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Improving Design Quality by Contractor Involvement: An Empirical Study on Effects

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Abstract: It is generally acknowledged that good-quality design is a prerequisite for good quality and productive construction work. One proposed measure to improve the quality of construction has been contractors' involvement in the design phase, and this phenomenon has been studied by several researchers. However, such approaches have not adequately addressed how this involvement affects the quality of the design. In this study, the aim was to study the effects of the early involvement of contactors on design quality based on evaluating the design quality factors. A case study was used to collect data and content analysis to analyze structural drawings and design meeting minutes of a large-scale infrastructure project. Particularly, the focus was on gathering information on the quality of the design and how it was addressed in the design coordination. We combined this quantitative data with qualitative open-ended thematic interviews, including respondents who led and coordinated the design on both the client and contractor sides. Our findings suggest that despite the vast amount of design changes, contractors' involvement and development work in the detailed design phase improved design quality and constructability. Our findings also suggest that the contractor's involvement during the schematic design phase had a design-enhancing effect in the detailed design phase. This study contributes to our understanding of contractors' valuable role in design quality.

Keywords: design quality; contractors' involvement; design development; contractors' role

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1. Introduction

Design is inherently a human activity that is often a source of reduced quality in the design process. Most people working in the construction industry recognize the effects of poor-quality design. In general, inadequate design quality does not lead to severe damage, such as the collapse of buildings, but it significantly hinders the performance of construction work and often leads to various quality-reducing workarounds on site. The development of the construction industry has come a long way with the so-called quality movement, and most players in the construction industry, including designers, have various quality certificates and systematic development work aimed at improving quality [1]. Authorities have also recognized the importance of design quality, and design is regulated in many countries to avoid serious construction mistakes [2]. Nevertheless, all parties involved in construction are aware of how design flaws can disrupt the construction process. Problems related to design quality have been studied for decades, and the effects of poor-quality design on construction quality, schedule, cost, and safety are known [3–6]. However, far too little attention has been paid to contractors' important role on quality of design, and therefore, the aim of this study was to find out the effects that the early involvement of contactors has on design quality.

This paper first gives a brief overview of the factors of design quality in construction and then presents the different roles affecting design quality. The remaining part of the introduction focuses on contractors' involvement and its observed effects on the construction process. The second section is concerned with the methodology used for this study and presents the design quality metrics derived from the literature and used in this study. Section 3 analyzes the findings of the content analysis and thematic open-ended interviews, focusing on three key themes of design quality. Finally, in the discussion and conclusion, the findings are looked at in light of past research, and research-specific limitations are identified.

2. Background

2.1. Design Quality

The quality of design has been studied from many perspectives. For example, a design that meets the expectations of the owner, meets the requirements of the authorities, meets the designer's own expectations, and meets the expectations of contractors is considered a key factor for the good quality of design [7]. Another view of design quality that is often used in the context of architecture is the functionality of the designed space, impacting the surrounding natural, human, and visible quality of the construction work [8,9]. O'Connor and Woo [10] concluded that design correctness, timely delivery, and design completeness are essential elements of design quality. Egan [11], however, pointed out that maintaining a focus on the client and a commitment to people should be the main criteria in design quality. Glavinich [12], Tilley et al. [13], McGeorge [14], and Arditi et al. [15] defined design quality as the ability to provide constructible design information in an effective and economic fashion to contractors to plan, monitor, and control construction production without delays.

A large volume of published studies describes the importance of avoiding design errors for construction quality, efficiency, and productivity. Kärnä and Junnonen [16] showed that designs containing errors and inconsistencies decreased productivity during construction. The effective delivery of construction projects relies highly on the quality of the design [3,4,17–19]. With the development of building information models (BIM), i.e., digitally created virtual models of buildings, into the main tools of designers, the design quality control has also moved to quality control performed through the BIM process [20]. Several researchers have prepared proposals for the quality control of the BIM-based design process, and this work has also been partially automated as rule-based inspection work performed with the help of software, which is well-suited to the task of a computer [21,22]. However, the traditional approach to reducing design defects, still used in building design, is based on the expert's visual review at the last phase of the design process [23]. Nevertheless, it is known that even after this expert inspection, the work may contain significant amounts of errors and variations affecting the throughput time of the design [24,25]. The role of the expert as a guarantor of design quality dates to the early days of an industrial revolution, when quality inspection was differentiated into its own type of work in production facilities by Taylor and his proponents [23]. Since then, the development of design quality's development has moved toward quality standards, quality systems, quality manuals, and a model in which each designer is responsible for their own quality according to pre-established guidelines and standards [1]. Nevertheless, the guarantee of design quality and the 'last lock of defense' is often still the quality inspector, an experienced discipline expert, or team of experts [26,27].

This chapter briefly demonstrated the multifaceted phenomenon of design quality and its significance to construction. It is now necessary to introduce the contractors' role and involvement and what research has revealed about it.

2.2. Contractor Involvement in Design

As discussed above, there are several factors in design quality, but little research has been done on the role of the contractor in relation to design quality. Instead, the role of the contractor in the design has been explored from several other perspectives. It has long been recognized that several 'non-designers' contribute to design; in addition to designers, special contractors, various technical experts, and building material suppliers and manufacturers all contribute to the quality of the design during the construction project [28]. The benefits of contractors' contributions have been extensively studied [29]. The benefits include reducing the cost risk of the project [30], although benefits such as improved collaboration, better constructability, more reliable schedule management, and improved occupational safety have also been made [15,31]. One motivator for linking a contractor to construction projects earlier is an effort to reduce the effects of widespread litigation in the industry [32]. Another aspect is the stagnant development of productivity in the construction sector, for which contractor's involvement is one way of improving cooperation between the parties [33].

Traditionally, contractors' involvement in design has been postponed to a late stage due to a one-stage procurement method (design-procurement-contracting), and this assumption has also been included in most contract forms worldwide [28]. It is obvious that with a model like this, the contractor's know-how can be utilized only in the tendering phase and later on-site. However, research showed that the contractor's involvement in the design should start as early as possible to maximize its benefits [29]. Of course, it must be recognized that owners have a major role to play in choosing a procurement strategy and how deep cooperation with designers and contractors is desired. Especially in public projects, collaborating with designers during contractors can also be legally challenging [34].

2.3. Design Quality Metrics for This Research

Based on previous studies, we defined aspects of design quality into three practical segments (see Figure 1): first, "Can you build with drawings", which means whether the information presented in the drawings is sufficient for construction, for example: is the design constructable, is the design error- and fault-free, and are there any missing drawings? Second, "customer value", which means that the designs are developed in such a way that the customer receives maximum value, minimizing the unnecessary changes in design. Third, "Can you deliver in time", which means whether the drawings are on schedule and at the right time at the construction site. These meters are presented in more detail in the following three paragraphs. The Methods section discusses in more detail how the quantitative and qualitative data of the case study were processed and how the metrics presented below were collected and calculated.

