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Collaborative and life cycle-based project delivery for environmentally sustainable building construction: views of Finnish project professionals and building operation and maintenance experts

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Abstract

Purpose – The energy performance gap (EPG) in building construction has been one of the major barriers to the realization of environmental and economic sustainability in the built environment. Although there have been a few studies addressing this issue, studying this topic with a special focus on the project delivery process has been almost overlooked. Hence, this study aims to address the EPG in building construction through the lens of collaborative and life cycle-based project delivery.

Design/methodology/approach – In order to realize the objective of this study, the development of a theoretical framework based on the literature review was followed by a qualitative study in which 21 semi-structured interviews were conducted with Finnish project professionals representing clients, design/planning experts, constructors and building operation/maintenance experts to explore their views on the topic under study.

Findings – The findings reveal the project delivery-related causes of EPG in building construction. Moreover, the obtained results present a collaborative and life cycle-based delivery model that integrates project and product (i.e. building) life cycles, and it is compatible with all types of contractual frameworks in building construction projects.

Research limitations/implications – Although the findings of this study significantly contribute to theory and practice in the field of collaborative and sustainable construction project delivery, it is acknowledged that these findings are based on Finnish professionals' input, and expanding this research to other regions is a potential area for further studies. Moreover, the developed model, although validated in Finland, needs to be tested in a broader context as well to gain wider generalizability.

Originality/value – The obtained results reveal the significance and impact of collaborative and life cycle-based project development and delivery on the realization of environmentally sustainable building construction.

Keywords Collaborative project delivery, Sustainable building construction, Life cycle-based project delivery, Construction management

Paper type Research paper

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Introduction

Buildings, in general, consume a striking amount of energy, accounting almost to 40% of the whole energy consumption in the world (Laconte and Gossop, 2016). This huge consumption profiles buildings as one of the main areas under focus for further research and development. Consequently, sustainable development goals (SDGs), outlined by United Nations, to a high extend apply to construction industry and, in particular, building construction projects. This high-level recognition has resulted in extensive research on the energy efficiency of building construction and renovation. Regarding building construction, there have been significant advancements (e.g. building information modeling, geothermal energy system), and subsequently the enhanced design expertise and capability in the past decade has aimed for high efficiency or even net-zero energy buildings, in which the amount of consumed and produced energy (i.e. electricity) are even. Although there have been some successes in the construction of highly energy efficient or net-zero-energy buildings in some of the developed countries (e.g. USA) (Kibert, 2016), many of newly constructed buildings have been still struggling to achieve the energy efficiency targets, developed in the design phase. This phenomenon is called energy performance gap (EPG) (Laconte and Gossop, 2016).

Energy performance gap has been one of the major barriers for the realization of environmental and economic sustainability in the built environment. Looking at the definition of EPG, it basically refers to one or more factors in the project life cycle and probably in the commissioning phase of the constructed building, which hinders the efficient performance of the building in terms of energy consumption. In this regard, studies addressing the barriers and enables of the EPG in building construction (e.g. Häkkinen and Belloni, 2011; Li and Yao, 2012; Moradi *et al.*, 2023; Qian *et al.*, 2015) have found that factors such as collaboration between parties, early involvement of key participants, designer's competence and integrating project delivery contribute toward solving the performance gap issue. These findings imply project delivery model's prominent role in filling the EPG because it accounts for the successful accomplishment of building construction projects. In this regard, there have been very few, if any, studies, employing collaborative project delivery as a theoretical lens for looking into the EPG issue. An important point to note is that the project delivery model's impact is not limited to the project life cycle; it also considerably affects the completed building's operational life cycle and the realization of energy efficiency goals. Thus, construction project delivery model needs to be collaborative and inclusive in terms of covering both project and product (i.e. building) life cycle.

However, the existing construction project delivery models mostly address project life cycle and almost avoid completed building's operation period. This is not a surprise as the terminology highlights the focus of the delivery model on the project only and not the product (i.e. constructed building). Consequently, the project parties are not usually held accountable in terms of their responsibility for the performance of the constructed building. This is particularly important for three reasons. First, the research shows that a completed building's operating costs in its operational life cycle can be even higher than its construction costs (Mike *et al.*, 2015). Second, realizing sustainable built environment is highly dependent on the actual performance of the buildings in terms of energy efficiency, not the design intentions. And third, actual performance of the building can be seen only in the operation phase. Hence, it seems that project and product life cycle and management are interconnected and need to be integrated in the context of building construction. Thus, further developments and improvements are needed.

In this regard, it is necessary to acknowledge that construction project delivery models have evolved significantly over the past 30 years. In the big picture, the mainstream typology of project delivery models divides them into three categories of traditional, collaborative, hybrid (Moradi *et al.*, 2022). Traditional delivery models in construction projects refer to design-bid-build, design-build and different types of construction management (e.g.

Construction Management (CM) and CM at Risk) (Forbes and Ahmed, 2010). In other words, the terminology associated with traditional delivery models comes from the name of the contract type used in those delivery models. The same logic somewhat applies to the collaborative delivery models which include alliance, partnering, lean project delivery (LPD) and integrated project delivery (IPD) (Engebø *et al.*, 2020; Lähdenpera, 2012; Mesa *et al.*, 2019). The hybrid category refers to those project delivery models which employ traditional contract but also take advantage of collaborative working practices like co-location of the project participants (Darrington, 2011; Moradi *et al.*, 2021a). Traditional delivery models are usually characterized by adversarial relationships, mistrust, unfair share of risk-reward, working in silos and dominance of low prince criteria for contractor selection. Conversely, collaborative delivery models feature early involvement of key participants; joint design, planning, control and decision making; open book cost management; aligned interests of stakeholders, continuous learning, fair share of risk-reward; open communication; and trust-based relationships (Moradi *et al.*, 2021b).

The emergence of collaborative delivery models has had a significant impact on the performance results of construction projects (e.g. Hanna, 2016; Ibrahim *et al.*, 2020). However, there are still two problematic issues left. The first one is the fact that traditional project delivery models are still dominant in many developing and developed countries and these countries are struggling to realize productive and sustainable building construction. The second issue is that even in collaborative project delivery models the shared risk-reward mechanism applies to the project life cycle and therefore the completed building's operational life cycle is taken into account in a limited manner. Thus, it is imperative to discover a solution for overcoming the mentioned challenges. Such solution could be developing a delivery model which is compatible with various contractual frameworks and tendering process in building construction projects and covers constructed building's life cycle. This study aims to realize this solution in order to the fill the mentioned knowledge gap and enable the realization of productive building construction and sustainable built environment in practice. Accordingly, this study's objective is to answer the following research questions:

RQ1. What are the project delivery-related barriers and solutions which affect the realization of energy efficiency targets in the operation phase of the constructed buildings?

RQ2. What kind of model can enable collaborative and life cycle-based delivery of building construction projects for filling the EPG?

The resultant article is structured in six sections, including the introduction, theoretical background, methodology, results, discussion and conclusions.

Theoretical background

Energy performance gap

When the measured (or actual) energy consumption of buildings differs from the expected energy consumption, the building is said to have an EPG (Zou *et al.*, 2018). This can mean the difference between simulated and measured energy performance or the difference between targets set by specifications or standards vs the measured performance. The EPG may exist may be observed in existing building as well as in retrofitting and new construction projects (Mahdavi *et al.*, 2021). In Europe, building energy efficiency is typically measured through the energy efficiency classification from A to G. While the EPG is typically mentioned in the context of higher-than-expected energy consumption, the gap may exist in either direction. For example, in the Swiss residential building stock buildings of low energy classification generally consume significantly less energy than assumed, while buildings of higher energy efficiency class tend to consume slightly more energy than expected (Cozza *et al.*, 2020).

However, Laconte and Gossop (2016) refer to cases where buildings are consuming as much as two or three times the designed energy. The EPG is also related to other types of building performance gaps, like issues with operations and indoor conditions (Rasmussen and Jensen, 2020). Frei *et al.* (2017) noted that the EPG can arise in three life cycle phases of the building: (1) design and planning (poor early design decisions, uncertainty in energy modeling, oversizing of systems), (2) construction and commissioning (economy over design, poor commissioning) and (3) operation (equipment issues, user interaction and change of building purpose). Boge *et al.* (2018) especially highlighted the role of early-phase planning. Saving money by not investing enough in the early stage may result in costly remedies in the operational stage and sometimes even permanent problems that cannot be fixed.

