Many building systems fail to perform as intended owing to lack of a systematic approach adopted during construction. Commissioning is known to enhance the building's operational efficiency through bringing a holistic perspective to design, construction, and operation. This study aims to investigate the building commissioning practices in Turkey with the intention of promoting energy efficient building communities in developing countries. Within this context, a questionnaire survey was designed and administered to the commissioning practitioners to explore their perceptions and experiences regarding a number of critical commissioning issues. The findings reveal that (i) most frequently encountered challenges are non-technical rather than technical; (ii) benefits realized in the post-occupancy period overweigh the pre-occupancy benefits; and (iii) experiential features of the commissioning agents are more important for the commissioning agent selection process than the technical and managerial features. The study contributes to the body of knowledge by presenting the main observations on building commissioning practices in a developing country and providing recommendations to enhance the commissioning performance. It is expected to provide a better understanding of the critical issues in building commissioning process and promote its implementation in developing countries.

1. Introduction

The real estate sector, involving residential and commercial buildings, is responsible for 21% of the world's delivered energy consumption [1] and the consumption of large proportions of natural resources [2]. The energy consumption of the industry is expected to increase even more with the economic development [3]. The complexity of buildings increases with the increasing number of interacting systems and components [4], resulting in a high risk of accidents [5]. Despite the growing building complexity, communication/coordination between the participants and building elements throughout the building lifespan is poor [6]. It is realized that many buildings fail to perform as intended [7,8] mainly due to the fragmented approach to building production. Even though such a failure may not necessarily prevent the systems from operating, it may decrease the product value and increase energy and operations and maintenance expenditures [9]. It should be noted that 80-90% of the overall energy usage in buildings occurs at the operational stage [10].

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Global warming has been the main reason behind the attempts to minimize energy consumption [11]. The energy performance of buildings has been the most essential component of the plans for climate change mitigation and future energy supply [12]. Energy-efficient buildings have been highlighted for achieving the goal of 80% reduction in carbon emission by 2050 [13]. The increasing global concern on energy efficiency has resulted in international collaborations. To illustrate, the International Energy Agency (IEA) Energy in Buildings and Communities Program has emphasized the role of building commissioning in promoting energy efficiency by completing two building commissioning research annexes, namely Annex 40 and Annex 47. The former provides a common understanding of the commissioning process, while the latter concentrates on the use of technology in commissioning [14].

Commissioning services have been shown to enhance the energy efficiency of commercial buildings by improving the quality of the process [15]. Building commissioning not only verifies the performance, but also checks for malfunctioning technologies [16]. Implementation of commissioning services in the building industry has been gaining momentum as a comprehensive quality assurance process to ensure that owner's project requirements are met [17]. Verifying building operational performance requires the involvement of an experienced party, called a commissioning agent, in building operations during the design and construction phases. Participation of both the commissioning agent and contractor in the design phase leads to the formation of an experienced project team capable of using integrated design techniques to improve both constructability and operability [18].

Commissioning is a systematic process that validates the compliance of all building facility systems with the design documentation and intent [6]. The process commences at the predesign phase and continues through the design, construction, and operation phases. It integrates and improves the traditionally separate functions by bringing a holistic perspective to design, construction, and operation [19]. The cost of the process varies largely by the scope of work and the benefits depend on the resultant performance improvements [9]. Realizing the full benefit of the commissioning process requires regulative support [20]. The benefits are mainly beneficial to the owner, operation, and maintenance (O&M) personnel, and the occupants [17].

Xiao and Wang [21] expressed four types of building commissioning, where initial commissioning is applied to the production of new buildings or installation of new systems; retro-commissioning refers to the implementation of the process to existing buildings where a documented commissioning has not been implemented before; re-commissioning implies the execution of the process after the initial commissioning or retro-commissioning, and on-going/continuous commissioning is the application of the process continually after the initial commissioning or retro-commissioning.

Energy-saving solutions can be executed in all construction phases of the building industry [22]. In that regard, the commissioning process is composed of several activities within four project phases, namely the pre-design phase, design phase, construction phase, and occupancy and operations phase. Pre-design phase contains the development of the commissioning plan and the owner's project requirements. The design phase comprises verification of the basis of design, development of the construction checklist, preparation of the commissioning specifications, establishment of the training requirements of the O&M staff, verification of the design submittals, and updating the owner's project requirements and basis of design as necessary. The construction phase covers the verification of the submittals, development of the functional test procedures, conducting site visits, verification of the training activities, execution of the functional tests, and documentation of the results. The occupancy and operations phase includes conducting a warranty review, seasonal testing, and lessons-learned meeting [23]. The responsibility of the commissioning agent is to ensure that these

activities are realized and the owner's project requirement is met.

Commissioning seems like a standard practice as erroneously assumed by many building owners. In fact, buildings are seldomly commissioned for energy savings, leading to undetected energy efficiency problems [19]. As the commissioning guidelines and standards are mostly generated for developed countries (e.g., ACG Commissioning Guideline [24], ASHRAE Standard 202 [25], The Building Commissioning Guide [26], ASHRAE Guideline 0 [27], 1.1 [28], and 1.5 [29], Building Commissioning Guide [30]), they are expected to follow the latest trends and employ the commissioning process effectively. However, implementation of the commissioning process should be much limited in developing countries. Thus, it becomes more of an issue to investigate the commissioning practices in developing and developed countries separately.

