Novel Approach to Overcoming Discontinuity in Knowledge: Application in Value-Adding Frameworks in Construction Industry

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Abstract: Knowledge discontinuity can be a significant obstacle to knowledge growth and accumulation, resulting primarily from the excessive tailoring of borrowed concepts, theories, and approaches. Research in the construction industry is prone to knowledge discontinuity because often after adopting a concept originally developed in another field of study, the link to the original trunk is gradually severed, thus inhibiting research progress. In fact, knowledge discontinuity slows advancement in the construction industry because it is an obstacle to the realization of the benefits achieved in other disciplines by means of the concept, theory, or approach. The research presented in this paper proposes a novel approach to overcoming the discontinuity in knowledge in construction-related research. It uses value-adding practice in the construction industry as a case study, establishing a common understanding of the predominant value-adding frameworks used in the construction industry and providing a measure for the similarity between the selected value-adding frameworks along with the shortcomings of the value-adding practice that need to be addressed. The paper concludes with defining the requirements for a unified framework for value adding in the construction industry. **DOI: 10.1061/(ASCE)CO.1943-7862.0001670.**

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Introduction

In his masterpiece *Archaeology of Knowledge*, Foucault (2013) considers discontinuity a major obstacle that hinders knowledge growth and accumulation. There are various elements that cause discontinuity in knowledge. Foucault (2013) states that "... the most radical discontinuities are the breaks effected by a work of theoretical transformation which establishes a science by detaching it from the ideology of its past and by revealing this past as ideological." This often occurs when researchers borrow concepts, theories, or approaches to implement in disciplines other than those for which they were originally developed. As part of this phenomenon of borrowing, concepts, theories, or approaches are tailored to the requirements of the destination discipline and, in many instances, assigned new names. The borrowed concepts then undergo a series of localized (within one discipline) developments that result in treating the branched-out concept as a new one. This localizing, as per Foucault's argument, prevents the localized branches from benefiting from further developments to the core and/or to other branches. A notable example in this context is how target costing (TC) branched out from value engineering (VE) as the Japanese auto industry borrowed the concepts of the latter, then target costing in turn was used as the basis for target value design (TVD) when lean construction (LC) practitioners adapted target costing along with other lean concepts. As a result, neither one of the mentioned approaches has benefited fully from further developments that have occurred in the original paradigms subsequent to the branching out.

In fact, it is a common practice in the construction industry to borrow concepts and tools developed in other disciplines, tailor them to the needs of the construction industry, and implement them. For example, building information modeling (BIM) began as an application of parametric modeling for manufacturing (Eastman et al. 2011), but took a different path of development once the name *BIM* had been coined. While parametric modeling platforms in manufacturing manage the life cycle of the product [the term *product lifecycle management* (PLM) is used to refer to such applications], BIM applications seem far from attaining this level PLM applications offer (Jupp and Singh 2014). Another example is the value-adding frameworks that have been implemented in the construction industry (e.g., value engineering and lean construction), where the continuous tailoring of the adopted frameworks as time elapses gives a false impression that practitioners are dealing with different value-adding approaches. Other areas of study also suffer from the same tendency. For instance, in the area of computer science, artificial intelligence and control theory have emerged as two separate fields even though they share the same foundation. Russell and Norvig (2010) give a detailed account on the genesis of these areas of science and their separation.

Indeed, the discontinuity of knowledge is a major impediment in research endeavors to accumulating knowledge and increasing efficiency. To overcome the impact of discontinuity resulting

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from knowledge discontinuity, the present research proposes an approach for studying the similarities among existing branches and determining the urgent issues to be addressed, such that theory and practice with regard to construction industry concepts borrowed from other disciplines can be improved. To illustrate the applicability of the proposed approach, this paper addresses the topic of value-adding frameworks in the construction industry. Through the case study, we aim to establish mutual assimilation of the fundamentals of value-adding practices in the construction industry by measuring the similarities among popular value-adding frameworks and the shortcomings associated with their implementation that need to be addressed.

Prior to introducing the methodology underlying the research, the paper provides background information pertaining to value-adding practice and the prominent value-adding frameworks in construction.

Background

Value can be simply defined as something good that people desire in a product, service, or process (Hart 1971; Schwartz 2007; Schroeder 2016). Researchers have developed several frameworks that connect the goodness people desire with tangible deliverables. These approaches can be case or discipline specific—e.g., increasing value in medical research (Neta et al. 2015) or creating social value (Kroeger and Weber 2014)—or can be generalized frameworks that are cross disciplinary in practice, such as lean production system (LPS) and value engineering.