In the operational phase of the building, facility managers have a significant role. Borgstein *et al.* (2018) found that energy performance issues relate to poor management and improper operation of systems. Insufficient energy performance guidelines and poor documentation can result in a lack of proper setpoints or high night-time loads. Floor plans with too large control zones for equipment also prevent correct operation of building automation systems. Facility managers from the USA report that the main reasons for the EPG are (1) higher than expected use of energy by the occupants, (2) there being more than the designed number of occupants and (3) technology failures (Liang *et al.*, 2019). Facility managers are in principle expected to continually improve energy efficiency in buildings, but are not actually required or incentivized to do so. In fact, some facility managers actively avoid trying to fix issues so as not be held responsible for possible worsening of the gap, referring to unavoidable differences between theory and practice (Willan *et al.*, 2020). Fears of causing disturbances in building operations and unfamiliarity with data-driven tools prevent the use of data-based recommendations (Markus *et al.*, 2022). However, it can be argued that continual energy performance improvement should be a key role for facility managers. This role should be started early on, while planning and construction is still taking place (Boge *et al.*, 2018). While the complexity of modern building services technology can be a cause of the EPG, new technologies may also offer a solution. For example, machine learning can be used to predict EPG based on risk data. This allows the project participants to react to potential energy performance issues early on, before final decisions are made (Yılmaz *et al.*, 2023).

Definition of project delivery model

Building construction projects go through different phases which include definition, design, planning, construction, closure and handover. This process is usually called project delivery model which is also known as project delivery method or project delivery system. In this article, the term project delivery model is utilized. Project delivery model, according to Mesa *et al.* (2019), has three defining elements which are project organization, operational system and contractual relationships. Although the mentioned elements by Mesa *et al.* (2019) are inclusive, they seem to be missing an important piece which is the delivery process, referring to the steps and activities encompassing project and/or building life cycle and the involved people in each phase. If the delivery process is added to this collection, a new framework can be developed for defining project delivery model. This framework is shown in Figure 1. This theoretical foundation is of prime importance as the authors' have often observed in the literature and practice that a certain contract type or operational system or project organization is called as project delivery model whereas all the defining elements shown in Figure 1 need to be in place to have a construction project delivery model.

Collaborative project delivery

According to Moradi *et al.* (2022), "Collaborative delivery model is one of the umbrella terms which has been utilized by different scholars in reference to alliance, partnering, integrated project delivery, and lean project delivery." In terms of typology, according to Engebø *et al.* (2020), Mesa *et al.* (2019) and Lähdenpera (2012), it can be argued that partnering, alliance, IPD and LPD are the pure collaborative project delivery models. However, this study aims to provide an in-depth conceptualization of collaborative project delivery model in construction. To do so, if the framework shown in Figure 1 combined with the features of collaborative delivery models (mentioned earlier in the introduction), the result would be something like Figure 2, which provides a new framework for defining/distinguishing collaborative project delivery model in construction. The framework, shown in Figure 2, is consisted of two main elements. The first element is the defining factors of construction project delivery which include project organization, operational system, contractual framework and delivery process. And the second element is the relevant features of collaborative project delivery to the mentioned defining factors. For instance, the collaborative features related to project organization are trust-based relationships and join decision making.

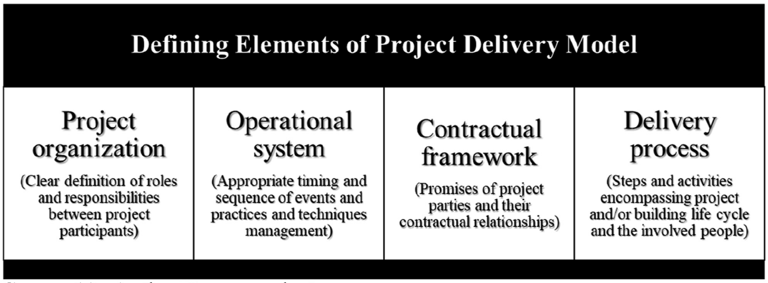

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Figure 1. Framework for defining project delivery model

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Figure 2. Conceptualization of collaborative project delivery model in construction

Previous research on collaborative project delivery models

Collaborative project delivery models have been extensively discussed in the recent review studies (e.g. Engebø *et al.*, 2020; Moradi *et al.*, 2022), and this study neither has aim to repeat those discussions in different words, nor it fits to the scope of this article. Instead, an abstract level analysis of the major studied themes is presented in Figure 3.

As can be seen, success factors and barriers is the only common theme among the conducted research on alliance, partnering, LPD and IPD. The study conducted by Moradi and Kähkönen (2022) has identified commonalities between success factors of collaborative delivery models. Among the research themes shown in Figure 3, success factors, trust and working relationship and team integration are the most relevant topics to the scope of this article. Hence, the findings of the studies representing those themes have been summarized and are shown in Table 1.

Research gap and theoretical framework

Collaborative project delivery models emerged, mainly, as a response and reaction to the five common challenges in traditional construction projects. These challenges include accident-free construction, reliability of planning, constructability of design, adversarial working relationships and dominance of low price for selecting the contractor (Forbes and Ahmed, 2010; Oakland and Marosszeky, 2017). The research shows that collaborative delivery models have had promising results in overcoming those challenges (e.g. Ibrahim *et al.*, 2020).

However, while the building code sets requirements for building energy consumption and developers set their own energy performance targets, a pitfall in both traditional and collaborative delivery models has been lackluster enforcement of these targets over the building's operational life cycle. Malfunctioning or inadequately calibrated systems due to lacking construction processes can often result in higher-than-expected energy consumption – an EPG. This gap is of prime importance for realizing sustainability goals, in particular environmental sustainability (energy efficiency and emission), as buildings account for almost 40% of global energy consumption (Laconte and Gossop, 2016).

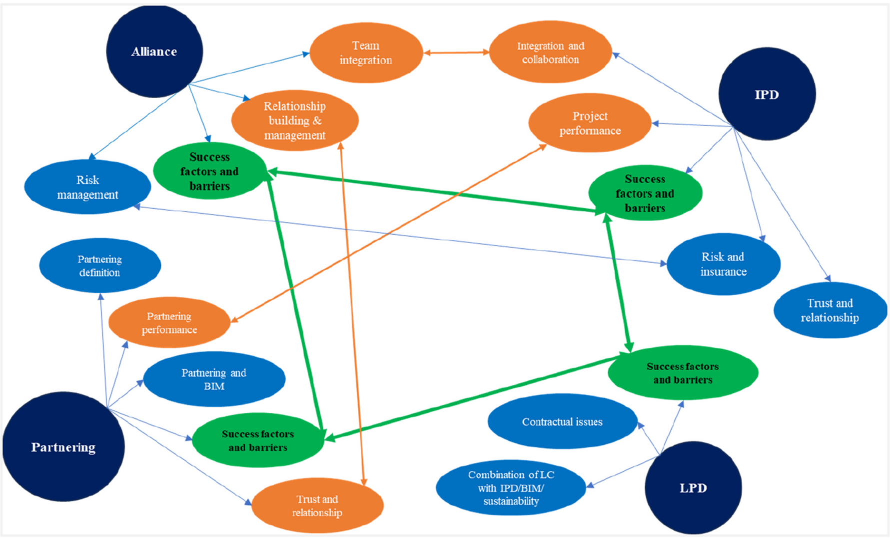

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Figure 3.
Major themes in the previous studies addressing collaborative project delivery models

Common theme	Delivery model	Main findings	Reference
Success factors and barriers	Alliance Partnering IPD	• According to the previous studies the common success factors for alliance, partnering and IPD include appropriate and relevant contract, commitment to win–win philosophy, collaboration and cooperation, equality, incentive system, open communication, mutual trust, selecting competent people for the project	Bellini *et al.* (2016) Hietajärvi *et al.* (2017a) Kent and Becerik-Gerber (2010) Ling *et al.* (2020) Lichtig (2005) Moradi and Kähkönen (2022) Nevstad *et al.* (2018) Chan *et al.* (2004 a, b) Cheng and Li (2004) Cho *et al.* (2010) MohammadHasanzadeh *et al.* (2014) Ng *et al.* (2002) Raslim and Mustaffa (2017) Whang *et al.* (2019) Young *et al.* (2016) Zhang and Kumaraswamy (2001)
	LPD	• Success factors for lean project delivery include a cooperative design phase including cross functional team members, supportive contract and procurement strategy, incorporating behavioral lean-based principles in the contract, fair share of risk/reward, incentive system, a combination of price competition, and competence-based criteria for selecting project team	Heidemann and Gehbauer (2010)
Trust and relationship between project parties	Alliance	• Trust, adequate resources, open communication, coordination, integration, top management support, creativity, and goal alignment are critical factors for the successful formation, operation, and evaluation phases of the relationship	Love *et al.* (2010)
		• Free-flowing, integrated and bi-directional communication is important for having good client–contractor relationships in the alliance projects	Lloyd and Varey (2003)
		• Informal socialization mechanisms are useful in both building relational capital (in terms of developing personal relationships, trust, and integration) in the tendering phase and enhancing it in the development phase, whereas formal socialization mechanisms (e.g. co-locational space) are mainly effective in the development phase for maintaining relational capital	Aaltonen and Turkulainen (2018)
	Partnering	• There are four types of owner-contractor relationships: (1) Adversarial, (2) Guarded adversarial, (3) Informal partners, and (4) Project partners • The stability of working relationships varies depending upon how the relationship commence. Projects that begin as formal partnerships are the most stable with over two-thirds ending as they began • The reasons for a declining relationship include unclear contracts and resulting litigation, changes in scope and schedules, personnel, failure to perform, lack of trust, and underbidding contracts • The reasons for improving relationships include trust and positive relationships, shared goals, teamwork and communication, personnel changes and the presence of a clear contract	Drexler and Larson (2000)
		• Developing a tool for supporting partnering relation management in the implementation of construction projects using AHP and Fuzzy AHP methods	Radziszewska-Zielina and Szewczyk (2016)
		• Transformation towards strategic partnering should preferably be based on extension of project partnering in two dimensions: extension in time through relationship development with suppliers and extension in space through increasing network orientation across projects	Sundquist *et al.* (2018)