The objective of this study is to investigate the building commissioning practices in Turkey as a representative of developing countries by addressing several building commissioning issues. In this context, the involvement phase of commissioning agents and the need for commissioning services were searched out. In addition, an extensive literature survey was conducted to prepare a list of challenges, benefits, and commissioning agency selection criteria. A questionnaire survey was designed and directed to the members of the Turkish Society of HVAC and Sanitary Engineers and The Mechanical Contractor's Association. The respondents were requested to (i) express their opinions on certain issues (involvement phase of commissioning agents, need for the commissioning services, etc.) and (ii) assess the significance of the factors in the prepared list by using 1-5 Likert scale (1: very low, 2: low, 3: medium, 4: high, 5: very high). The obtained data were statistically analyzed.

2. Literature review

Commissioning has largely been neglected both in practice and in the literature [31]. Considering its influences on the quality and efficiency of the complicated building systems, the number of studies conducted in recent years leaves a lot to be desired. Previous studies on commissioning can be divided into three groups based on the field of interest.

Among the limited number of studies, the majority have focused on the "process". Burnett [9] studied the effectiveness of building commissioning practices in terms of their costs and benefits. A need for improving the testing and commissioning skills amongst contractors in Hong Kong's building construction industry was emphasized. Elzarka [18] identified the best practices for commissioning services and compared them with the current practices in the United States. The discussed issues were the involvement time, independence, and certification of the commissioning provider; selection criteria; and clear definition of the scope of work. A marked difference was observed between the current and recommended practices. Djuric and Novakovic [6] had a review of the building's lifetime commissioning. They presented the European and USA laws for energy performance of the buildings and introduced a number of commissioning tools. Mills [19] conducted a meta-analysis of commissioning experience including 643 non-residential buildings. The median normalized cost of commissioning was stated as $1.16/ft2 for new construction and $0.30/ft2 for existing buildings. Energy savings were reported as 13% and 16% in new construction and existing buildings, respectively. Agustsson and Jensen [17] examined how the commissioning process was undertaken in Denmark. They outlined the benefits obtained and proposed ways to enhance the commissioning process in the country. Kantola and Saari [32] identified the benefits and opportunities of the commissioning procedure over nearly zero-energy building (nZEB) projects. The solutions offered by the commissioning process to the challenges confronted in nZEB technology were established. Coyner and Kramer [33] investigated the long-term benefits of building commissioning. Building commissioning was reported to provide greater benefits, especially in high-tech buildings. Crowe et

al. [34] quantified the benefits of building commissioning by extending the data set of a previously conducted study. The savings varied between 3% and 16% depending on the project type.

Another group of studies has focused on "models and tools", specifically on their developments and implementations. Turkaslan-Bulbul and Akin [35] described an Embedded Commissioning Model in order to make architectural evaluation an indispensable part of the building lifecycle. The research showed that building product models could represent more information than conventional methods and utilization of a building information model could enhance building evaluation activities in various stages of the building lifecycle. Ahmed et al. [36] proposed a multi-dimensional performance data model. They described the model based on data warehouse technology and introduced the dedicated graphical user interface. They demonstrated the advantages of multi-dimensional performance data management in a case study. Ginestet and Marchio [37] tested International Performance Measurement and Verification Protocol (IPMVP), by using retro and ongoing commissioning tools in an existing building. Bynum et al. [15] developed and tested an Automated Building Commissioning Analysis Tool (ABCAT) in order to extend the benefits of commissioning. The tool used a mathematical model to predict the energy consumption for given weather conditions. They presented some cases where the tool successfully identified the energy consumption deviations. Gillis and Cudney [23] presented a four-phase quality function deployment model for the commissioning process. They provided the practitioners with the steps to take the model to through each phase of the process to ensure that the final product delivered all the customer's requirements. Harmer and Henze [38] developed a monitoring-based commissioning system and demonstrated its usage for commercial buildings. The model-based commissioning system was observed to successfully predict both the magnitude and time of energy and demand. It could also forecast cooling capacity shortfalls. Jradi et al. [39] generated a continuous commissioning framework to monitor the building energy performance. The framework included a number of performance tests for building energy subsystems. Kramer et al. [40] examined the utilization of energy management and information systems (EMIS) tools for monitoring-based commissioning practices. They reported a median cost saving of 7% annually.

A set of studies have targeted the commissioning of "certain building systems". Wang and Wang [41] developed software that could automatically diagnose and assess the Building Management System sensors of building refrigeration systems during both commissioning and recommissioning. They presented some examples of applications. Xiao and Wang [21] had an overview of the state of art techniques for automatic commissioning of heating, ventilation, and air conditioning (HVAC) systems. They emphasized the significance of making a greater effort to develop automatic commissioning tools integrated with building automation systems. Painter et al. [42] introduced a sensor overlay system that could support building control commissioning by providing high-resolution data and facilitating detailed investigations of internal conditions. They highlighted the cost-effectiveness of the method as it utilized proven off-the-shell technology. Wang et al. [7] demonstrated the process of monitoring-based HVAC commissioning by using an existing office building as a case study. With the execution of trend data analysis and functional testing, they identified several faulty operations in the HVAC systems. They indicated an energy saving of 10% as a consequence of the cost-effective measures. Gunay et al. [43] investigated the advantages of detecting the common sensor and actuator faults through a building performance simulation. They reported that if the faults can be detected within a month, the negative influences on the building's energy and comfort could noticeably be mitigated.