2.4. Metric 1: Constructability of Design

Constructability can be summed up in the phrase "can we build with drawings". The most important factor behind the concept, of course, is whether the drawings can be used as such in construction or whether, for example, the design needs to be revised or supplemented in some way. This factor has a clear link to customer value, as drawings that are unsuitable for construction and need to be revised, for example, cannot be considered high-quality design. From the customer's perspective, a wasteful rework is required to start the work on site. To improve constructability, researchers have identified several ways, such as constructability reviews [15], clash detection [35], and four-dimensional computer-aided design [36]. Fisher et al. [37] also developed a framework for ensuring constructability, and they introduced several improvement tools for constructability.

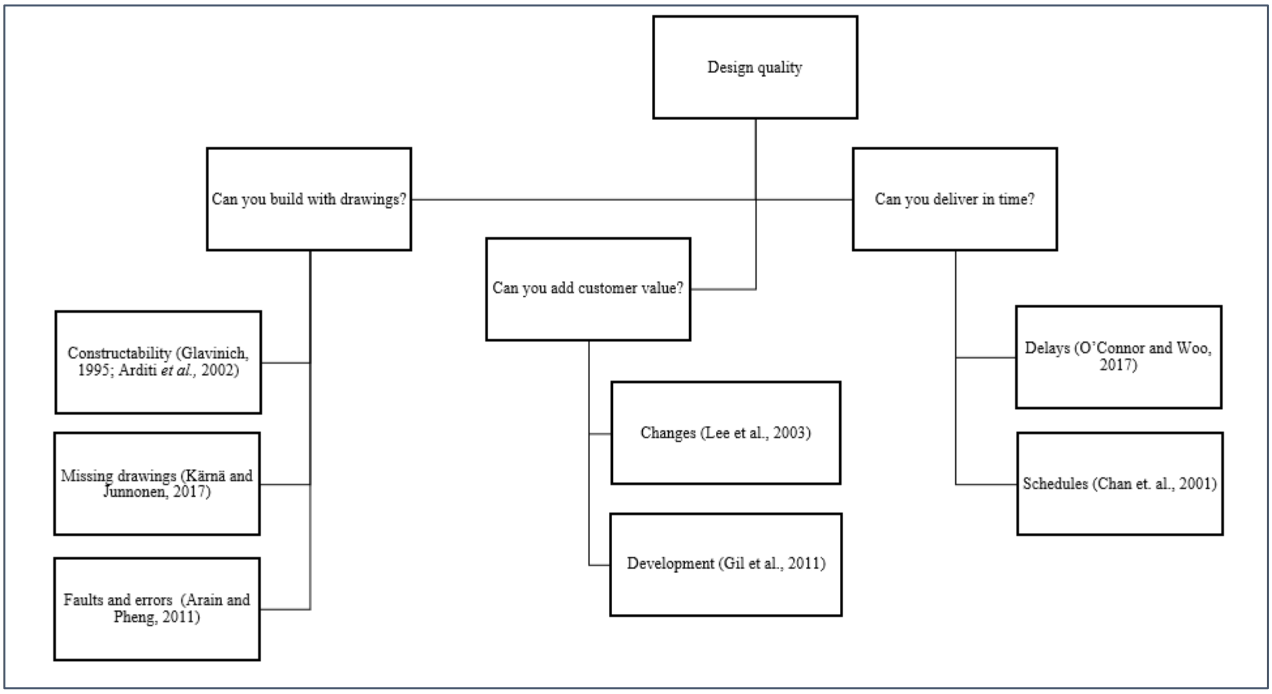

Figure 1. Conceptual framework of design quality key factors used in this study.

Another factor in terms of constructability is the lack of drawings, which is related to the schedule: if some of the drawings are totally missing, the construction work cannot be completed, and therefore, construction work usually suffers delays for this reason [16]. Delays from the design schedule may be a background factor for poor-quality design, but the root cause may also be related to other factors. Love et al. [38] pointed out how an inexperienced design team or lack of communication with the contractor may lead to confusion, and the design team does not know all the requirements of construction work.

The third factor in constructability is errors and deficiencies in design that have a straightforward impact on the construction process—erroneous and incomplete drawings can halt construction work, or if errors are not detected in time, cause significant additional costs and delays due to rework [39]. In addition to expert review [37], various checklists [40], risk management tools [41], and lesson-learned practices [42] have been developed to reduce errors in the design. However, inadequate constructability is not always caused by mistakes or a lack of drawings, although it can lead to a situation where construction work simply stops. This can happen, for example, when a beam made exactly according to the drawings does not fit in place because the installation method of the component has not been examined properly. Although constructability practice still appears to rely on expert reviews [37], automated reviews and constructability metrics were also explored [43].

2.5. Metric 2: Design Value for the Customer

The first factor that affects customer value is design changes. As scholars [3,6] have stated, design and construction are complex human systems where changes cause iterative cycles which often have a significant impact on the project schedule. In addition to the effects of the iterative cycles caused by the changes, the harmful effects may be greater than expected if these flaws and changes are not found in time [44]. According to Ballard [45], the reasons for design changes may be flaws in the drawings or impracticable solutions chosen by the designer, drawings being made too early for genuine site needs, and drawings needing to be changed, for example, due to the procurement process. However, the traditional perspective on the harmfulness of design changes and iterations has been criticized, and such changes and iterations can also be considered part of the design process as a basic feature of its product development nature. For example, Hansen and Olsson [46] suggested that if design changes lead to increased customer value, design changes and iterations should not be considered waste. They argued that design iterations are an essential part of the innovative design process and a method for developing design [46]. Therefore, another factor we present that affects customer value is development.

2.6. Metric 3: Timeliness of Design

It is common practice for contractors to demand earlier delivery from designers, which reduces the time reserved for design work and ultimately leads to a vicious cycle that constantly requires the earlier delivery of designs [47]. Large scheduling buffers between construction partners can protect the contractor from the effects of delay, but this is often costly due to extended construction time and lower productivity [48]. However, the role of the owner cannot be underestimated in this respect either; the requirements and decision making of the owner significantly affect the design schedule [49]. Therefore, it is important and apparent that design timeliness is one of the key metrics in this study.

2.7. Conceptual Framework of Design Quality

This section provides a summary of the relevant literature relating to design quality and the factors related to this study. Figure 1 shows a conceptual framework of the design quality factors introduced in previous chapters. The framework was developed from the perspective of this study, in which the quality of the design is viewed primarily through the contractor's 'lens', supported by previous research. Looking through the contractor's 'lens' was chosen as a perspective in this study since it aims to focus on the impact of contractors' involvement on the quality of the design.

The study now proceeds to empirical evidence showing how contractor involvement can affect the quality of design. In the next section, we present the case study and the research procedures.

3. Materials and Methods

3.1. Participants and Design

An exploratory case study research method was used to obtain evidence from an ongoing project. An exploratory case study is well-suited to our research problem and can be used to test our proposition on the impact of contractor involvement on design quality. Through an explanatory case study, the phenomenon and data can be examined accurately at both the surface and deep levels to explain the phenomenon [50]. Even though the case study research method also has its own shortcomings [51,52], for our research problem, it is difficult to find statistical data; therefore, the research design selected was the case study. In addition to using qualitative data, the reliability of the research was increased by using a quantitative analysis of design quality metrics.