(continued)

Table 1. Main findings of the previous studies addressing success factors, trust and relationship and team integration in the context of collaborative project delivery models

Common theme	Delivery model	Main findings	Reference
Team integration	Alliance	• Key indicators of alliance team integration, which include team leadership, trust and respect, single team focus on project objectives and key results areas, collective understanding, commitment from project alliance board, the creation of single and collocated alliance team, and free flow communication	Ibrahim *et al.* (2015a, b) Ibrahim *et al.* (2016) Ibrahim *et al.* (2018)
		• Everyday dynamics are very important for managing integration. They also stated that project complexity and a lack of previous collaboration experience among participants increase the uncertainty of the project and create a need for high levels of integration	Hietajärvi *et al.* (2017b, c)
	IPD	• Collaboration contributes toward team integration • Frequent interaction of project parties in IPD projects foster mutual trust and improve collaboration and team integration	Lee *et al.* (2013) Franz *et al.* (2017) Zhang *et al.* (2016)
		• Factors such as the early involvement of the contractor in the project can be useful for team integration	Mollaoglu-Korkmaz *et al.* (2013)
	Alliance, IPD, LPD, and partnering	• Establishing the equality and mutual respect between project team members is the fundamental step toward trust development and open communication • Equality is the fair share of organizational and contractual authority, responsibility, risk, and reward between project parties and team members throughout the project • Equality and mutual respect together with mutual trust and open communication seem to be the prerequisites for constructive collaboration and cooperation between project team members • Achieving team integration requires collaboration (working together) and cooperation (exchanging information) between project participants for the best of the project	Moradi *et al.* (2022)

Source(s): Authors' own work

Table 1.

This becomes even more important if it is noted that there is usually a considerable EPG in building construction projects in terms of the discrepancy between design intentions and actual energy consumption of the building (Laconte and Gossop, 2016). In this regard, the project delivery model seems to have a big role in this EPG. Thus, studying sustainable and collaborative project delivery for building construction with a life cycle perspective is a major research gap which needs to be addressed. Hence, this study aims to do so through developing a conceptual framework (see Figure 4), identifying the causes of EPG associated with the project delivery and validating the developed framework to be resulted in the development of a state-of-the-art delivery model which can enable the realization of productive building construction and sustainable built environment in practice.

Methodology

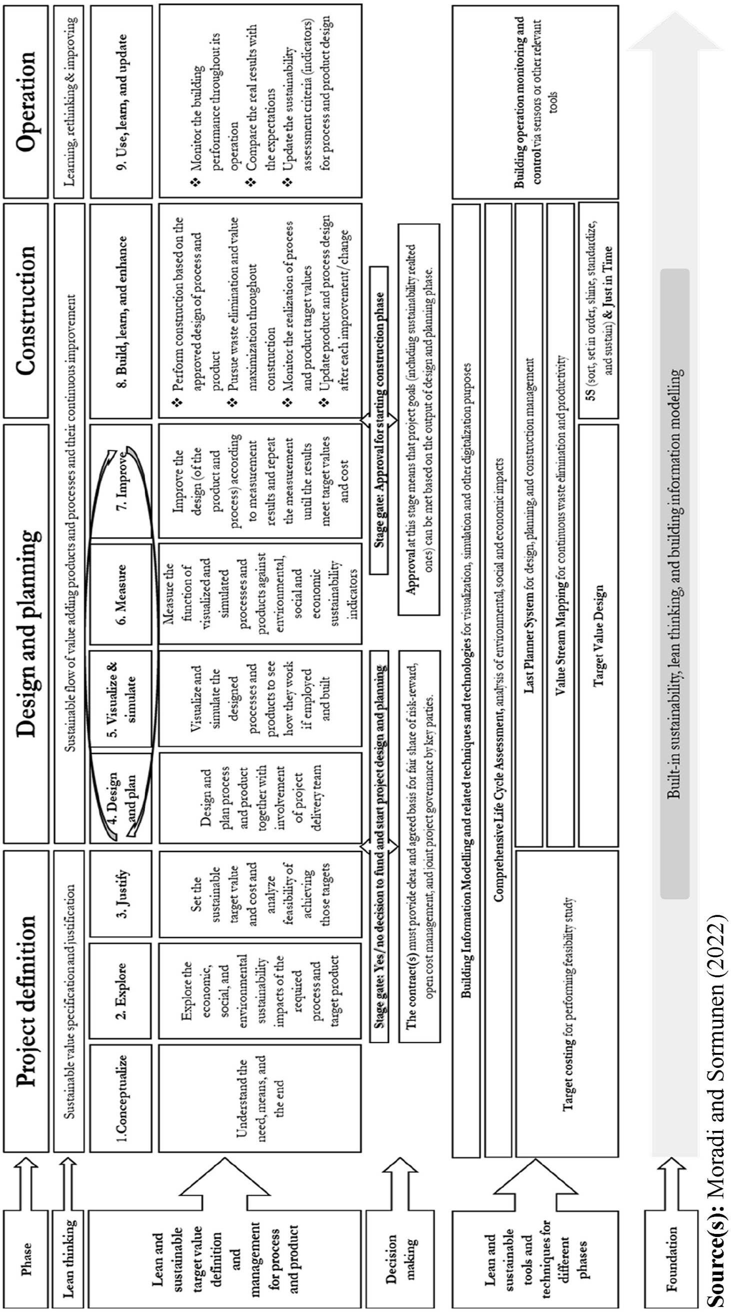
Research design

This study aims to address the EPG in building construction through the lens of project delivery model. To do so, the research process started with formulating the following research questions:

(1) What are the challenges/barriers of achieving energy efficiency in building construction projects which are related to project delivery process?

(2) What kind of project delivery model could contribute toward filling the EPG in building construction projects?

Due to the adequacy of literature on the addressed topic in this study, the deductive approach was adopted (Saunders *et al.*, 2019). Accordingly, literature study and semi-structured



Source(s): Moradi and Sormunen (2022)

Figure 4.
Conceptual model for collaborative and sustainable delivery of building construction projects

interviews were selected as the data collection methods and thematic as well as content analysis as the data analysis methods. These choices were justified with regard to the exploratory purpose of the research (Saunders *et al.*, 2019). The next step in the research design was to determine the context of study and make a choice about the sampling method. To do so, building construction and renovation projects was selected as the focus of the study. In terms of the building type (construction category), residential buildings, institutional buildings (i.e. school and hospital) and commercial buildings (i.e. shopping mall and office building) were included in the scope of the study.

Concerning sampling method, a combination of quota sampling and purposive sampling method (Saunders *et al.*, 2019) was utilized in this study through which four groups of interviewees were specified by the research team. These interviewee groups included (1) client project manager, (2) contractor project manager, (3) design manager and (4) property management (i.e. building operation and maintenance) experts. The research team targeted at least five interviewees in each group with a provision to conduct more interviews in each group if data saturation was not achieved (Saunders *et al.*, 2019). Then, the research team filled each quota by intentionally choosing relevant individuals (i.e. interviewees) in the possession of relevant knowledge and experiences related to the quota and the research topic. The defined interviewee groups in this study provided a basis for life cycle-based and inclusive study of performance gap through the lens of project delivery process based on the input from key project participants in different phases of project life cycle. The life-perspective in data collection was imperative due to the diversity of disciplines involved in the design, construction and operation of a building.

Data collection

Data collection started with formulating the protocol and questions of the semi-structured interviews. The developed questions aimed to the explore the *project delivery-related causes* behind the EPG in building construction projects based on the viewpoints of key project participants involved in different phases of project life cycle. The developed interview protocol and questions was piloted in the first four interviews (one interview in each interviewee group) to seek feedback from the interviewees. Since there was neither negative feedback nor any changes in the interview protocol and questions, the first four interviews, which had been conducted with piloting purpose, were also considered valid to be analyzed in the data analysis stage.