Like other industries, the construction industry demands frameworks that can translate the desired value(s) into deliverables. This has led construction researchers and practitioners to adopt several generalized value-adding frameworks, such as value engineering, lean, and analytic hierarchy process. In this context, a search in Scopus (up to the beginning of 2018) using the criteria of

1. articles and reviews that were published in English before 2018;
2. articles and reviews that have "value," "construction industry," and "framework" mentioned in their title, abstract, or keywords; and
3. articles and reviews that are published in the areas of business, management, and accounting; computer science; decision sciences; and engineering.

Then skimming the keywords of the retrieved articles yields the frequency of use of value-adding frameworks in the retrieved sample expressed in Fig. 1.

Based on the frequency of mentions as shown in Fig. 1, VE, lean, and TC can be considered the most popular value-adding frameworks among construction researchers and practitioners. During the preparation of the present research, the authors came across a value-adding framework that is gaining considerable attention in the aeronautics industry, called value-driven design (VDD). VDD puts the focus of the assessment process on the performance of the engineering systems that are used in aircrafts more than on customers' requirements (Bertoni et al. 2015). Construction researchers have begun in recent years to explore the potential of this framework in the construction industry, e.g., Zhuang et al. (2017). Hence, we explored the principles and limitations of this framework along with the other widely used value-adding frameworks under consideration.

Origins of the Value-Adding Frameworks under Consideration

This section contributes to the common understanding of the shared origins of the various value-adding frameworks by providing a brief historical account of the origins of these frameworks, the motivations underlying their emergence, and how they have manifested themselves in the construction industry. The original value-adding frameworks are discussed in order to establish the continuity of knowledge necessary to unify research efforts toward further improving these value-adding frameworks.

Value Engineering, Value Analysis, and Value Management

Driven by the shortage of supplies during and following World War II and the resulting need for lower prices, a purchasing team at General Electric led by Lawrence D. Miles proposed a systematic approach for problem solving to reduce unnecessary costs. The approach was called value analysis (VA), a concept that Miles (1961) defined as "a complete system for identifying and dealing with the factors that cause uncontracting cost or effort in products,

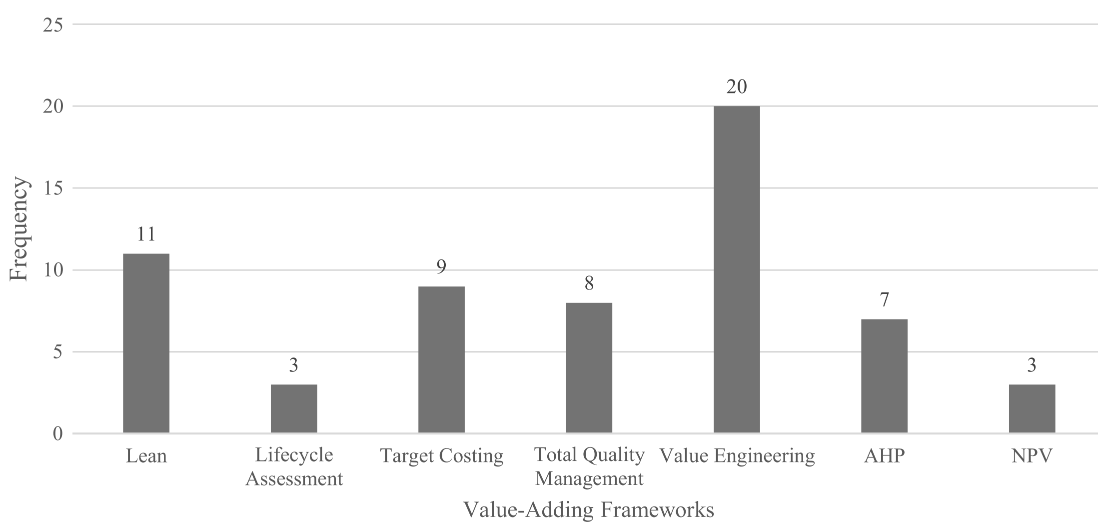

Fig. 1. Mentioning frequencies of value-adding frameworks in the construction industry. AHP = analytic hierarchy process; and NPV = net present value. Value engineering included other terms such as value analysis and value management.

processes, or services." Due to the success this framework achieved in reducing costs, the US Department of Defense (DoD) adopted it into practice in 1954 (Dell'Isola 1982), changing the name to value engineering as proposed by Admiral Wilson D. Leggett who was the head of the Naval Engineering Experiment Station in Annapolis (Fowler 1990). The construction industry adopted the concepts of VE/VA in the early 1960s mainly through the efforts of Dell'Isola (Fowler 1990). In the 1980s, amid increasing interest in management sciences, practitioners coined the term *value management* (VM) to describe the application of VA concepts in the management sciences (Barton 2001).