Our case study involves a Finnish municipally owned infrastructure project that consists of seven large construction sites. The project was chosen as the subject of the case study because despite its single case study nature, the project was divided into several large contracts and involved a vast range of designers of different sizes of design offices. The scale of this selected case and the diversity of its contractors reduce the micro-level impact typical of case studies, which limits its generalizability [53]. Another factor in the selection of the case study was the willingness of the owner to participate in the study and openly share the project data for the use of the researchers [54].

In the selected case, project management contractors were building six of the sites, and one site was being built by a consortium of contractors. During the research, the project had progressed to the MEP installation phase and finishing works of the buildings; therefore, the research focused on the BIM-based structural engineering of the frame structures, which was already completed, and possible design quality problems were mostly revealed and handled among the project team. The project design management organization consisted of site-specific design managers under the authority of the design director, main designers, users, owners, and local rescue department's experts. A total of 156 structural engineers from 6 structural engineering companies participated. All of the structural engineering offices involved in the case study used BIM in their design work, and except for some principal details, all structural drawings were made with BIM software.

The first data source was design review meeting minutes, which contained meeting minutes from all the project parties, the client, the designers, and the contractor. Before the design review meeting, the design coordinator prepared a draft of the meeting minutes containing the preliminary material and distributed it to all persons invited to the meeting before the meeting date. Unannounced matters were transferred to the next meeting. The meeting only dealt with planning issues related to design, drawings delivery, design schedules, and design-related safety issues. Other contractual issues were discussed at the site meeting; however, the design review meeting was the main forum for the project management contractor to demonstrate the contractor's obligatory design development procedure for all other project parties. The second data source was the structural drawings of each of the seven construction sites. The drawings that were reviewed during the analysis were in PDF format and covered the last valid versions of the detailed drawings. In addition to the drawings, drawing lists were available and used. To analyze these two data sources, we utilized content analysis as the research method. Content analysis is a research method that can be used to draw conclusions from documents [55]. The material collected from the documents can also be processed in the content analysis, both quantitatively and qualitatively, as was also performed in this study.

Third, to collect insights from practitioners related to the quality of the design, a total of 8 thematic open-ended interview sessions were organized. The open-ended interview technique was chosen to support content analysis by enriching the data and revealing information that could not be discovered through content analysis [56]. The chosen interview method also allows for the triangulation of research data and contributes to the validity of the research [57].

3.2. Overall Procedure

The data from the case study were delineated after a conceptual framework (see Figure 1) was developed. The researchers divided the research data into two parts, minutes and drawings, for content analysis. Consistent coding was developed for both so that the information from the sources could be compared in the next step [58]. Once the coding was compiled, questions for the open-ended thematic interviews were developed, which were also themed according to the chosen framework. The coding used in the content analyses and interviews is shown in Figure 2.

As can be seen in Figure 2, the codes used in the meeting minutes are linked to all three design quality factors, while the codes used in the drawings are not linked to the timeliness factor. However, the researchers collected the dates for the submission dates of the drawings and the number of revisions, although the researchers did not have access to the design schedules, which would have allowed them to compare the actual dates of the drawing deliveries with the agreed baseline. However, the timeliness factor was able to be examined using meeting minutes that provided comprehensive material on contractors' views on whether the design was on schedule in relation to procurement and production. This information gathered from meeting minutes could also be used to calculate site-specific values for contractor inquiries from designers and owners. This inquiry, 'request for information' (RFI), was used in this study because of the commonly used meaning of this term [59]. The themes of the open-ended thematic interviews connect all the design quality factors together and provide a qualitative perspective on the quantitative data from the meeting minutes and drawings. This is shown in the figure by the lines connecting all the factors.

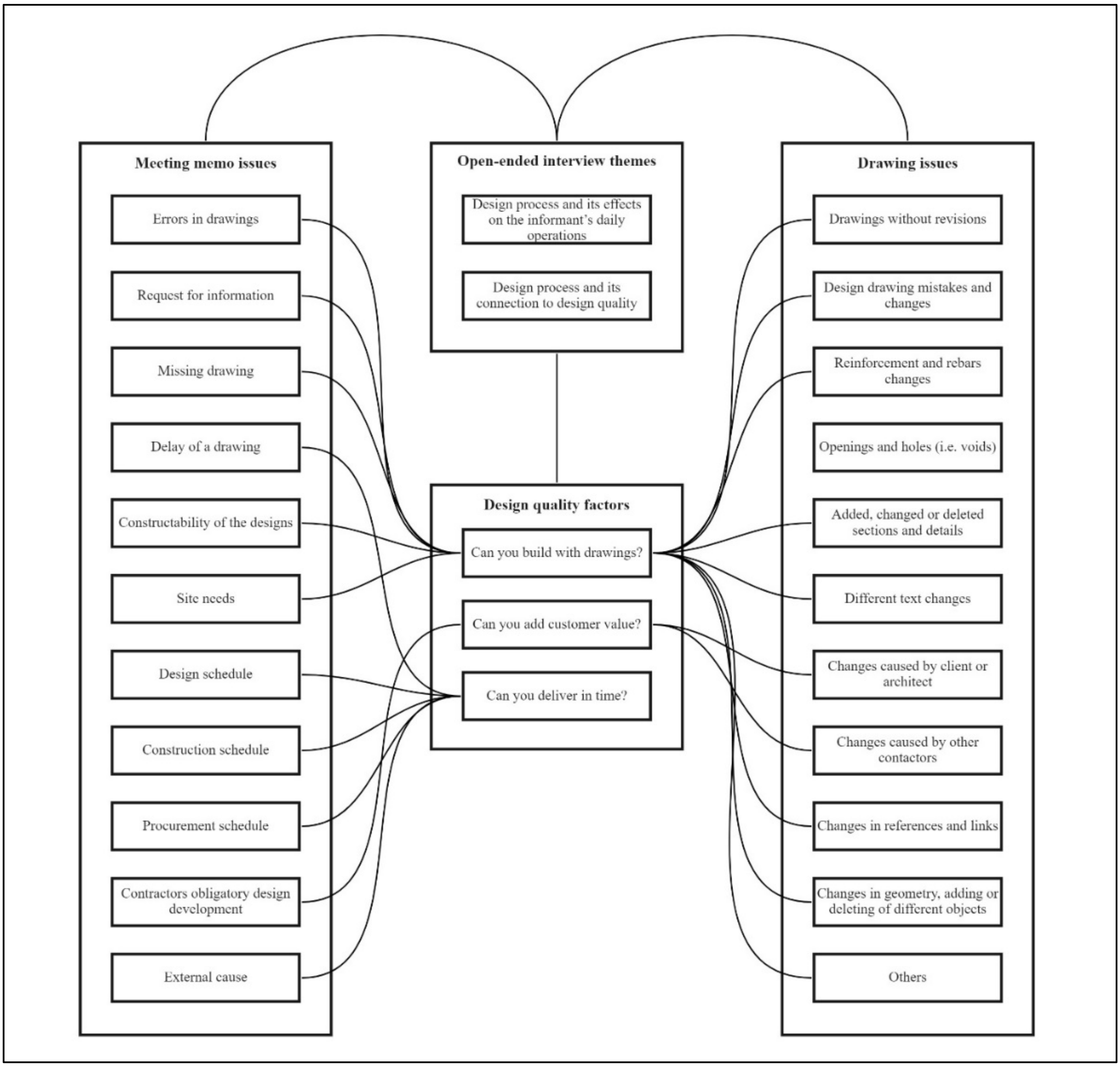

Figure 2. Coding hierarchy and connections between the design quality factors used in this study.