In the next step, the research team conducted 21 semi-structured interviews in Finland with project professionals representing client, design/planning experts, contractors and building operation/maintenance experts. Since data saturation was achieved in each interviewee group, there was no need for conducting additional interviews (Saunders *et al.*, 2019). The conducted interviews were audio recorded based on the obtained consent from the interviewees. Then they were transcribed and translated to English language by the native Finnish speaking member of the research team. Table 2 shows interviewees' discipline, role and their latest project's type, budget and duration. In addition, Figure 5 shows the demographic information of the interviewees.

Data analysis and validation

The analysis process started with thematic analysis which was performed by inductively coding the extracted research data as a result of analyzing the interview transcripts. The labels of the codes were data derived by the researcher (Saunders *et al.*, 2019). Validating the generated codes was accomplished through reviewing them three times (each time by one member of the research team) and making the required corrections. The validated codes representing project delivery were formed a theme titled "project delivery."

Interviewee group	Role in the latest project	Type of the latest project	Budget of the latest project's
Project management (client)	Project manager	Building construction	€150,000,000
	Site manager	Building renovation	€52,000,000
	Project manager	Building construction	€7,000,000
	Project manager	Building renovation	€10,000,000
	Project manager	Building renovation	€10,000,000
Design management	Geothermal heating design consultant	Building construction	€30,000,000
	Principal HVAC designer	Building construction	€75,000,000
	Architect	Building construction	€140,000,000
	Structural designer	Building construction	€40,000,000
	Design manager	Building renovation	€2,000,000
Project management (contractor)	Design and sustainability manager	Building renovation	€80,000
	Project manager	Building construction	€40,000,000
	Project manager	Building renovation	€1,000,000
	Project manager	Building construction	€90,000,000
	Head of Project Business Unit	Building construction	€110,000,000
Property management (i.e. building operation and maintenance)	Service delivery manager	Ongoing maintenance of existing buildings	€300,000
	Real estate manager	Building construction	€300,000,000
	Real estate manager	Ongoing maintenance of existing buildings	€60,000
	Service unit director	Ongoing maintenance of existing buildings	€200,000
	Chief strategy officer	Ongoing maintenance of existing buildings	€500,000
	Senior Specialist, indoor air	Ongoing maintenance of existing buildings	€200,000,000

Source(s): Authors' own work

Table 2. Interviewees' discipline, role and their latest project's type, budget and duration

The establishment of the themes was done based on the sameness or similarity of the codes in terms of the meaning and/or title. Then, a content analysis was performed through which the challenges/barriers and solutions/enablers in the established themes were listed and synthesized based on the similarity or sameness of the title and/or meaning. Finally, the cross validation was carried out through showing the results of thematic and content analysis to the interviewees to ensure the interpretations made in the analysis process were valid. All the interviewees approved the results of thematic and content analysis.

Model development

Following the cross validation, the identified barriers and enablers together provided a basis for modifying the developed conceptual framework (Figure 4) in the literature study and developing a collaborative and life cycle-based delivery model for sustainable building construction. The developed model was validated in two steps. The first step of the validation included two case studies in which the modified model was shown to the project managers of one successful and one unsuccessful building construction project (in terms of energy efficiency and on time and on budget completion) to seek their feedback. The obtained feedback from the case projects was then applied, and the developed delivery model was validated.

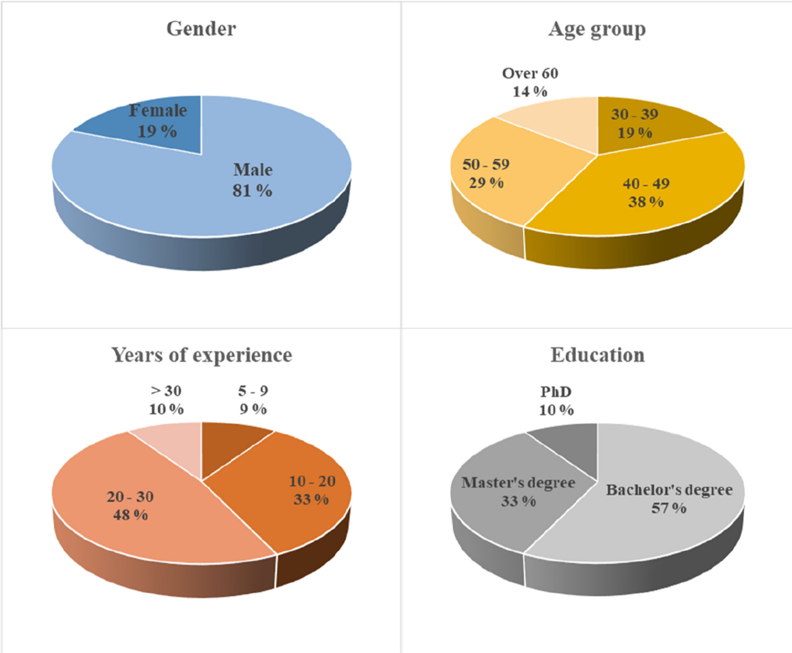


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Figure 5. Demographic information of the interviewees

Results

Project delivery related challenges and solutions of energy performance gap in building construction

Analyzing the conducted interviews resulted in the identification of several barriers and solutions for achieving energy efficiency in building construction projects (see Appendix). Among them, some were frequently mentioned by the interviewees, which are shown in Table 3. As the barriers and enablers implies, the existing delivery models (both collaborative and traditional) ignore the building performance in its operational life cycle and lack

Table 3. Project delivery-related challenges and solutions of realizing energy efficiency

Challenge/barrier
Lack of/inadequate involvement of HVAC contractors and operation/maintenance people in the project definition and design phase
Fragmented (i.e. divided/isolated) procurement, project delivery, and maintenance process (multiple contracts) of energy efficient systems
Dominance of low-price criteria in the tendering process for selecting contractors which usually have low capacity to deliver their promises
Solution/enabler
Life cycle contract
Collaborative project delivery model
Involving building services people in the project definition and design phase
Involvement of client and its representative (consultant) from project definition phase until the end of the project
Early definition of the use of the building and its spaces

Source(s): Authors' own work

sufficient strength for involving building services and maintenance experts in building design and construction phases. Moreover, limiting the contractor's responsibility to the project life cycle causes fragmentation in the maintenance and optimization of building operation. Dominance of low-price criteria for tendering is another chronic problem which results in the selection of low-capacity contractors who fail to deliver the project efficiently and are incapable of taking responsibility for the building performance in its operational life cycle. Thus, collaborative and life cycle-based delivery model seems to be a viable solution for filling the EPG in building construction projects.

Collaborative and life cycle-based project delivery model (CLCPDM) for sustainable building construction

The literature study and obtained data provided a basis for the development of a collaborative and life cycle-based project delivery model (CLCPDM) for sustainable building construction. This model has two versions: (1) The abstract version, as can be seen in Figure 6, shows the main steps in the delivery of the project and operation of the building and the main output in each step, and (2) the detailed version also includes descriptions of what happens in each step (see Figure 7).

This model has two key differences with the existing delivery models in the literature. First, CLCPDM is inclusive and covers both project life cycle and operational life cycle of the constructed building. Second, it has a combined feature of both traditional and collaborative construction projects, thereby increasing its compatibility with both contexts. The second feature also combines the strengths of both collaborative and traditional delivery models and covers their weaknesses. In other words, it is new a generation of construction project delivery model with capability to realize productivity and sustainability in both project and product life cycle.

In short, the developed model:

(1) Fully realizes the significance of proper project definition, feasibility study and competent as well as price-based contractor selection,