Examining the areas of interest of previous studies, it is realized that no study has investigated the country-specific conditions and contextual

implementation differences. Considering the differences in terms of the availability of standards and guidelines, cultural structures, and corporate structure of organizations, it is essential to investigate the building commissioning process from the perspective of developing and developed countries separately. This study focuses on the commissioning practices in Turkey, addresses a number of critical commissioning issues, and aims at identifying the similarities/differences in implementation compared to previous studies.

3. Methodology

This study investigates the building commissioning practices in Turkey as a representative of developing countries. The building commissioning practices have been examined in terms of several critical commissioning issues including (i) involvement phase of commissioning agents, (ii) need for commissioning services, (iii) challenges confronted during commissioning, (iv) benefits obtained from the commissioning process, and (v) commissioning agency selection criteria (Fig. 1).

The first two critical commissioning issues are the involvement phase of commissioning agents and the need for commissioning services. In order to examine the former, the respondents were requested to state the involvement phase of commissioning agents based on the construction projects they had worked. The phases were expressed as the design phase, beginning of the construction phase, and end of the construction phase. The latter is about the reasons why a client may need the commissioning services. According to Demkin [44], the commissioning services are needed (a) when construction structures include complex building systems, (b) when facility environment tolerances are highly critical, (c) to make sure that building energy use is in line with the predicted amount, and (d) to verify that the performance of the building meets the mandatory requirements. These reasons were introduced to the respondents and they were requested to select the most appropriate one based on their experiences.

The other critical commissioning issues are challenges confronted during commissioning, benefits obtained from the commissioning process, and commissioning agency selection criteria. A pilot study was conducted with a team of experts of two academicians and three industry practitioners having been involved in the commissioning process for more than 20 years. The literature was reviewed to prepare an initial list of challenges, benefits, and commissioning agency selection criteria. The initial list of factors was then refined to obtain a more accurate list. Factors having similar meanings were merged and renamed. The refined list incorporated a total of eleven challenges, twelve benefits, and nine commissioning agency selection criteria.

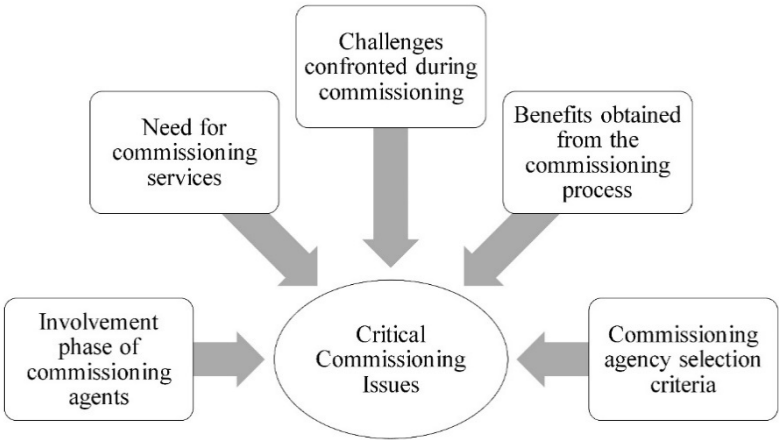

Fig. 1. Critical commissioning issues examined

Eleven challenges were listed;

- CHL1 : Individual functional tests missing whole system approach [45],
- CHL2 : Integrated testing is required by some control systems [45],
- CHL3 : Lack of details regarding the commissioning tests [45,46],
- CHL4 : Not carrying out the system tests under real operating conditions [47],
- CHL5 : Pressure to perform commissioning remotely [45,47],
- CHL6 : Understanding and testing new systems and technologies [47],
- CHL7 : Difficulty in finding qualified personnel/service providers [32,47],
- CHL8 : Difficulty in quantifying the obtained value [6,9,48],
- CHL9 : Initial extra cost required for the commissioning agency [9,48,49],
- CHL10 : Lack of authority of the commissioning team [45,46],
- CHL11 : Late invitation of the commissioning agency to the project [18,45].

A total of twelve benefits were identified including;

- BNF1 : Better documentation of installed building systems [23,48,49],
- BNF2 : Enhanced quality control during construction [32,48,49],
- BNF3 : Fewer change orders and claims [6,19,49],
- BNF4 : Improved planning and coordination [49],
- BNF5 : Minimized risk of project delay [19,49,50],
- BNF6 : Smoother handover of the project [49],
- BNF7 : Decreased operational and maintenance cost [6,9,48,49,50],
- BNF8 : Early detection of problems decreasing post-occupancy work [23,49,50],
- BNF9 : Facility performance satisfying owner requirements [9,23],
- BNF10 : Improved thermal comfort and indoor air quality [6,9,48,49],
- BNF11 : Satisfied building occupants with fewer complaints [50],
- BNF12 : Well-trained operation and maintenance staff [23,48,49].