In the next phase, the researchers shared three data sources (minutes, drawings, and interviews) from the subdivision with the researcher in charge, who was responsible for collecting, coding, and tabulating the data. All data were grouped by site, and the sites were anonymized with the codes "Site A" to "Site G". Interviewees answered the interview questions anonymously. Content analysis data were stored in Excel spreadsheets, and audio-recorded interviews were transcribed verbatim and then imported into qualitative analysis software, ATLAS.ti (version 8.4.4, Scientific Software Development GmbH, Berlin, Germany) for further processing.

3.3. Procedure for Content Analysis

Minutes of the meeting issues related to the design stability of reviewed design meeting minutes were collected in a spreadsheet and grouped into 11 categories, as presented in Figure 2. The same issue could be related to several areas in the spreadsheet, and color coding was used to highlight which of the different areas was the most significant based on the number of appearances. Once the meeting issues were counted and grouped at each construction site, they were imported to the summary table in Excel. RFI data were compiled in a similar way by calculating the duration of the RFI processing time from meeting minutes (from requested to receiving), and the obtained data were transferred to an Excel spreadsheet and later a diagram format. One month was used as the time measurement interval for the RFI data, as no other data were available from the monthly meeting interval.

The contents of the drawings and the subjects of the changes were examined visually using the tables of changes and the texts written on them (i.e., revision data). If the text did not provide sufficient classification, the drawing was reviewed in detail, and the researcher attempted to interpret the category of change by visual methods and reasoning. Content analyses were performed on the design data from all the sites, which included the whole set of the structural drawing review to classify all revisions into the 10 categories presented in Figure 2.

3.4. Procedure for Open-Ended Interviews

The interview questions were formed based on two major themes: the design process and its effects on the informant's daily operations and design process and its connection to design quality. The duration of each interview session varied between 36 min and 58 min, and the mean duration was 48 min. A total of 9 construction professionals were interviewed, covering all the sites. Two were the main contractors, and these two persons worked in a design manager's role. Seven other interviewees represented the owner of the whole project and worked in a design manager's role in the owner's project organization. The interviewees' work experience related to design management was between 4 years and 25 years. Before each interview, the informants were briefed about the purpose of the research and how their data were anonymized, stored, and handled.

The nature of the analysis process was iterative, and the 3 main categories for each analysis related to the quality of design segments were (1) can you build with drawings, (2) can you deliver in time, and (3) customer value. For each of these segments, several codes were selected. The selection was based on the selected codes, which were: (a) constructability, (b) faults and errors, (c) missing drawings, (d) delays, (e) schedules, (f) changes, and (g) design development. The codes were selected based on a preliminary review of the content of the interviews via transcribed text, and in this context, the codes that were not detected were also not addressed in the analysis. In the second round of analysis, each quote linked to each code was marked as either positive or negative based on its context and meaning. The analysis was then structured in a table so that the codes (positive and negative) were grouped under appropriate themes, followed by an illustrative extract from the transcribed interview text. The collected data were stored in Microsoft Excel, which was used to sort it with filter functions, tables, and graphs.

4. Results

To assess the impact of contractors' involvement on design quality, the results collected from the meeting minutes were reviewed. Three important findings emerged from the dataset, and they all focused on site C, where the contractor started its design development earlier than the other sites. The first observation was that site C, where the contractor had already entered the schematic design stage, was clearly different from other construction sites in terms of negative issues in the design meeting minutes. Another observation was that site C also differed in the number of RFIs, with site C clearly having fewer RFIs than the other sites. The results were still clearly different from the others, even though there were site-specific differences in the number of meeting minutes. A third finding that distinguishes site C from other sites was the obligatory design development of contractors. Site C had only two issues related to the development of the design recorded in the meeting minutes, while other sites clearly had more. The differences between the sites are detailed in Table 1.

Table 1. Summary table of design quality—background information and meeting minute issues. Abbreviations: Background information = BI; Quantitative = QTV.

Collected Data	Data Type	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Design responsibilities								
Detailed design	BI	Owner	Owner	Contractor	Owner	Owner	Owner	Owner
Manufacturing design (i.e., shop drawings)	BI	Contractor	Contractor	Contractor	Contractor	Contractor	Contractor	Contractor
Size of the structural design company (*)	BI	EUR1524m	EUR69m/EUR580m [1]	EUR0.275m	EUR44m	EUR580m	EUR4.9m	EUR69m/EUR580m/EUR44m/EUR1524m [1]
Design meeting minutes review								
Total amount of reviewed meeting minutes	BI	10	18	12	9	16	15	16
Total amount of categorized issues	BI	424	1005	214	647	558	637	425
Negative MoM issues								
Flaws in drawing	QTV	30	97	9	43	63	58	38
Missing drawing	QTV	33	62	10	59	34	46	30
Delayed drawing	QTV	6	49	6	8	4	13	0
Feasibility/constructability of the drawing	QTV	0	12	1	27	4	11	3
Total of negative issues	QTV	69	220	26	137	105	128	71
Total of negative issues [%]	QTV	16%	22%	12%	21%	19%	20%	17%
Neutral MoM issues								
Request for information (RFI)	QTV	237	278	132	210	282	254	197
Design schedule	QTV	34	228	37	114	31	116	49

Table 1. *Cont.*

Collected Data	Data Type	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Construction schedule	QTV	24	67	7	56	38	48	32
Procurement schedule	QTV	11	32	3	31	18	27	16
External cause	QTV	2	9	0	15	17	4	1
Total of neutral issues	QTV	308	614	179	426	386	449	295
Total of neutral issues [%]	QTV	73%	61%	84%	66%	69%	70%	69%
Positive MoM issues								
Sufficient drawings for work (% of total meeting minutes)	QTV	100%	100%	Term not used	78%	69%	47%	94%
Site needs	QTV	9	8	7	5	1	2	6
Contractors obligatory design development	QTV	38	163	2	79	66	58	53
Total of positive issues	QTV	48	172	9	84	67	60	59
Total of positive issues	QTV	11%	17%	4%	13%	12%	9%	14%

[1] Annual revenue on year of the study. In consortiums, revenue is presented separately for all partner companies, separated by oblique marks. (*) The company's turnover during the research.

Closer inspection of the table also shows that the absence of drawings for site C was clearly less frequently recorded in the design meeting memorandum than for other sites. Similarly, there were fewer negative-toned entries in the acquisition and construction schedule for site C than for other sites, even though there were no entries in the minutes of the meeting for site C as to whether the contractor had sufficient drawings for his work. This difference in the method of recording could have been influenced by the differences in the form of the contract, in which site c had a wider design responsibility than other contractors and which also started earlier at other stages.