(2) Involves the design team and contractor when they have the highest impact,

(3) Features life cycle-based and collaborative project definition and design,

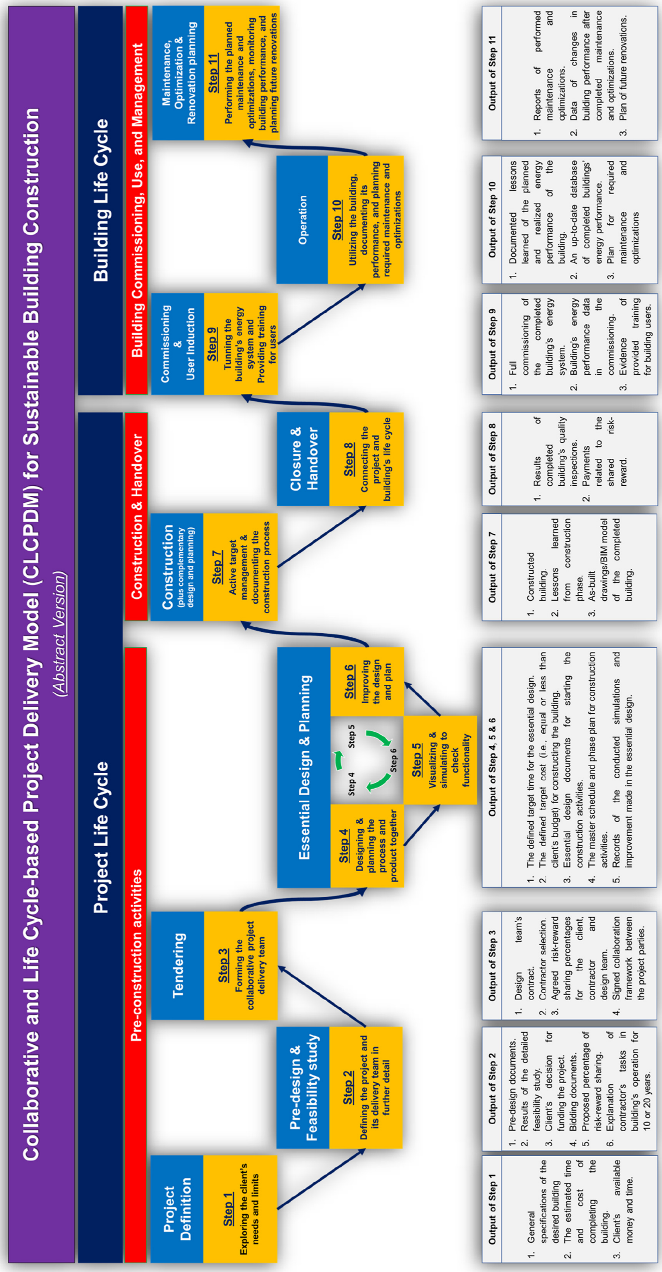
(4) Treats essential design and planning as an iterative cycle to realize the required improvements,

(5) Employs collaborative tools and working practices in design and construction phases and

(6) prioritizes systematic and continuous documentation of project and building performance data.

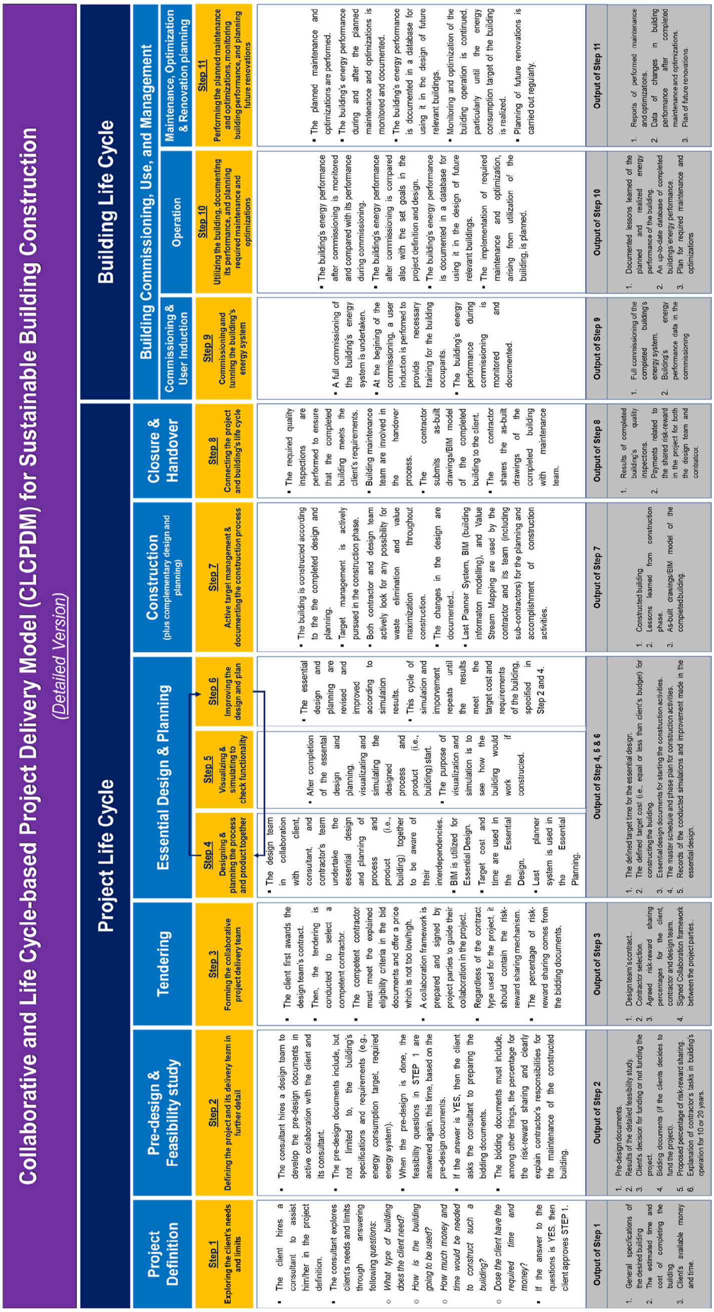
Discussion

Project delivery has been a mechanism for the successful completion of construction projects. The traditional model of this mechanism has not yielded satisfactory results most of the time, particularly in the complex projects, resulting in the over budget, waste, low quality, accident full and delayed delivery of building construction projects (e.g. Forbes and Ahmed, 2010; Moradi and Sormunen, 2023). Collaborative project delivery emerged to be an effective replacement, and it has had promising performance results (e.g. Hanna, 2016; Ibrahim *et al.*, 2020). In spite of this advancement, building construction projects, to a high extent, are still struggling to meet the environmental sustainability goals; their actual energy consumption is



Source(s): Authors' own work

Figure 6.
Abstract version of collaborative and life cycle-based project delivery model (CLCPDM) for sustainable building construction



Source(s): Authors' own work

Figure 7.
Detailed version of collaborative and life cycle-based project delivery model (CLCPDM) for sustainable building construction

considerably higher than expectations (e.g. Laconte and Gossop, 2016). Of course, there are several factors behind this EPG phenomenon one of which is project development and delivery process (Moradi and Sormunen, 2022). In fact, this factor happens to be a major cause of the EPG. In particular, the findings showed that inadequate and/or late involvement of key project participants (including building services people) together with fragmented project delivery and maintenance process and dominance of low-price criteria for contractor selection are the key barriers of achieving energy efficiency in building construction (Moradi *et al.*, 2023). The identified enablers in this study were relevant to the barriers, which can be seen as an indication of the reliability of the obtained results.

The involvement issue can be explained as the missing impact which contractor as well as maintenance experts can have in the project definition and design stages. In other words, these people are a dynamic database of building performance data which can help the client and design team to first reasonably define the goals and then provide input for ensuring constructability of the design in the construction phase and functionality of building in its operation phase. The fragmented project delivery and maintenance exactly reflects on the discovered research gap in this study and its purpose, addressing the fact that project and product life cycle need to be integrated and the key people involved in project life cycle need to be involved and accountable in the product life cycle as well. Finally, the third issue, dominance of low-price criteria, has been a problem for a long time which results in the selection of low-capacity contractors which do not have the required resource and competence. Although collaborative delivery models (e.g. alliance, IPD) has removed this dominance and mostly consider the competency as the selection criteria, they are also missing an important point which is the reasonable price offered by the contractor. Thus, it seems that a mature contractor selection mechanism needs to take into account both tendering (based on a reasonable price range specified in the project definition) and contractor's capacity (i.e. experience, knowledge, adequate financial resources, sufficient and competent workforce), as the competency criteria. The same selection logic must be also applied for employing the design team. The mentioned solutions in Table 3 concisely characterize the project delivery model, developed in this study, which can overcome the related barriers for achieving energy efficiency in building construction.

The obtained results in this study contribute to the existing body of knowledge in two aspects. First, the findings fill the knowledge gap on the role of project development and delivery in the EPG in building construction. To the best of the knowledge of the authors, this is the first study looking into the EPG in building construction through the lens of project development and delivery process. The second contribution is the development of a novel delivery model which features collaboration and life cycle perspective as its building blocks, and it is yet compatible with the traditional contracts and tendering processes. In other words, CLCPDM is the new generation of construction project delivery model which contributes toward productivity and sustainability achievement in both project and product (i.e. constructed building) life cycle.

From practical perspective, the discussed challenges and solutions together with the developed delivery model informs project professionals and clients on the project delivery related causes of EPG and then provide a practical solution for collaborative and life cycle-based project development and delivery. In particular, the model provides a practical guidance for clients on how to develop their project with a life cycle perspective over the benefits and loss resulting from different decisions. It also reveals the best time for involving the design team and contractor to benefit from their impact.