In this context, Jay and Bowen (2015) point out that VE is used to define the processes used within design-related tasks, while VA is used to describe the same methodology applied to postdesign phases of the project. This trend began with DoD post-VA adoption and continued in the manufacturing sector (Anderson and Sury 1979; Hartley 2000) and the Japanese automotive industry (Sato and Kaufman 2005). As for VM, some researchers argue that the term can be used interchangeably with VA and VE (Dell'Isola 1982; Fowler 1990; Parker 1998), while others see VM as an umbrella term that covers VE and VA in a generic manner (Shen and Liu 2004; Shen and Yu 2012). However, Barton (2001) asserts that the term VM was not introduced with the intention of defining a new approach, but rather of tailoring the application to better suit the soft nature of value in the managerial field, which imposed considerable changes to the original method. For a full comparison between VE and VM, the reader may refer to Barton (2012).

Lean Production System and Lean Construction

"Catch up with America in 3 years. Otherwise, the automobile industry of Japan will not survive." These words marked the dawn of the Toyota Production System (TPS) (Ohno 1988). To catch up with the efficiency of the American industry, Taiichi Ohno, the father of TPS (Sugimori et al. 1977), began by identifying and eliminating process waste in the production line. This effort culminated in the introduction of just-in-time manufacturing—feeding the flowing process with the exact number of needed parts at the time they are needed (Ohno 1988)—and autonomation—focusing on automation while giving workers the opportunity to improve (Sugimori et al. 1977), two innovations that came to characterize the TPS (Ohno 1988). The process improvement brought in by TPS assisted Toyota in overcoming the challenges imposed by oil crises in the 1970s (Ohno 1988), positioning it to become the most profitable automotive company in the world with a market capitalization (i.e., the market value of the company's outstanding shares) of \$184.8 billion (New York Times 2017). As Japanese companies became more competitive globally, the TPS garnered increasing attention, and the name *lean* was coined by John F. Krafcik to emphasize the core principle of TPS in reducing process waste (Staats et al. 2011). Lean principles have since been implemented in many aspects of modern life, including education (Emiliani 2005), health care (Mazzocato et al. 2010), the services sector (Kanakana 2013), and the construction industry.

Despite the differing characteristics of the manufacturing and construction industries, pioneer researchers began to explore the adoption of lean thinking in construction in the late 1980s (Howell 1999). In 1992, Koskela presented his research on considering workflow holistically when studying individual construction activities in order to reduce the process waste associated with then-current construction management frameworks (Koskela 1992). The development of a planning system for construction that accounts for the principles of LPS started in 1992 (Ballard 2000), and the formal introduction of this system, i.e., Last Planner, in academia came shortly thereafter, at the inaugural conference of the International Group for Lean Construction (Ballard 1993). The late 1990s saw the establishment of the Lean Construction Institute, which was the result of collaboration between Glenn Ballard and Greg Howell (Ballard 2000) "to develop and disseminate new knowledge regarding the management of work in projects" (Lean Construction Institute 2017). Henceforth, lean construction drew considerable attention among construction practitioners, with a recent report published by McGraw-Hill Construction (2013) showing that 43% of those surveyed indicating that they have implemented lean construction in practice.

Target Costing and Target Value Design

The notion of designing within certain cost constraints by evaluating several technological options based on their influence on the overall cost and quality of the product is not a new one. A noteworthy example of this is the design in the 1930s of the Volkswagen Beetle, which featured a price cap of 990 German marks (Rösler 1997; Feil et al. 2004). Soon after World War II, due to the scarcity of resources, VE practitioners acknowledged the importance of maximizing the product attributes that matter most to consumers. Japanese companies adopted VE and its concepts in the early 1960s, at which time it was widely implemented in various industries (Fowler 1990). Japanese companies, chiefly Toyota, also extended the VE concept (Gagne and Discenza 1995; Ansari et al. 2006) and utilized it in their production system under the name *Genka Kikaku* (Nicolini et al. 2000; Feil et al. 2004). *Genka Kikaku*, rendered in English as target costing, was then changed to target cost management by the Japan Cost Society in 1995 (Feil et al. 2004). TC, it should be noted, can be defined as "a technique to strategically manage a company's future profits" (Cooper and Slagmulder 1999).