As can be seen from Table 2, site C had fewer RFIs than the other sites. The phenomenon seemed interesting, and therefore, we compiled Figure 3 below based on data from design meeting minutes on how many unresolved RFIs were work in progress (WIP) on each site. The vertical axis shows the number of unresolved RFIs per meeting, and the horizontal axis shows the design meetings where the data were collected. The lines in the graph represent the RFI WIP rolling average for each site.

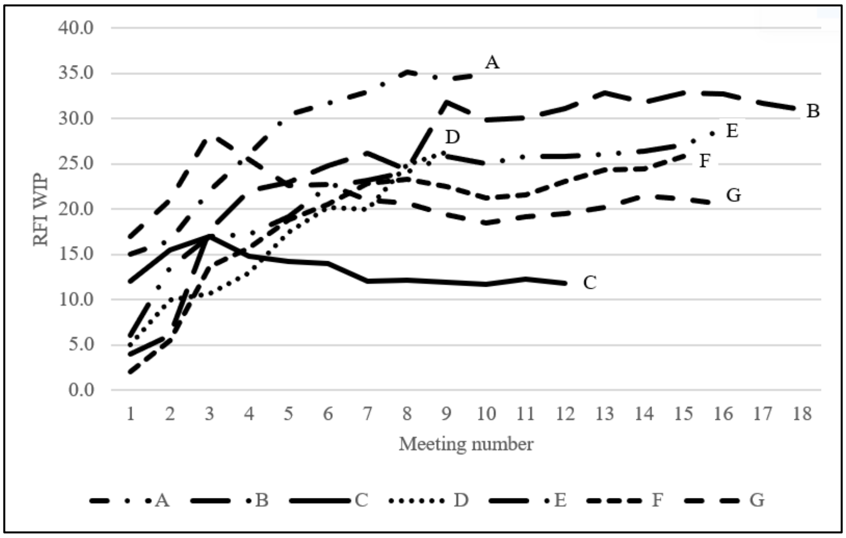

Figure 3. Response time of RFIs—drawing review.

Figure 3 shows how site C, where the contractor started cooperating in design earlier, differed significantly from other sites. The number of unresolved RFIs increased for all sites at the start of the design, but it remained at a permanently lower level for site C than for other sites. The mean value of open RFIs discussed at site C design meetings was 11.8 RFIs, while the mean value for other sites ranged from 20.5 to 34.9.

The drawing quality results are summarized in Table 2. Regarding the quality of the drawings, the most significant differences between the sites are shown in the number of design changes, where sites C, D, and G differ from sites A, B, E, and F. Sites C and F had the smallest number of revisions in the reinforcement drawings, and sites C and F had the smallest number of void-related changes (holes and openings). Despite the early involvement of site C, this was still not reflected in the changes in the drawings as a whole, and a considerable number of drawing changes were made at all sites. The number of unrevised drawings varied across the sites between 23 and 42%, which means that about 1/4 to 2/3 of all drawings had been modified or corrected during the construction phase.

The results of the interviews were also added to the end of Table 2, which are reviewed next. The results from the design manager interviews are presented in Table 3. The interview results were categorized into two-level hierarchies. The structure follows the defined factors for design quality: (1) can you build with drawings, (2) can you deliver in time, and (3) customer value. Each factor of design quality is followed by analysis codes that target those segments. Every code had either a positive or negative view from the informant. The number in brackets associated with each code presents the number of interview mentions related to those views. The following is an illustrative extract from the interview data.

Table 2. Summary table of design quality—drawing review. Abbreviations: Background information = BI; Quantitative = QTV; Qualitative = QLT.

Collected Data	Data Type	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Drawing review								
Total amount of reviewed drawings	BI	352	840	548	402	573	536	461
Total amount of design changes	BI	577	873	303	350	595	411	542
No revisions [%] (=first-pass yield)	QTV	42%	41%	41%	34%	32%	41%	23%
Design quality issues								
Design drawing mistakes and changes	QTV	121	207	72	35	216	106	76
Reinforcement, rebars, etc.	QTV	68	152	18	81	40	47	18
Added, changed, or deleted sections and details	QTV	56	61	17	17	29	51	42
Different text changes	QTV	21	12	19	1	5	9	12
Design coordination/management issues								
Openings and holes (i.e., voids)	QTV	118	161	66	100	140	68	112
Client or architect	QTV	8	9	20	1	1	0	19
Different contactors	QTV	1	26	11	0	7	2	23
References and links	QTV	36	30	6	1	11	5	100
Geometry, adding or deleting of different objects	QTV	86	192	73	110	136	105	110
Others	QTV	62	23	1	4	10	18	30
Total of design coordination/management issues	QTV	311	441	177	216	305	198	394
Interview results								
Design management problems (pos;neg)	QLT	1;11	0;5	2;8	5;19	0;8	1;7	1;9

For interviews, it was observed that contractors saw obligatory design development mainly as a positive thing, whereas other design changes were seen mostly as negative issues. Deduced from the interviews and the data available, the structural designers spent a considerable amount of time finalizing the drawings feasible for construction work. From the client's point of view, this can be considered an unfortunate issue because of the lengthy time it took to design; however, it was positive that the contract model allowed the contractor to participate and develop the design more closely with the production team. The interviewees also felt that the development of structural design had an impact on the product, i.e., the customer's value increased as a result. Although the high number of design flaws and errors and the considerable amount of rework and missing drawings adversely affected project scheduling and production, contractors were also active in their design development work at these sites.

Table 3. Factors of design quality and their relation to their design factors. Findings from the interviews.

Factors of Design Quality	Categories	Illustrative Quotes from the Interviews
Can you build with the drawings?	Constructability, positive (8) Constructability, negative (9)	" . . . and the contractor suggested that they could be on the shallow pad footings because they are bolted to the rock on the sides and top and hang on them just fine and it does not need much of that filling and it won't ever frost, so couldn't it be on the shallow pad footing. But now that we are done with shallow pad footings, it can be done at any time, and the amount of groundwork required for it is a much smaller, much more feasible solution . . . " " . . . the first version that usually comes from some structure is rarely feasible as such . . . "
	Faults and errors, positive (0) Faults and errors, negative (26)	" . . . but there are situations where those three reinforcement bars are colliding with each other and that's why the drawings are still printed . . . "
	Missing drawings, positive (0) Missing drawings, negative (20)	" . . . that there has been a lack of drawings, no one has really known, that of course when a drawing needs schedule is based on a drawing list, designer looks through the drawings and puts a date next to it, but if it is missing 10 drawings then it comes as a surprise to everyone, designer should know if something is missing . . . "
Can you deliver in time?	Delays, positive (1) Delays, negative (17)	" . . . clearly when that design responsibility is contractors, it does not cause as many schedule delays as when that design responsibility is clients . . . " " . . . that might be more related to this delay, when we had this process in the data management system, so that no works should not be started before this third-party or client's inspector has approved the drawings, so the contractor has complained that there are the delays . . . "
	Schedules, positive (11) Schedules, negative (11)	" . . . now, when we have gone a little here to the final stage of structural design, then it has been very reliable to produce additional drawings . . . " " . . . well, in the beginning it is the coordination of design work, and thus later it is the coordination of work phases. It is clearly such a demanding task, and it has not been quite successful. That it is noticed almost daily that there are some problems with it . . . "
Customer value	Changes, positive (0) Changes, negative (6) Development, positive (20) Development, negative (8)	" . . . in a way, we have started with some of the initial data, which has not been correct then, but that the initial data has had to be changed. And when you start to change the initial data, it always has schedule and cost implications . . . " " . . . yes, sometimes both site D and G have received some suggestions from other contractors and in such a way that this could be useful for other sites, and the contractors themselves always demand and ask us to ensure that is this issue already been resolved in some other site so that they do not have to do development. But yes, contractors are clearly interested in the completion of their own sites and the goals of their own sites . . . " " . . . yes, kind of sub-optimization is visible in the sense that the contractor does not see what effect the customer's design has in some of their proposed changes, that in those cost effects, for example, they have not calculated that how many hours our architect, MEP designer, or structural designer has to make to their changes, so in that sense contractor's own interest is visible . . . "