Although the main focus of the developed model (Figures 6 and 7) is on the delivery process, it still includes the application of relevant tools for measurement, simulation, monitoring and optimization purposes, but does not prescribe/recommend any specific tool. Such optimization could be performed with the help of a digital twin that allows the real-time comparison of actual energy performance to that predicted by simulations (Spudys *et al.*, 2023). A digital twin might be created from building information modeling (BIM) data that are used in the design phase of the building. The combination of BIM and digital twins could also be used to expand the life cycle optimization to cover not only environmental, but also social and economic impacts (Boje *et al.*, 2023). As more and more data from buildings becomes available, increasingly accurate prediction of building energy consumption can be made using machine learning methods (Miller *et al.*, 2020). Artificial intelligence (AI)-based systems may be used to optimize various aspects of buildings, such as energy consumption, thermal comfort and lighting conditions, both in the design and operational phases of the building life cycle (Mousavi *et al.*, 2023). Accordingly, there is a great potential for the continuous improvement of construction project delivery through the integration of dynamic digital tools like BIM and digital twins.

Conclusions

This study aimed at discovering the project delivery related barriers and solutions of realizing energy efficiency in building construction projects and to develop a collaborative and life cycle-based delivery model for sustainable building construction. This was accomplished through a literature review combined with a qualitative study involving semi-structured interviews. The opinion of project professionals representing client, design, contractor and property management (i.e. building operation and maintenance experts) were obtained and analyzed. Accordingly, it is concluded that:

(1) The project delivery model considerably accounts for the success or failure of the realization of energy efficiency in building construction projects.

(2) Involvement of building services experts and maintenance people in the project definition and design seem to enhance the constructability of the building services design and functionality of the building's Heating, Ventilation, and Air conditioning (HVAC) system in the operation phase.

(3) Project delivery contract should expand the responsibilities (including risk and reward) of project parties into the constructed building's operational life cycle.

(4) Collaborative and life cycle-based delivery model combines strengths of both traditional and collaborative delivery models' and covers their weaknesses. The developed model in this study fulfills this purpose.

The obtained results in this study considerably contribute toward existing body of knowledge in two areas of EPG in building construction and collaborative project delivery. However, it is acknowledged that the findings are based on Finnish professionals' input and expanding this research to other regions is a potential area for further research. Moreover, the developed model, although validated in Finland, needs to be tested in a broader context as well to increase its generalizability. Furthermore, it is also acknowledged that in this study the interviews were conducted with certain groups of professionals involved in project delivery process and building operation as well as maintenance, and including building users as the fifth groups of interviewees could have been value adding. Hence, obtaining building users' input is suggested to be considered in the future relevant studies.

References

Aaltonen, K. and Turkulainen, V. (2018), "Creating relational capital through socialization in project alliances", *International Journal of Operations and Production Management*, Vol. 38 No. 6, pp. 1387-1421, doi: 10.1108/IJOPM-02-2017-0091.

Bellini, A., Aarseth, W. and Hosseini, A. (2016), "Effective knowledge transfer in successful partnering projects", *Energy Procedia*, Vol. 96, pp. 218-228, doi: 10.1016/j.egypro.2016.09.127.

Boge, K., Salaj, A., Bjørberg, S. and Larssen, A.K. (2018), "Failing to plan – planning to fail: how early phase planning can improve buildings' lifetime value creation", *Facilities*, Vol. 36 Nos 1/2, pp. 49-75, doi: 10.1108/F-03-2017-0039.

Boje, C., Menacho, Á.J.H., Marvuglia, A., Benetto, E., Kubicki, S., Schaubroeck, T. and Gutiérrez, T.N. (2023), "A framework using BIM and digital twins in facilitating LCSA for buildings", *Journal of Building Engineering*, Vol. 76, 107232, doi: 10.1016/j.jobe.2023.107232.

Borgstein, E.H., Lamberts, R. and Hensen, J.L.M. (2018), "Mapping failures in energy and environmental performance of buildings", *Energy and Buildings*, Vol. 158, pp. 476-485, doi: 10.1016/j.enbuild.2017.10.038.

Chan, A.P., Chan, D.W., Chiang, Y.H., Tang, B.S., Chan, E.H. and Ho, K.S. (2004a), "Exploring critical success factors for partnering in construction projects", *Journal of Construction Engineering and Management*, Vol. 130 No. 2, pp. 188-198, doi: 10.1061/(ASCE)0733-9364(2004)130:2(188).

Chan, A.P., Scott, D. and Chan, A.P. (2004b), "Factors affecting the success of a construction project", *Journal of Construction Engineering and Management*, Vol. 130 No. 1, pp. 153-155, doi: 10.1061/(ASCE)0733-9364(2004)130:1(153).

Cheng, E.W. and Li, H. (2004), "Development of a practical model of partnering for construction projects", *Journal of Construction Engineering and Management*, Vol. 130 No. 6, pp. 790-798, doi: 10.1061/(ASCE)0733-9364(2004)130:6(790).

Cho, K., Hyun, C., Koo, K. and Hong, T. (2010), "Partnering process model for public-sector fast-track design-build projects in Korea", *Journal of Management in Engineering*, Vol. 26 No. 1, pp. 19-29, doi: 10.1061/(ASCE)0742-597X(2010)26:1(19).

Cozza, S., Chambers, J. and Patel, M.K. (2020), "Measuring the thermal energy performance gap of labelled residential buildings in Switzerland", *Energy Policy*, Vol. 137, 111085, doi: 10.1016/j.enpol.2019.111085.

Darrington, J. (2011), "Using a design-build contract for lean integrated project delivery", *Lean Construction Journal*, pp. 85-91, available at: https://lean-construction-gcs.storage.googleapis.com/wp-content/uploads/2022/08/08161000/Design-build_contract_for_Lean_IPD.pdf

Drexler, J.A., Jr. and Larson, E.W. (2000), "Partnering: why project owner-contractor relationships change", *Journal of Construction Engineering and Management*, Vol. 126 No. 4, pp. 293-297, doi: 10.1061/(ASCE)0733-9364(2000)126:4(293).

Engebø, A., Lædre, O., Young, B., Larssen, P.F., Lohne, J. and Klakegg, O.J. (2020), "Collaborative project delivery methods: a scoping review", *Journal of Civil Engineering and Management*, Vol. 26 No. 3, pp. 278-303, doi: 10.3846/jcem.2020.12186.

Forbes, L.H. and Ahmed, S.M. (2010), *Modern Construction: Lean Project Delivery and Integrated Practices*, CRC Press, Boca Raton, FL, ISBN: 9780429145278.

Franz, B., Leicht, R., Molenaar, K. and Messner, J. (2017), "Impact of team integration and group cohesion on project delivery performance", *Journal of Construction Engineering and Management*, Vol. 143 No. 1, doi: 10.1061/(ASCE)CO.1943-7862.0001219.

Frei, B., Sagerschnig, C. and Gyalistras, D. (2017), "Performance gaps in Swiss buildings: an analysis of conflicting objectives and mitigation strategies", *Energy Procedia*, Vol. 122, pp. 421-426, doi: 10.1016/j.egypro.2017.07.425.

Häkkinen, T. and Belloni, K. (2011), "Barriers and drivers for sustainable building", *Building Research and Information*, Vol. 39 No. 3, pp. 239-255, doi: 10.1080/09613218.2011.561948.

Hanna, A.S. (2016), "Benchmark performance metrics for integrated project delivery", *Journal of Construction Engineering and Management*, Vol. 142 No. 9, doi: 10.1061/(ASCE)CO.1943-7862.0001151.

Heidemann, A. and Gehbauer, F. (2010), "Cooperative project delivery in an environment of strict design-bid-build tender regulations", *Proceedings of the 18th Annual Conference of the International Group for Lean Construction (IGLC-18)*, Perth, 28-31 July, pp. 590-591, available at: https://iglc.net/Papers/Details/674

Hietajärvi, A.M., Aaltonen, K. and Haapasalo, H. (2017a), "What is project alliance capability?", *International Journal of Managing Projects in Business*, Vol. 10 No. 2, pp. 404-422, doi: 10.1108/IJMPB-07-2016-0056.

Hietajärvi, A.M., Aaltonen, K. and Haapasalo, H. (2017b), "Opportunity management in large projects: a case study of an infrastructure alliance project", *Construction Innovation*, Vol. 17 No. 3, pp. 340-362, doi: 10.1108/CI-10-2016-0051.

Hietajärvi, A.M., Aaltonen, K. and Haapasalo, H. (2017c), "Managing integration in infrastructure alliance projects: dynamics of integration mechanisms", *International Journal of Managing Projects in Business*, Vol. 10 No. 1, pp. 5-31, doi: 10.1108/IJMPB-02-2016-0009.

Ibrahim, C.K.I.C., Costello, S.B. and Wilkinson, S. (2015a), "Establishment of quantitative measures for team integration assessment in alliance projects", *Journal of Management in Engineering*, Vol. 31 No. 5, doi: 10.1061/(ASCE)ME.1943-5479.0000318.

Ibrahim, C.K.I.C., Costello, S.B. and Wilkinson, S. (2015b), "Development of an assessment tool for team integration in alliance projects", *International Journal of Managing Projects in Business*, Vol. 8 No. 4, pp. 813-827, doi: 10.1108/IJMPB-02-2015-0019.