Nine criteria were specified in total for commissioning agency selection including;

- CAS1 : Ability to deliver operation and maintenance training [24,32,50],
- CAS2 : Documentation and reporting abilities [23,51],
- CAS3 : Having professional commissioning certification [18,49],
- CAS4 : Knowledge of building operation and maintenance [20,46,51],
- CAS5 : Commissioning experience in similar projects [24,49],
- CAS6 : Experience in system testing and balancing [20,24,51],
- CAS7 : Familiarity with codes and regulations [20],
- CAS8 : Communication and interpersonal skills [49],
- CAS9 : Team building and organization skills [24,49].

The factors were then categorized based on their contents. The challenges were categorized under two main headings, namely technical and non-technical challenges. Technical challenges stand for the technical issues encountered during the execution of system tests. On the other part, non-technical challenges can be economic, procedural, or other obstacles. The benefits of the commissioning process were separated into two main groups, namely pre-occupancy and post-occupancy benefits. The pre-occupancy benefits represent the benefits obtained during the design and construction phases. The post-occupancy benefits are the ones realized during the operation and maintenance phases. Commissioning agency selection criteria were listed under three categories, namely technical, experiential, and managerial criteria. The categorized list of factors and their descriptions are presented in Table 1.

Table 1. List of factors

		#	Description
Challenges	Technical	CHL1	Difficulty in predicting the solidity of the overall system as the functional tests are developed for individual equipment
		CHL2	Difficulty in testing each component of the system when they interact with each other
		CHL3	Not having a detailed explanation of the commissioning tests
		CHL4	Possibility to have problems when the facility starts running as the facility is not in use while carrying out the system tests
		CHL5	Difficulty in performing the commissioning remotely as some systems require the presence of humans for adjustments
		CHL6	Difficulty in following new systems and technologies, especially how to apply the test standards and methodologies
	Non-Tech	CHL7	Lack of qualified personnel/service providers in developing countries
		CHL8	Difficulty in estimating the financial equivalents of benefits (e.g., decreased number of change orders)
		CHL9	Pushed up costs for hiring a commissioning agency
		CHL10	Unrecognized authority of the commissioning team by the project participants
		CHL11	Lost opportunity for the commissioning agents to get involved in the design stage and participate in decision-making
Benefits	Pre-Occupancy	BNF1	Smoothly documenting all the systems and assemblies of a facility in design, construction, and testing
		BNF2	Increased quality by checking whether the equipment is installed correctly or not during construction
		BNF3	Fewer corrective actions by enhanced coordination on-site during the construction phase
		BNF4	Greater cooperation among the team members and facilitated integration and communication throughout the project
		BNF5	Minimizing the risk of project delay by increasing the productivity and reducing change orders
		BNF6	A better handover experience by revealing all the required information/documents
	Post-Occupancy	BNF7	Cost reduction by optimizing energy-efficient design features and having fewer unscheduled equipment repairs
		BNF8	Preventing the contractor from spending a great amount of money by detecting these problems before they occur
		BNF9	Ensuring that the building systems perform interactively and continuously in accordance with the owner's operational needs
		BNF10	Enhanced air quality by properly running and maintaining the HVAC systems
		BNF11	Increased satisfaction of the building occupants and reduced complaints through improved indoor air quality
		BNF12	Verifying that the operation and maintenance staff are well trained
Agency Selection	Tech	CAS1	Making the operation and maintenance staff understand the working principle of the systems and equipment
		CAS2	Ability to accurately prepare a complete set of as-built design documents to be used over the building lifespan
		CAS3	Having obtained professional commissioning certification from a widely recognized institution
		CAS4	Being knowledgeable about the building operation and maintenance steps to be able to estimate potential post-occupancy problems
	Exp	CAS5	Having been involved in similar projects with potentially similar challenges
		CAS6	Having experienced system testing and balancing steps to have a solid and reliable approach to troubleshooting subsequent issues
		CAS7	Having worked with the corresponding country's codes and regulations, being familiar with the terminology
	Mn	CAS8	How the commissioning agency interacts with the other participants of the project
		CAS9	Being capable of forming an effective working team via promoting cooperation and increasing the team motivation

A questionnaire survey was designed and administered to industry practitioners to assess the significance of each factor using a Likert Scale ranging from 1 (strongly disagree) to 5 (strongly agree). The survey was sent online to the members of major associations related to the commissioning process such as the Turkish Society of HVAC and Sanitary Engineer and The Mechanical Contractor's Association. In an attempt to obtain reliable responses, having at least two years of commissioning experience was stated as the requirement to participate in the survey. A total of 117 questionnaires were sent to the targeted respondents and 26 of them were returned, resulting in a response rate of 22%.

4. Results and discussion

4.1. Respondents' profiles

The responses are collected from industry practitioners with an average age of 42 and industry experience of 17 years. The majority of the respondents are managers/directors (39%) followed by experts/consultants (23%), engineers/architects (19%), and owners/board members (19%). They have been involved in more than 21 commissioning projects (31%), 16-20 projects (15%), 11-15 projects (12%), 6-10 projects (19%), and 0-5 projects (23%). The area of expertise of their companies is shown in Fig. 2. The companies are dominantly project management & consultancy firms (76%) and the rest are investors (8%), prime contractors/subcontractors (8%), project design firms (4%), and manufacturer's representatives (4%).