5. Discussion

Our findings suggest that early involvement of the contractor in this case study had a positive impact on the quality of the design. Based on the findings, it could be concluded that early involvement really benefits the quality of the design in many respects. These positive findings were made for certain design changes, design coordination issues, and RFI processing. On the other hand, it could also be concluded from the interviews that the contributions of the contractors who later joined the design process were considered valuable in terms of the quality of design. This conclusion is also supported by the results of sites D, G, and F for some of the measured quantities, such as repairs in the reinforcement drawings and limited void changes. However, our case study did not provide any indication that early involvement of the contractor would have a significant impact on the quality of the design in terms of the amount of drawing changes during the construction phase.

Positive observations have long been made about the utilization of a contractor's know-how at the earliest possible stage of a construction project [29,60,61]. The aim of this study was to seek more information on the research gap related to the impact of early contractor involvement on design quality. The idea of the relationship between the quality of design and the early involvement of the contractor is not new; for example, Gransberg and Windel [62] obtained similar results in their interview-based studies and Song et al. [5] in their simulation-based studies. Our findings support this effect through the triangulation of extensive research data.

Constructability, customer value, and timeliness were selected as factors in the design quality for the study. Our results largely focused on the relationship between constructability and design quality, which is logical given the chosen research design. In terms of constructability, our findings indicate from the design meeting notes that the impact of early involvement of the contractor on the quality of the design was reflected in the lower number of missing and faulty drawings and open RFIs. The drawings contributed to the fact that early involvement in the design process was evident in the smaller number of changes to the reinforcement and void drawings. In terms of customer value, the contractor's contribution to the development of the design was most evident in the interview results. For timeliness, we did not find a similar substantial difference between early involvement by a contractor and subsequent involvement. These findings related to design quality should be considered in future research and practice when considering the role and importance of contractors in construction projects.

Surprisingly, no differences were found amounting to change work (i.e., drawing changes or revisions) in design during the construction process. The drawings were changed equally during the construction phase at all sites, regardless of how long the contractor had been involved in the development of the design. One possible explanation for this contradictory finding may be that when designers know that a contractor is involved in the development of design, they intentionally postpone the finishing of the drawings to avoid duplication of work. This result seems to support previous studies [45,46], where changes to drawings have not been perceived as harmful but as part of the normal design process and value generation. This phenomenon could be detrimental because drawings must be changed many times, but there is also a value-adding side to the phenomenon, as mentioned by Ballard [45] and Hansen and Olsson [46]. One may speculate that by intentionally leaving the design unfinished before the contractor joins the project, the designer may also seek to save the client's money, as changing the detailed design is expensive. It appears that this perspective on contractors' early involvement effects has not been thoroughly investigated, and further research should be undertaken to investigate this.

The current paradigm in design quality in the construction industry still seems to be the so-called 'expert review' process in which drawings are reviewed by another expert in the same field [63,64]. Based on our research, it seems that to increase the quality of design, industry players should consider splitting the expert review process into two parts, with another expert with specific expertise checking that the design meets the regulatory requirements, is technically complete, and meets general and project-specific technical standards, and another expert checking that design meets constructability issues. This idea is not new and has also been suggested by, for example, Pulaski and Horman [65] and Lam and Wong [66]. However, our observation suggests that the use of another expert who is a representative of the contractor could improve not only the constructability aspect but also the quality of the design. Our research also suggests that the earlier a 'second-stage expert' is involved in a project, the greater the reduction in design errors during construction and improvement in design quality. It is also worth noting that, in light of previous research, changes to traditional roles (such as 'second-stage expert') can also improve collaboration between the parties in BIM-based design [67]. Therefore, we suggest that the inclusion of a second-stage expert' should be experimented further, from different perspectives and by challenging traditional roles. This is an important issue for future research.

The generalizability of these results is subject to certain limitations. We recognize that many other noteworthy aspects of the design process have an impact on design quality [8]. However, in delimiting this perspective, we excluded various factors related to the design process, such as aesthetic aspects relevant to architecture and factors related to the use of space [68]. Similarly, we entirely omitted the factors essentially related to the quality of design related to the performance of technical systems [40]. The focus we chose is not because these factors would not be important when examining the quality of the design; however, our limitation is due to our research data, which are from structural design. In structural design, the aforementioned factors that are intrinsically related to design quality are beyond the control of this design discipline and are often determined prior to the work of the structural designer. One major limitation is the use of a single geographically limited case study as a research subject. Another limitation is the number of interviewees, where the owner's design managers were the majority and the contractors' design managers were the minority. This means that not all opinions could be gathered evenly from all sites.

However, despite the research limitations, we see certain directions for further research and encourage researchers to look for similar cases in other design fields from different countries and to try to replicate our research findings by using the metrics presented in this study. The research methodology and analytics are openly presented so that the research is reproducible, and we believe that a comprehensive description of the methodology and analysis contributes to strengthening the reliability of our research.

6. Conclusions

The study contributes to our understanding of contractors' early involvement and its effects on design quality. By using the design quality factors of constructability, customer value, and timeliness, this study showed that the early involvement of the contractor has a positive impact on the quality of the design, and that the parties also perceive these changes as largely beneficial to the project. Our findings revealed new information on the research gap regarding the quality of the design and contributed to the confirmation of previous studies on the early involvement of contractors. The findings of this study suggest that the earlier a contractor gets involved in design, the more the quality of the design can increase. On the other hand, according to our findings, the contractor also enters into a clear improvement in the quality of the design from a later point of view.

Our findings can be used in research focusing on the importance of collaboration between the parties in improving the quality of design. It is evident that the work of the designer alone is not enough for high-quality design, but to achieve the best possible result, the contractor must also be involved in bringing his skills to develop the designs to be less error-prone, more constructable, and more valuable. The practical contribution of our research is to all structural designers and those who do design coordination. The research method we used, which combined the recordings of design meeting notes and the analysis of the causes of drawing changes, was also suitable for measuring the quality of design in projects.