Ibrahim, C.K.I.C., Costello, S.B. and Wilkinson, S. (2016), "Application of a team integration performance index in road infrastructure alliance projects", *Benchmarking: An International Journal*, Vol. 23 No. 5, pp. 1341-1362, doi: 10.1108/BIJ-06-2015-0058.

Ibrahim, C.K.I.C., Costello, S.B. and Wilkinson, S. (2018), "Making sense of team integration practice through the 'lived experience' of alliance project teams", *Engineering, Construction and Architectural Management*, Vol. 25 No. 5, pp. 598-622, doi: 10.1108/ECAM-09-2016-0208.

Ibrahim, M.W., Hanna, A. and Kievet, D. (2020), "Quantitative comparison of project performance between project delivery systems", *Journal of Management in Engineering*, Vol. 36 No. 6, doi: 10.1061/(ASCE)ME.1943-5479.0000837.

Kent, D.C. and Becerik-Gerber, B. (2010), "Understanding construction industry experience and attitudes toward integrated project delivery", *Journal of Construction Engineering and Management*, Vol. 136 No. 8, pp. 815-825, doi: 10.1061/(ASCE)CO.1943-7862.0000188.

Kibert, C.J. (2016), *Sustainable Construction: Green Building Design and Delivery*, John Wiley & Sons.

Laconte, P. and Gossop, C. (2016), *Sustainable Cities: Assessing the Performance and Practice of Urban Environments*, Bloomsbury Publishing, New York, NY, ISBN: 978-1784532321.

Lahdenperä, P. (2012), "Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery", *Construction Management and Economics*, Vol. 30 No. 1, pp. 57-79, doi: 10.1080/01446193.2011.648947.

Lee, H.W., Tommelein, I.D. and Ballard, G. (2013), "Energy-related risk management in integrated project delivery", *Journal of Construction Engineering and Management*, Vol. 139 No. 12, A4013001, doi: 10.1061/(ASCE)CO.1943-7862.0000753.

Li, B. and Yao, R. (2012), "Building energy efficiency for sustainable development in China: challenges and opportunities", *Building Research and Information*, Vol. 40 No. 4, pp. 417-431, doi: 10.1080/09613218.2012.682419.

Liang, J., Qiu, Y. and Hu, M. (2019), "Mind the energy performance gap: evidence from green commercial buildings", *Resources, Conservation and Recycling*, Vol. 141, pp. 364-377, doi: 10.1016/j.resconrec.2018.10.021.

Lichtig, W.A. (2005), "Sutter health: developing a contracting model to support lean project delivery", *Lean Construction Journal*, Vol. 2, pp. 105-112, doi: 10.60164/70f9c0e7d.

Ling, F.Y., Teo, P.X., Li, S., Zhang, Z. and Ma, Q. (2020), "Adoption of integrated project delivery practices for superior project performance", *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 12 No. 4, 05020014, doi: 10.1061/(ASCE)LA.1943-4170.0000428.

Lloyd, H.L. and Varey, R.J. (2003), "Factors affecting internal communication in a strategic alliance project", *Corporate Communications: An International Journal*, Vol. 8 No. 3, pp. 197-207, doi: 10.1108/13563280310487658.

Love, P.E., Mistry, D. and Davis, P.R. (2010), "Price competitive alliance projects: identification of success factors for public clients", *Journal of Construction Engineering and Management*, Vol. 136 No. 9, pp. 947-956, doi: 10.1061/(ASCE)CO.1943-7862.0000208.

Mahdavi, A., Berger, C., Amin, H., Ampatzi, E., Andersen, R.K., Azar, E., Barthelmes, V.M., Favero, M., Hahn, J., Khovalyg, D. and Knudsen, H.N. (2021), "The role of occupants in buildings' energy performance gap: myth or reality?", *Sustainability*, Vol. 13 No. 6, 3146, doi: 10.3390/su13063146.

Markus, A.A., Hobson, B.W., Gunay, H.B. and Bucking, S. (2022), "Does a knowledge gap contribute to the performance gap? Interviews with building operators to identify how data-driven insights are interpreted", *Energy and Buildings*, Vol. 268, 112238, doi: 10.1016/j.enbuild.2022.112238.

Mesa, H.A., Molenaar, K.R. and Alarcón, L.F. (2019), "Comparative analysis between integrated project delivery and lean project delivery", *International Journal of Managing Projects in Business*, Vol. 37 No. 3, pp. 395-409, doi: 10.1016/j.ijproman.2019.01.012.

Mike, E.M., Schmitz, A. and Netherton, L.M. (2015), *Real Estate Development. Principles and Process*, 5th ed., ULI Urban Land Institute, Washington, DC, ISBN: 978-0874203431.

Miller, C., Arjunan, P., Kathirgamanathan, A., Fu, C., Roth, J., Park, J.Y., Balbach, C., Gowri, K., Nagy, Z., Fontanini, A.D. and Haberl, J. (2020), "The ASHRAE great energy predictor III competition: overview and results", *Science and Technology for the Built Environment*, Vol. 26 No. 10, pp. 1427-1447, doi: 10.1080/23744731.2020.1795514.

MohammadHasanzadeh, S., Hosseinalipour, M. and Hafezi, M. (2014), "Collaborative procurement in construction projects performance measures, case study: partnering in Iranian construction industry", *Procedia - Social and Behavioral Sciences*, Vol. 119, pp. 811-818, doi: 10.1016/j.sbspro.2014.03.091.

Mollaoglu-Korkmaz, S., Swarup, L. and Riley, D. (2013), "Delivering sustainable, high-performance buildings: influence of project delivery methods on integration and project outcomes", *Journal of Management in Engineering*, Vol. 29 No. 1, pp. 71-78, doi: 10.1061/(ASCE)ME.1943-5479.0000114.

Moradi, S. and Kähkönen, K. (2022), "Success in collaborative construction through the lens of project delivery elements", *Built Environment Project and Asset Management*, Vol. 12 No. 6, pp. 973-991, doi: 10.1108/BEPAM-09-2021-0118.

Moradi, S. and Sormunen, P. (2022), "Lean and sustainable project delivery in building construction: development of a conceptual framework", *Buildings*, Vol. 12 No. 10, 1757, doi: 10.3390/buildings12101757.

Moradi, S. and Sormunen, P. (2023), "Revisiting the concept of waste and its causes in construction from analytical and conceptual perspectives", *Construction Management and Economics*, Vol. 41 No. 8, pp. 621-633, doi: 10.1080/01446193.2023.2189278.

Moradi, S., Kähkönen, K., Klakegg, O.J. and Aaltonen, K. (2021a), "A competency model for the selection and performance improvement of project managers in collaborative construction projects: behavioral studies in Norway and Finland", *Buildings*, Vol. 11 No. 4, p. 4, doi: 10.3390/buildings11010004.

Moradi, S., Kähkönen, K., Klakegg, O. and Aaltonen, K. (2021b), "Profile of project managers' competencies for collaborative construction projects", in Scott, L. and Neilson, C.J. (Eds), *Proceedings of the 37th Annual ARCOM Conference*, 6-7 September, Association of Researchers in Construction Management, pp. 350-359, available at: https://www.arcom.ac.uk/-docs/archive/2021-Indexed-Papers.pdf

Moradi, S., Kähkönen, K. and Sormunen, P. (2022), "Analytical and conceptual perspectives toward behavioral elements of collaborative delivery models in construction projects", *Buildings*, Vol. 12 No. 3, p. 316, doi: 10.3390/buildings12030316.

Moradi, S., Hirvonen, J. and Sormunen, P. (2023), "A qualitative and life cycle-based study of the energy performance gap in building construction: perspectives of Finnish project professionals and property maintenance experts", *Building Research and Information*, pp. 1-13, doi: 10.1080/09613218.2023.2284986.

Mousavi, S., Marroquín, M.G.V., Hajiaghaei-Keshteli, M. and Smith, N.R. (2023), "Data-driven prediction and optimization toward net-zero and positive-energy buildings: a systematic review", *Building and Environment*, Vol. 242, 110578, doi: 10.1016/j.buildenv.2023.110578.

Nevstad, K., Børve, S., Karlsen, A.T. and Aarseth, W. (2018), "Understanding how to succeed with project partnering", *International Journal of Managing Projects in Business*, Vol. 11 No. 4, pp. 1044-1065, doi: 10.1108/IJMPB-07-2017-0085.

Ng, S.T., Rose, T.M., Mak, M. and Chen, S.E. (2002), "Problematic issues associated with project partnering—the contractor perspective", *International Journal of Project Management*, Vol. 20 No. 6, pp. 437-449, doi: 10.1016/S0263-7863(01)00025-4.