The respondents were requested to indicate whether they had been involved in the commissioning process of certain systems. The results are presented in Fig. 3. Respondents possess experience in all types of commissioning systems. Almost all of them have participated in the commissioning of HVAC (92%) and domestic hot water systems (85%). Land irrigation (23%) and security systems (31%) are the least frequently commissioned systems

4.2. Involvement phase of commissioning agents

The involvement phase of commissioning agents is shown in Fig. 4. A great portion of the respondents (77%) have stated that commissioning agents are involved at the end of the construction phase. Almost one-fifth of the respondents (19%) have indicated the involvement time as the beginning of the construction phase. Only 4% of the respondents have experienced the start of the commissioning process at the design phase. Such a finding demonstrates that the current situation in developing countries is far from the ideal case. The commissioning process should ideally start at the predesign phase [19]. The finding also indicates that the situation is worse in developing countries compared to developed countries. A previously conducted study by Elzarka [18] in the United States demonstrated a greater trend for early involvement. It was reported that in almost half of them (47%) of new construction projects, the commissioning agents got involved in the design development or previous phases.

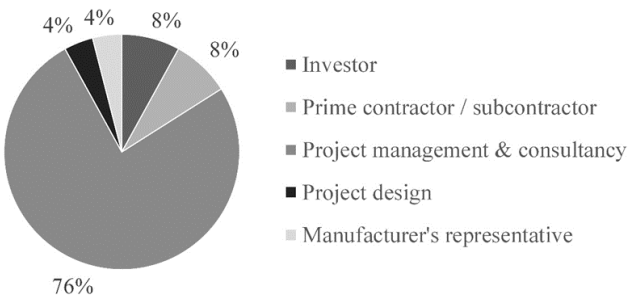

Fig. 2. Area of expertise of the respondents' companies

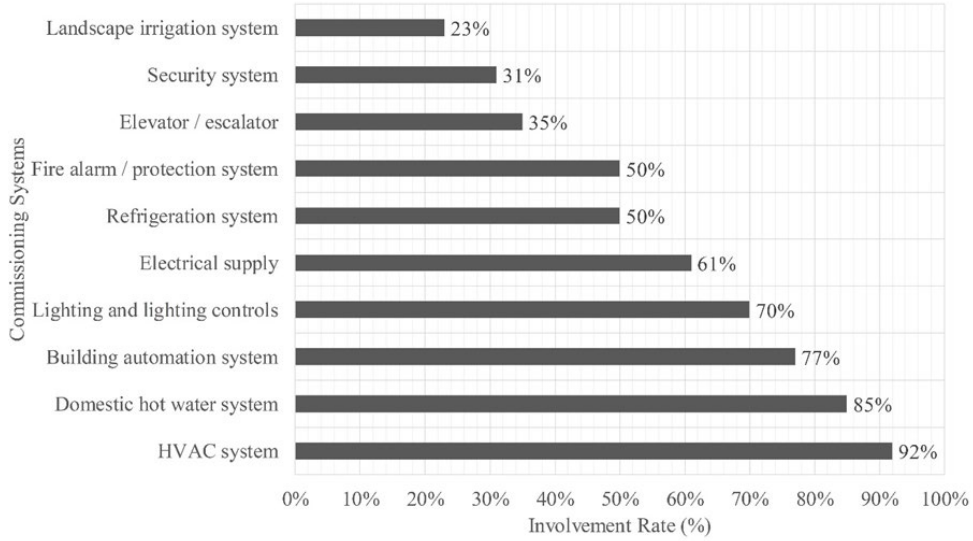

Fig. 3. Respondents' experiences in various commissioning systems

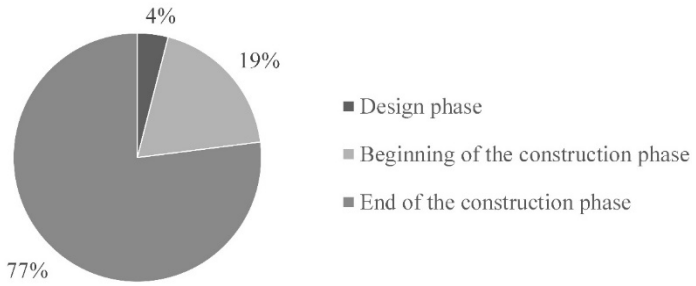

Fig.4. Involvement phase of commissioning agents

4.3. Need for the commissioning services

Fig. 5 presents the need for the commissioning services. The commissioning services are observed to be mainly applied (41%) for verifying that mandatory requirements are met. Optimizing the building energy usage is specified as another important reason by almost one-third of the respondents (31%). The complexity of building systems and criticality of facility environment tolerances are detected as less significant reasons. According to responses, it can be claimed that even though the benefits of the commissioning process have been widely emphasized in the literature, the process would not be undertaken in developing countries unless there are mandatory requirements to be verified.

4.4. Challenges, benefits, and commissioning agency selection criteria

Challenges confronted during the commissioning process are summarized in Table 2. Late invitation of the commissioning agent to the project is identified as the most significant challenge followed by difficulty in finding qualified personnel/service providers. The commissioning process should ideally commence at the schematic design phase and continue through the other phases. Such a practice would allow the commissioning team to assist in preparing the owner's project requirements, review the drawings and specifications, and ensure that the basis of design documents is in line with the owner's project requirements.