In addition to the reproducibility of the results of our study, we see that future research should be undertaken to explore how the dual expert review process can be managed and how contractual responsibilities and liability questions should be considered. This topic has already been partially investigated, although by taking a design quality perspective into further research, it is possible to seek new scientific knowledge regarding the evolution of the roles of contractor and designer.

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References

1. Arditi, D.; Gunaydin, H.M. Total quality management in the construction process. *Int. J. Proj. Manag.* **1997**, *15*, 235–243. [CrossRef]
2. Joyce, R. *The Construction (Design and Management) Regulations, 1994: Explained*; Thomas Telford: London, UK, 2001; pp. 7–32.
3. Lee, S.H.; Pena-Mora, F.; Park, M. Reliability and Stability Buffering Approach in Concurrent Design and Construction Projects. In Proceedings of the 11th Annual Conference of the International Group for Lean Construction, Blacksburg, VA, USA, 22–24 July 2003; pp. 1–10.
4. Tilley, P.A. Lean Design Management: A New Paradigm for Managing the Design and Documentation Process to Improve Quality? In Proceedings of the 13th Annual Conference of the International Group for Lean Construction, Sydney, Australia, 19–21 July 2005; pp. 1–10.
5. Song, L.; Mohamed, Y.; AbouRizk, S.M. Early contractor involvement in design and its impact on construction schedule performance. *J. Manag. Eng.* **2009**, *25*, 12–20. [CrossRef]
6. Lopez, R.; Love, P.E.; Edwards, D.J.; Davis, P.R. Design error classification, causation, and prevention in construction engineering. *J. Perform. Constr. Facil.* **2010**, *24*, 399–408. [CrossRef]
7. Gray, C.; Hughes, W. *Building Design Management*; Routledge: London, UK, 2007; pp. 24–26.
8. Gann, D.; Whyte, J. Design quality, its measurement and management in the built environment. *Build. Res. Inf.* **2003**, *31*, 314–317. [CrossRef]
9. Prasad, S. Clarifying intentions: The design quality indicator. *Build. Res. Inf.* **2004**, *32*, 548–551. [CrossRef]
10. O'Connor, J.T.; Woo, J. Proactive approach to engineering and design deliverables quality enhancement. *J. Manag. Eng.* **2017**, *33*, 04017005. [CrossRef]
11. Egan, J. *Rethinking Construction: The Report of the Construction Task Force to the Deputy Prime Minister on the Scope for Improving the Quality and Efficiency of UK Construction*; Department for the Environment, Transport and the Regions: London, UK, 1998; pp. 1–40.
12. Glavinich, T.E. Improving constructability during design phase. *J. Archit. Eng.* **1995**, *1*, 73–76. [CrossRef]
13. Tilley, P.; Wyatt, A.; Mohamed, S. Indicators of Design and Documentation Deficiency. In Proceedings of the 5th Annual Conference of the International Group for Lean Construction, International Group for Lean Construction, Griffith University, Gold Coast, Australia, 16–17 July 1997; pp. 137–148.
14. McGeorge, J.F. Design productivity: A quality problem. *J. Manag. Eng.* **1988**, *4*, 350–362. [CrossRef]
15. Arditi, D.; Elhassan, A.; Toklu, Y.C. Constructability analysis in the design firm. *J. Constr. Eng. Manag.* **2002**, *128*, 117–126. [CrossRef]
16. Kärnä, S.; Junnonen, J.M. Designers' performance evaluation in construction projects. *Eng. Constr. Archit. Manag.* **2017**, *24*, 154–169. [CrossRef]
17. Roësset, J.M.; Yao, J.T. State of the art of structural engineering. *J. Struct. Eng.* **2002**, *128*, 965–975. [CrossRef]
18. Andi, A.; Minato, T. Design documents quality in the Japanese construction industry: Factors influencing and impacts on construction process. *Int. J. Proj. Manag.* **2003**, *21*, 537–546. [CrossRef]