Oakland, J.S. and Marosszeky, M. (2017), *Total Construction Management: Lean Quality in Construction Project Delivery*, Routledge, Abingdon, ISBN: 9781315694351.

Qian, Q.K., Chan, E.H. and Khalid, A.G. (2015), "Challenges in delivering green building projects: unearthing the transaction costs (TCs)", *Sustainability*, Vol. 7 No. 4, pp. 3615-3636, doi: 10.3390/su7043615.

Radziszewska-Zielina, E. and Szewczyk, B. (2016), "Supporting partnering relation management in the implementation of construction projects using AHP and fuzzy AHP methods", *Procedia Engineering*, Vol. 161, pp. 1096-1100, doi: 10.1016/j.proeng.2016.08.854.

Raslim, F.M. and Mustaffa, N.E. (2017), "The success factors of relationship-based procurement (RBP) in Malaysia", *International Journal of Civil Engineering and Technology*, Vol. 8, pp. 1616-1625, available at: http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=8&IType=8

Rasmussen, H.L. and Jensen, P.A. (2020), "A facilities manager's typology of performance gaps in new buildings", *Journal of Facilities Management*, Vol. 18 No. 1, pp. 71-87, doi: 10.1108/JFM-06-2019-0024.

Saunders, M.N.K., Lewis, P. and Thornhill, A. (2019), *Research Methods for Business Students*, 8th ed., Pearson Education, Harlow, ISBN: 9781292208787.

Spudys, P., Afxentiou, N., Georgali, P.Z., Klumbyte, E., Jurelionis, A. and Fokaides, P. (2023), "Classifying the operational energy performance of buildings with the use of digital twins", *Energy and Buildings*, Vol. 290, 113106, doi: 10.1016/j.enbuild.2023.113106.

Sundquist, V., Hulthén, K. and Gadde, L.E. (2018), "From project partnering towards strategic supplier partnering", *Engineering, Construction and Architectural Management*, Vol. 25 No. 3, pp. 358-373, doi: 10.1108/ECAM-08-2016-0177.

Whang, S.-W., Park, K.S. and Kim, S. (2019), "Critical success factors for implementing integrated construction project delivery", *Engineering, Construction and Architectural Management*, Vol. 26 No. 10, pp. 2432-2446, doi: 10.1108/ECAM-02-2019-0073.

Willan, C., Hitchings, R., Ruyssevelt, P. and Shipworth, M. (2020), "Talking about targets: how construction discourses of theory and reality represent the energy performance gap in the United Kingdom", *Energy Research and Social Science*, Vol. 64, 101330, doi: 10.1016/j.erss.2019.101330.

Yılmaz, D., Tanyer, A.M. and Toker, İ.D. (2023), "A data-driven energy performance gap prediction model using machine learning", *Renewable and Sustainable Energy Reviews*, Vol. 181, 113318, doi: 10.1016/j.rser.2023.113318.

Young, B., Hosseini, A. and Lædre, O. (2016), "The characteristics of Australian infrastructure alliance projects", *Energy Procedia*, Vol. 96, pp. 833-844, doi: 10.1016/j.egypro.2016.09.145.

Zhang, X. and Kumaraswamy, M.M. (2001), "Procurement protocols for public-private partnered projects", *Journal of Construction Engineering and Management*, Vol. 127 No. 5, pp. 351-358, doi: 10.1061/(ASCE)0733-9364(2001)127:5(351).

Zhang, L., Cheng, J. and Fan, W. (2016), "Party selection for integrated project delivery based on interorganizational transactive memory system", *Journal of Construction Engineering and Management*, Vol. 142 No. 3, doi: 10.1061/(ASCE)CO.1943-7862.0001068.

Zou, P.X., Xu, X., Sanjayan, J. and Wang, J. (2018), "Review of 10 years research on building energy performance gap: life-cycle and stakeholder perspectives", *Energy and Buildings*, Vol. 178, pp. 165-181, doi: 10.1016/j.enbuild.2018.08.040.

Appendix

Table A1. Complete list of the project delivery related challenges and solutions

Representing challenge/barrier	References
Lack of/inadequate involvement of HVAC contractors and operation/maintenance people in the project definition and design phase	INT 2 (PropertyMgmt) INT 1 (PMContractor), INT 6 (PropertyMgmt), INT 4 (PMContractor)
Fragmented (i.e. divided/isolated) procurement, project delivery, and maintenance process (multiple contracts) of energy efficient systems	INT 1 (PMContractor), INT 2 (DM) INT 5 (PMContractor) INT 1 (PMClient)
Dominance of low-price criteria in the tendering process for selecting contractors which usually has low capacity to deliver their promises	INT 1 (DM), INT 5 (PMContractor)
Construction phase errors (e.g. problems in building structure, building services)	INT 5 (PropertyMgmt)
Deviation between designed and purchased/installed devices/equipment by contractor for securing his/her own benefits	INT 3 (PMClient)
Delay and low quality in the work of low-capacity contractors, selected solely because of the low price	INT 5 (PMContractor)
Delivery problems in the supply chain of required equipment	INT 3 (DM)
Difficulty of diagnosing construction errors in use phase of the building with regard to their impact of energy efficiency (for instance in terms of air tightness)	INT 5 (PropertyMgmt)
High variation between the design and the execution of building services systems (especially heating part)	INT 3 (DM)
High variability among resources of different companies in projects with fragmented delivery processes	INT 5 (PMContractor)
Inadequate investment of time and cost in project definition and design/planning phases	INT 4 (PMContractor)
Lack of integrated and directed efforts between people, processes and technology	INT 1 (PMContractor)
Lack of contracts with project and building life cycle responsibility and benefits for the key parties (including energy providers)	INT 1 (PMContractor)
Low priority of energy efficiency as a goal in project definition phase	INT 2 (PMClient)
Lack of planning (in project definition and design phases) for details and processes of collecting and analyzing energy consumption data in the operation phase	INT 3 (PropertyMgmt)
Lack of standardized and routine process for design and implementation of hybrid energy systems	INT 4 (PMContractor)
Lack of attention to the delivery capacity (resource and competence), content of the offer (e.g. schedule) besides the price	INT 5 (PMContractor)
Scheduling issues	INT 3 (PMContractor)
Traditional contracting model (energy system providers are not involved and accountable for the performance of building energy system in the operation phase)	INT 1 (PropertyMgmt)
Traditional contracts which foster isolated and fragmented working	INT 3 (PropertyMgmt)
Unreliable information flow between parties in the project definition, design, and construction phases about energy efficiency goals	INT 1 (PMClient)
Unavailability of required material/components due to the natural (e.g. corona pandemic) or political (war in Ukraine) crises	INT 5 (PMContractor)

(*continued*)

Representing solution/enabler	References
Life cycle contract	INT 1 (PropertyMgmt) INT 2 (PropertyMgmt) INT 3 (DM) INT 3 (PMClient) INT 3 (PMContractor) INT 3 (PropertyMgmt) INT 4 (PMContractor) INT 5 (DM) INT 5 (PropertyMgmt) INT 5 (PMContractor) INT 5 (PMContractor) INT 2 (DM)
Collaborative project delivery models (e.g., alliance)	INT 1 (PMClient) PMContractor INT 2 (PMContractor) INT 3 (DM)
Involving building services people in the project definition and design phase	INT 2 (PMContractor) INT 2 (PropertyMgmt) INT 3 (PMClient) INT 4 (PMContractor)
Involvement of client and its representative (consultant) from project definition phase until the end of the project	INT 1 (DM) INT 2 (PropertyMgmt) INT 3 (PMClient)
Early definition of the use of building and its spaces	INT 1 (PMContractor) INT 3 (PMClient)
Applying a system thinking method in project definition phase to clarify the consequence of a change or choice about one aspect of the building on the other aspects	INT 3 (PMClient)
Creating more tempting incentives for achieving high energy efficiency	INT 4 (PMContractor)
Early definition and determination of the operational feature of the building for having an accurate and realistic estimation of energy consumption	INT 5 (PMContractor)
Flexible target setting for budget	INT 5 (PMClient)
Having a third-party inspector for assessing efficiency of building energy systems	INT 2 (PropertyMgmt)
Involvement of design team in the project definition phase	INT 1 (PMClient)
Identifying and analyzing the probability and impact of the risk of changing the use of the building space in the project definition phase	INT 3 (PMClient)
Involvement of maintenance experts in the design phase	INT 6 (PropertyMgmt)

(*continued*)

Table A1.

Representing solution/enabler	References
Paying attention to the delivery capacity (resource and competence), content of the offer (e.g. schedule) besides the price	INT 5 (PMContractor)
Sufficient investment of time and cost in project definition phase	INT 3 (PMClient)
Updating the energy consumption target when there is a change in the design and use of building spaces and	INT 3 (PMClient)
Using lessons learned of similar projects in the project definition and design phase	INT 2 (PMClient)

Table A1.

Source(s): Authors' own work

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