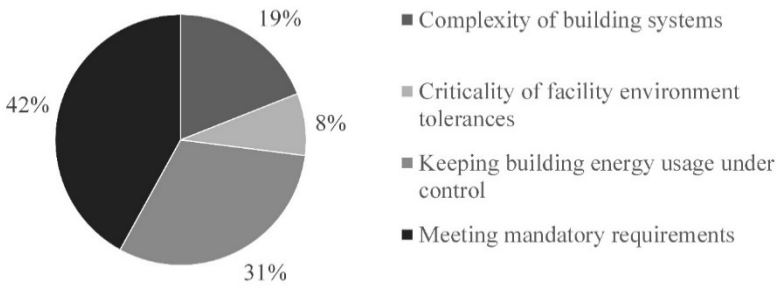

Fig. 5. Need for commissioning services

Table 2. Challenges confronted during the commissioning process

Factors	Grades					
	1	2	3	4	5	Average
Late invitation of the commissioning agency to the project	0%	11%	8%	31%	50%	4.19
Difficulty in finding qualified personnel/service providers	0%	4%	11%	54%	31%	4.12
Difficulty in quantifying the obtained value	0%	4%	15%	69%	12%	3.88
Integrated testing required by some control systems	0%	0%	19%	81%	0%	3.81
Not carrying out the system tests under real operating conditions	0%	8%	27%	46%	19%	3.77
Individual functional tests missing whole system approach	0%	4%	31%	54%	11%	3.73
Initial extra cost required for the commissioning agency	0%	15%	27%	43%	15%	3.58
Lack of authority of the commissioning team	0%	15%	27%	46%	12%	3.54
Lack of details regarding the commissioning tests	0%	19%	19%	54%	8%	3.50
Understanding and testing new systems and technologies	4%	11%	23%	54%	8%	3.50
Pressure to perform commissioning remotely	0%	23%	23%	54%	0%	3.31

Nevertheless, the common approach in developing countries, as indicated in the previous section, is to invite the commissioning agents at the end of the construction phase. This attitude makes things hard for the commissioning team to follow a precise commissioning process. Another notable challenge is resource-related, which is the lack of qualified personnel/service providers. In developing countries, buildings are rarely commissioned by a professional third party due to financial obstacles. The scarcity of commissioning applications makes it difficult for the owners to find experienced service providers with a crowded list of recent references. Pressure to perform commissioning remotely, understanding and testing new systems and technologies, and lack of details regarding the commissioning test is found to be the least significant factors (less than or equal to 3.50) even though they have been frequently cited in the literature [45,46,47]. It is realized that these three factors belong to the technical category.

Table 3 presents the benefits obtained from the commissioning process. The most significant benefit has been observed as better documentation of installed building systems followed by early detection of problems decreasing post-occupancy work. Documentation is one of the key activities of the commissioning process. It includes up-to-date information regarding the design, construction, operation, maintenance, cleaning, management, and modifications to be used over the life of the building. Improving the documentation quality can make things easier for the facility management staff. Identification of problems in the early stages is considered another valuable outcome of the commissioning process.

Table 3. Benefits obtained from the commissioning process

Factors	Grades					
	1	2	3	4	5	Average
Better documentation of installed building systems	0%	4%	8%	42%	46%	4.31
Early detection of problems decreasing post-occupancy work	0%	0%	11%	50%	39%	4.27
Decreased operational and maintenance cost	0%	4%	15%	42%	39%	4.15
Well trained operation and maintenance staff	0%	4%	11%	50%	35%	4.15
Improved thermal comfort and indoor air quality	0%	4%	11%	58%	27%	4.08
Facility performance satisfying owner requirements	0%	0%	19%	62%	19%	4.00
Enhanced quality control during construction	0%	8%	11%	58%	23%	3.96
Improved planning and coordination	0%	4%	15%	62%	19%	3.96
Smoother handover of the project	0%	4%	19%	54%	23%	3.96
Satisfied building occupants with fewer complaints	0%	4%	27%	46%	23%	3.88
Minimized risk of project delay	0%	12%	34%	42%	12%	3.54
Fewer change orders and claims	4%	12%	38%	38%	8%	3.35

Potential problems that may arise due to inefficient system design and operation can be identified early in the construction phase, and responsible parties can provide cost-effective solutions to overcome them. Fewer change orders and claims are the least recognized benefit (the only benefit below 3.50) despite having been emphasized in numerous studies [6,19,49].

Criteria used for selecting the commissioning agency are summarized in Table 4. The most crucial features of commissioning agencies have been identified as commissioning experience in similar projects and experience in system testing and balancing. Both features are realized to be experience-related. Experience is a highly appreciated phenomenon for technically complicated processes that contain numerous uncertainties. As the commissioning process incorporates various technical challenges, experienced commissioning agents can shine amongst others. Having encountered typical scenarios can provide knowledge regarding how to deal with the challenges. Lessons learned in previous cases can help them identify not-so-obvious solutions. Having professional commissioning certification is the only criterion with an average below 4.00. The study performed by Elzarka [18] revealed that commissioning certification is highly appreciated in the United States. Almost two third of the respondents (63%) stated that certification is a good indication of a highly qualified commissioning agent. This situation clearly shows the difference between the developing and developed countries in terms of the emphasis given to the commissioning certification.