19. Gao, Z.; Walters, R.C.; Jaselskis, E.J.; Wipf, T.J. Approaches to improving the quality of construction drawings from owner's perspective. *J. Constr. Eng. Manag.* **2006**, *132*, 1187–1192. [CrossRef]
20. Sacks, R.; Eastman, C.; Lee, G.; Teicholz, P. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*; John Wiley & Sons: Hoboken, NJ, USA, 2018; pp. 109–110.
21. Choi, J.; Lee, S.; Kim, I. Development of Quality Control Requirements for Improving the Quality of Architectural Design Based on BIM. *Appl. Sci.* **2020**, *10*, 7074. [CrossRef]
22. Koo, H.J.; O'Connor, J.T. A Strategy for Building Design Quality Improvement through BIM Capability Analysis. *J. Constr. Eng. Manag.* **2022**, *148*, 04022066. [CrossRef]
23. Ashford, J.L. *The Management of Quality in Construction*; Routledge: London, UK, 2002; pp. 87–107.
24. Deming, W.E. *Out of the Crisis*; MIT Press: Cambridge, MA, USA, 2018; pp. 260–261.
25. Uusitalo, P.; Seppänen, O.; Lappalainen, E.; Peltokorpi, A.; Olivieri, H. Applying level of detail in a BIM-based project: An overall process for lean design management. *Buildings* **2019**, *9*, 109. [CrossRef]
26. Musa, S.; Obaju, B.N. Effects of Design Errors on Construction Projects. In Proceedings of the 4th Applied Research Conference in Africa (ARCA), Ibadan, Nigeria, 27–29 August 2015; pp. 137–151.
27. Achilov, S.S. Expert Method of Quality Management of Road Construction Project. *Middle Eur. Sci. Bull.* **2021**, *15*, 692. [CrossRef]
28. Mosey, D. *Early Contractor Involvement in Building Procurement: Contracts, Partnering and Project Management*; John Wiley & Sons: Hoboken, NJ, USA, 2009; pp. 6–36.
29. Laryea, S.; Watermeyer, R. Early contractor involvement in framework contracts. *Proc. Inst. Civ. Eng. Manag. Procur. Law* **2016**, *169*, 4–16. [CrossRef]
30. Eadie, R.; Graham, M. Analysing the advantages of early contractor involvement. *Int. J. Procure. Manag.* **2014**, *7*, 661–676. [CrossRef]
31. Jergeas, G.; Put, J.V.D. Benefits of constructability on construction projects. *J. Constr. Eng. Manag.* **2001**, *127*, 281–290. [CrossRef]
32. Rahmani, F.; Khalfan, M.; Maqsood, T. The Application of Early Contractor Involvement (ECI) in Different Delivery Systems in Australia. In Proceedings of the International Conference on Construction in a Changing World (CIB), Dambulla, Sri Lanka, 4–7 May 2014; pp. 1–12.
33. Hampson, K.D.; Kwok, T. Strategic alliances in building construction: A tender evaluation tool for the public sector. *J. Constr. Procur.* **1997**, *3*, 28–41.
34. Wondimu, P.A.; Hosseini, A.; Lohne, J.; Laedre, O. Early contractor involvement approaches in public project procurement. *J. Public Procur.* **2018**, *18*, 355–378. [CrossRef]
35. Seo, J.H.; Lee, B.R.; Kim, J.H.; Kim, J.J. Collaborative process to facilitate BIM-based clash detection tasks for enhancing constructability. *J. Korea Inst. Build. Constr.* **2012**, *12*, 299–314. [CrossRef]
36. Mahalingam, A.; Kashyap, R.; Mahajan, C. An evaluation of the applicability of 4D CAD on construction projects. *Autom. Constr.* **2010**, *19*, 148–159. [CrossRef]
37. Fisher, D.J.; Anderson, S.D.; Rahman, S.P. Integrating constructability tools into constructability review process. *J. Constr. Eng. Manag.* **2000**, *126*, 89–96. [CrossRef]
38. Love, P.E.; Lopez, R.; Edwards, D.J. Reviewing the past to learn in the future: Making sense of design errors and failures in construction. *Struct. Infrastruct. Eng.* **2013**, *9*, 675–688. [CrossRef]
39. Pheng, L.S.; Arain, F.M.; Fang, J.W.Y. Applying just-in-time principles in the delivery and management of airport terminal buildings. *Built Environ. Proj. Asset Manag.* **2011**, *1*, 104–121. [CrossRef]
40. Hassanain, M.A.; Aljuhani, M.; Sanni-Anibire, M.O.; Abdallah, A. Interdisciplinary design checklists for mechanical, electrical and plumbing coordination in building projects. *Built Environ. Proj. Asset Manag.* **2019**, *9*, 29–43. [CrossRef]
41. Gangolells, M.; Casals, M.; Gassó, S.; Forcada, N.; Roca, X.; Fuertes, A. Assessing concerns of interested parties when predicting the significance of environmental impacts related to the construction process of residential buildings. *Build. Environ.* **2011**, *46*, 1023–1037. [CrossRef]
42. Raviv, G.; Shapira, A.; Sacks, R. Empirical investigation of the applicability of constructability methods to prevent design errors. *Built Environ. Proj. Asset Manag.* **2022**, *12*, 53–69. [CrossRef]
43. Tauriainen, M.; Puttonen, J.; Saari, A.; Laakso, P.; Forsblom, K. The Assessment of Constructability: BIM cases. In *eWork and eBusiness in Architecture, Engineering and Construction*; CRC Press/Balkema: EH Leiden, The Netherlands, 2014; pp. 55–61.
44. Ballard, G. The Last Planner System of Production Control. Ph.D. Thesis, University of Birmingham, Birmingham, UK, 2000; pp. 1–193.
45. Ballard, G. Positive vs. Negative Iteration in Design. In Proceedings of the 8th Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK, 17–19 July 2000; pp. 17–19.
46. Hansen, G.K.; Olsson, N.O. Layered project—layered process: Lean thinking and flexible solutions. *Archit. Eng. Des. Manag.* **2011**, *7*, 70–84. [CrossRef]
47. Ballard, G.; Howell, G. Toward Construction JIT. In *Lean Construction*; Taylor & Francis Group: Abingdon, UK, 1995; p. 5.
48. Kenley, R.; Seppänen, O. *Location-Based Management for Construction*; CRC Press: Boca Raton, FL, USA, 2010; pp. 233–238.
49. Yang, J.B.; Wei, P.R. Causes of delay in the planning and design phases for construction projects. *J. Archit. Eng.* **2010**, *16*, 80–83. [CrossRef]

50. Tight, M. Key Debates in Case Study Research. In *Understanding Case Study Research*; SAGE Publications Ltd.: Thousand Oaks, CA, USA, 2017; pp. 18–40.
51. Diefenbach, T. Are case studies more than sophisticated storytelling? Methodological problems of qualitative empirical research mainly based on semi-structured interviews. *Qual. Quant.* **2009**, *43*, 875–896. [CrossRef]
52. Barratt, M.; Choi, T.Y.; Li, M. Qualitative case studies in operations management: Trends, research outcomes, and future research implications. *J. Oper. Manag.* **2011**, *29*, 329–342. [CrossRef]
53. Tellis, W. Introduction to Case Study. *Qual. Rep.* **1997**, *3*, 1–14. [CrossRef]
54. Marshall, J.; Reason, P. Quality in research as "taking an attitude of inquiry". *Manag. Res. News* **2007**, *30*, 368–380. [CrossRef]
55. Bengtsson, M. How to plan and perform a qualitative study using content analysis. *NursingPlus Open* **2016**, *2*, 8–14. [CrossRef]
56. Vuori, T.O. An Open-Ended Interview Approach for Studying Cognition and Emotion in Organizations. In *Methodological Challenges and Advances in Managerial and Organizational Cognition (New Horizons in Managerial and Organizational Cognition, Vol. 2)*; Emerald Publishing Limited: Bingley, UK, 2017; pp. 59–71.
57. Cameron, R. A sequential mixed model research design: Design, analytical and display issues. *Int. J. Mult. Res. Approach.* **2009**, *3*, 140–152. [CrossRef]
58. Gioia, D.A.; Corley, K.G.; Hamilton, A.L. Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organ. Res. Methods* **2013**, *16*, 15–31. [CrossRef]
59. Hughes, N.; Wells, M.; Nutter, C.; Zack, J. *Impact & Control of RFIs on Construction Projects: A Research Perspective Issued by the Navigant Construction Forum™*; Navigant Construction Forum: Chicago, IL, USA, 2013; pp. 1–35.
60. O'Connor, J.T.; Davis, V.S. Constructability improvement during field operations. *J. Constr. Eng. Manag.* **1988**, *114*, 548–564. [CrossRef]
61. Trigunarsyah, B. Constructability practices among construction contractors in Indonesia. *J. Constr. Eng. Manag.* **2004**, *130*, 656–669. [CrossRef]
62. Gransberg, D.D.; Windel, E. Communicating design quality requirements for public sector design/build projects. *J. Manag. Eng.* **2008**, *24*, 105–110. [CrossRef]
63. Maher, M.L. Expert systems for structural design. *J. Comput. Civ. Eng.* **1987**, *1*, 270–283. [CrossRef]
64. Mohammed, A.A.; Ambak, K.; Mosa, A.M.; Syamsunur, D. Expert system in engineering transportation: A review. *J. Eng. Sci. Technol.* **2019**, *14*, 229–252.
65. Pulaski, M.H.; Horman, M.J. Organizing constructability knowledge for design. *J. Constr. Eng. Manag.* **2005**, *131*, 911–919. [CrossRef]
66. Lam, P.T.; Wong, F.W. A comparative study of buildability perspectives between clients, consultants and contractors. *Constr. Innov.* **2011**, *11*, 305–320. [CrossRef]
67. Sebastian, R. Changing roles of the clients, architects and contractors through BIM. *Eng. Constr. Archit. Manag.* **2011**, *18*, 176–187. [CrossRef]
68. Eilouti, B. Reinventing the wheel: A tool for design quality evaluation in architecture. *Front. Archit. Res.* **2020**, *9*, 148–168. [CrossRef]