Data obtained from the questionnaire survey was used to compare the significance of the categories provided in the methodology part. Such a comparison would help the researchers identify whether a significant difference could be observed between the technical and non-technical challenges; the pre-occupancy and post-occupancy benefits; and the technical, experiential, and managerial features of the commissioning agents. In order to compare the mean values of the mentioned categories, parametric analyses such as t-test and ANOVA were intended to be used. However, these parametric tests require normal distribution of the data. Therefore, the normality of the data distribution was separately checked for the challenges, benefits, and commissioning agency selection criteria by using Kolmogorov-Smirnov and Shapiro-Wilk tests.

Table 4. Criteria for selecting the commissioning agency

Factors	Grades					
	1	2	3	4	5	Average
Experience in system testing and balancing	0%	0%	0%	50%	50%	4.50
Commissioning experience in similar projects	0%	0%	0%	50%	50%	4.50
Familiarity with codes and regulations	0%	0%	4%	50%	46%	4.42
Documentation and reporting abilities	0%	0%	8%	46%	46%	4.38
Knowledge of building operation and maintenance	0%	0%	8%	50%	42%	4.35
Ability to deliver operation and maintenance training	0%	0%	15%	50%	35%	4.19
Communication and interpersonal skills	0%	0%	19%	50%	31%	4.12
Team building and organization skills	0%	0%	8%	77%	15%	4.08
Having professional commissioning certification	0%	0%	27%	58%	15%	3.88

For the test of normality, the hypotheses are set as follows:

- H_0: Data is normally distributed.
- H_1: Reject H_0. Data is non-normally distributed.

The results are shown in Table 5. The significance values for both the Kolmogorov-Smirnov and Shapiro-Wilk tests are found to be lower than 0.05, indicating that H_0 is rejected and the data is non-normally distributed for challenges, benefits, and commissioning agency selection criteria. Rejection of the hypothesis leads to utilization of the non-parametric equivalence of the t-test and ANOVA, namely Mann-Whitney U and Kruskal-Wallis tests, for comparing the significance of the categories.

The descriptive statics for the challenges is shown in Table 6. The mean value of the non-technical challenges is noticed to be greater than the mean value of the technical challenges. In order to determine whether the difference between the means is significant, the non-parametric equivalent of the t-test, namely Mann-Whitney U test was employed.

The hypotheses for the Mann-Whitney U test are set as follows:

- H_0: Technical and non-technical challenges are equally important.
- H_1: Reject H_0. Technical and non-technical challenges are not equally important.

Table 7 shows the result of the Mann-Whitney U test. The difference between the mean values is observed to be significant as the asymptotic significance is less than 0.05. Therefore, it is concluded that non-technical challenges are more frequently encountered than technical challenges during the commissioning process. It is highly surprising to see that the commissioning process, being composed of technically complicated activities regarding systems and equipment, has non-technical challenges dominating the technical ones. These non-technical challenges belong to economic, procedural, or resource-related issues. In order to promote the commissioning process in developing countries, the focus point must be on non-technical issues rather than the technical ones.

Table 8 shows the descriptive statics for the benefits. Post-occupancy benefits are realized to have greater mean value than the pre-occupancy benefits. Again, to determine if the difference is significant, Mann-Whitney U test was employed.

The hypotheses are set as follows:

- H_0: Pre- and post-occupancy benefits are equally important.
- H_1: Reject H_0. Pre- and post-occupancy benefits are not equally important.

Table 9 shows that the significance value is 0.015, which is less than 0.05. Thus, H_0 is rejected and a significant difference is confirmed between pre- and post-occupancy benefits.

Table 5. Test of normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Challenges	0.310	858	0.000	0.845	858	0.000
Benefits	0.278	936	0.000	0.841	936	0.000
Commissioning Agency Selection	0.298	702	0.000	0.769	702	0.000

[a]Lilliefors Significance Correction

Table 6. Descriptive statistics for challenges

Challenges	Sample Size	Mean	Std. Deviation
Technical	468	3.60	0.807
Non-Technical	390	3.86	0.893
Total	858	3.72	0.857

Table 7. Mann-Whitney U test statistics for challenges

Item	Value
Mann-Whitney U	75586.500
Wilcoxon W	185332.500
Z	-4.742
Asymptotic Significance (2-tailed)	0.000

Table 8. Descriptive statistics for benefits

Benefits	Sample Size	Mean	Std. Deviation
Pre-Occupancy	468	3.85	0.864
Post-Occupancy	468	4.09	0.746
Total	936	3.97	0.816

Table 9. Mann-Whitney U test statistics for benefits

Item	Value
Mann-Whitney U	93460.500
Wilcoxon W	203206.500
Z	-4.214
Asymptotic Significance (2-tailed)	0.000

This situation may explain why the commissioning agents are lately invited to the projects in developing countries. Benefits of the commissioning process are assumed to be realized mostly during the post-construction phase. Hence, the pre-occupancy benefits can be overlooked and stakeholders may have the tendency to delay hiring of commissioning agents up to the end of construction. However, it must be noted that the extent of post-occupancy benefits usually depends on the robustness of the whole commissioning process. The quality of the process has been shown

to depend highly on the early involvement of the commissioning agents [52].

Descriptive statistics for the commissioning agency selection are shown in Table 10. The experiential features of the commissioning agent are detected as the most significant criteria followed by the technical and managerial features. The non-parametric equivalent of ANOVA, namely Kruskal-Wallis test, was intended to check whether a significant difference exists among the mean values of these three categories.

For the Kruskal-Wallis test, the hypotheses are set as follows:

- H_0: Technical, experiential, and managerial features are equally important.
- H_1: Reject H_0. Technical, experiential, and managerial features are not equally important.

Kruskal-Wallis test statistics are shown in Table 11. The asymptotic significance is less than 0.05, meaning that at least one of the categories has a different mean value.

In order to make a one-to-one comparison and understand which category is significantly more important than the other, post-hoc test was employed. Due to the non-normal distribution of the data, a non-parametric equivalent of the post-hoc test, namely the pairwise Mann-Whitney U-test, was utilized. The results of Mann-Whitney U-tests are summarized in Table 12. Significant differences are observed between technical and experiential categories; and between experiential and managerial categories. An insignificant difference is detected between the technical and managerial categories. Thus, it can be noted that the experiential features of commissioning agencies are significantly more important than the technical and managerial ones.

Table 10. Descriptive statistics for commissioning agency selection

Features	Sample Size	Mean	Std. Deviation
Technical	312	4.20	0.672
Experiential	234	4.47	0.526
Managerial	156	4.10	0.599
Total	702	4.27	0.628

Table 11. Kruskal-Wallis test statistics for commissioning agency features

Item	Value
Kruskal-Wallis H	38.358
df	2
Asymptotic Significance	0.000

Table 12. Mann-Whitney U test statics for commissioning agency features

	Tech. - Exp.	Exp. - Man.	Tech. - Man.
Mann-Whitney U	28962.000	12492.000	22086.000
Wilcoxon W	77790.000	24738.000	34332.000
Z	-4.614	-6.007	-1.823
Asymptotic Significance (2-tailed)	0.000	0.000	0.068

5. Conclusion

This study has investigated the building commissioning practices in Turkey as a developing country. Developing countries are known to fall behind in following the latest developments in the architectural, engineering, and construction industry. Thus, a number of critical building commissioning issues have been examined to assess the current situation in a developing country. Key observations of this study are summarized below:

- Commissioning agents are usually invited to the project at the end of construction, which can be considered the main obstacle to a successful implementation of commissioning.
- Commissioning agents are invited to the project earlier in developed countries, compared to developing countries.
- The existence of mandatory requirements can be considered the primary reason behind the implementation of commissioning practices.
- Even though commissioning is a highly technical process, the main challenges confronted in practice are non-technical (economic, procedural, or resource-related).
- Benefits are believed to largely occur in the post-occupancy period, which might explain why the commissioning agents are typically invited at the end of the construction phase.
- However, it should be noted that the extent of post-occupancy benefits depends considerably on the involvement time of commissioning agents. Early involvement of commissioning agents can greatly improve the process and thus, the benefits obtained.
- The experiential features of commissioning agents are appreciated more than their technical and managerial capabilities.
- Having commissioning certification is not appreciated as it is done in developed countries.

Based on the observations for Turkey as a representative of developing countries, owners are recommended to invite the commissioning agents in earlier phases. Commissioning agents should be invited at the schematic design phase to be able to deliver the best performance. Earlier involvement of commissioning agents can increase the quality of the final product, which in turn would provide savings due to the enhanced energy efficiency and fewer corrective actions. In addition, the significance of the commissioning process and commissioning certification should be emphasized. Although a high-quality commissioning process is beneficial to the project stakeholders from many perspectives, the benefits are not appreciated enough as the mandatory requirement is still the main reason behind its implementation. The benefits should be conveyed to key participants through conferences, seminars, or symposiums. Moreover, the focus point of industry organizations should be on non-technical challenges. The main challenges have been observed to be economic, procedural, or resource-related. Economic and procedural challenges might be overcome by emphasizing the significance of the commissioning process as already mentioned. It should be highlighted that the benefits obtained from a successfully conducted commissioning process outweighs its costs. Resource-related problems can be solved by establishing institutions that offer commissioning training and certification programs.

The research contributes to the knowledge by (i) revealing when commissioning agents are involved and why a client might need commissioning services, (ii) bringing a detailed explanation of the benefits obtained from the commissioning process, challenges encountered during the commissioning process, and key commissioning agency features; (iii) categorizing the underlying factors; (iv) developing some novel hypothesis, and (v) testing and discussing them based on data obtained from commissioning practices in a developing country. It is expected to promote the role of the commissioning process in the construction industry by presenting the key observations and emphasizing their significance to the building owner and building occupants.

Data were collected from 26 professionals, which can be considered a limitation. This is mainly due to the lack of experienced practitioners in Turkey. Obtaining greater data could lead to varying results that might slightly change the

observations. Also, the data was collected only from the building commissioning practitioners in Turkey. If a similar study is conducted in another developing country, different results could be obtained.

Ethics Committee Permission

The authors acquired ethics committee permission for surveys implemented in this manuscript from the Ethics Committee of Sakarya University of Applied Sciences (Date: 30.03.2022, No. E-26428519-044-43598).

Declaration of conflicting interests

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