TC came to be adopted by lean construction researchers, as did several other manufacturing concepts. The adaptation of TC to the construction industry is called target value design (Zimina et al. 2012; P2SL 2017). It is a reversed approach that begins with setting a goal—usually the monetary value of the project—rather than beginning with the design (Helms et al. 2005). Proponents of lean construction argue that TVD has significantly reduced cost and improved the cost control process for construction (Ballard 2008, 2012; de Melo et al. 2016; Obi and Arif 2015).

Value-Driven Design

Implementing VE, LPS, and TC has enabled several branches of industry to expand their market and their profit margins. Nevertheless, large-scale and highly complex projects continued to see cost overruns and schedule delays, which is partially attributable to technical performance having been overlooked during design (Collopy and Hollingsworth 2011). In the late 1960s, Herbert Simon considered that the problem of engineering design has its origins at the interface between the internal structure of a product and the external features that reflect the users' requirements (Cheung et al. 2012), underscoring the need to assign equal importance to user requirements and internal system requirements. In the 1960s and 1970s, several researchers suggested incorporating value into the system design process through optimization and the application of utility theory in the design process (Collopy and Hollingsworth 2011; Cheung et al. 2012). The work of Hazelrigg (1998) provided a strong base for incorporating design theory into the design process and established an initial framework for VDD, although the term itself would not be coined until 2006 by Jim Struges, a pioneer researcher in VDD (Collopy and Hollingsworth 2011). VDD can be

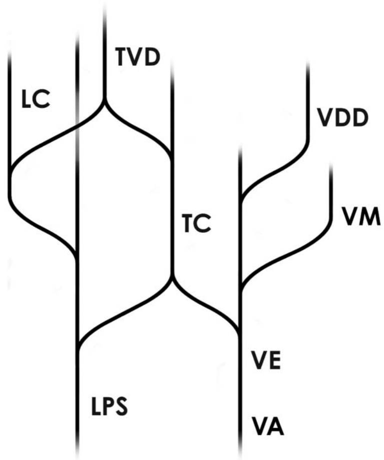

Fig. 2. Relationships between considered value-adding frameworks.

described as an engineering-oriented framework that focuses on the hardware of systems in order to deliver high overall performance while incorporating value as a constraint in the design process (Bertoni et al. 2015).

Reference to system performance as a value separate from other values may create some confusion for the reader, so further clarification is warranted. Performance is an intrinsic value. It is also an integral component of quality (Owlia and Aspinwall 1998), the assurance of which is a principal goal of VE, LPS, and TC. However, as can be seen in the work of Collopy and Hollingsworth (2011) and Bertoni et al. (2015), VDD researchers observe that the traditional practice for adding value gives higher priority to fulfilling end user requirements than to optimizing the technical aspects of the designed systems.

Based on the brief history presented in this section, Fig. 2 illustrates the branching that has occurred in the last 75 years with regard to value-adding practice.

Methodology

The present research aims to overcome the problem of knowledge discontinuity, employing value-adding frameworks to demonstrate the application of the proposed approach. It follows a two-step methodology that begins with scrutinizing the literature to define the principles and limitations of the considered concepts (e.g., VE and VM, LPS and LC, TC and TVD, and VDD), then analyzing the retrieved literature using a combination of grounded theory (GT) and quantitative concepts developed by the authors (i.e., similarity index and priority index) to define the similarities and shortcomings. The details of the proposed methodology are explained in the following subsections.

Step 1: Defining the Principles and Limitations of the Considered Frameworks

Several researchers, such as Fink (2001) and Osei-Kyei and Chan (2015), have underscored the importance of following a systematic approach when searching for literature. The present research adapted the approach proposed by Chan and Owusu (2017) for searching and reviewing literature, which begins with ranking journals based on the number of publications on the topic of study (which, in this research, is value adding in the construction industry), then proceeds to search the top-ranked journals for the

Table 1. Priority of sources

Priority	Source type	Explanations
1	Leading construction journals	Journals that have the largest number of publication pertaining to value-adding frameworks in the construction industry
2	Class-A books	Books written by the founders and pioneers of the value-adding frameworks
3	Peer-reviewed journals	Journals that are not mentioned in Priority 1
4	Class-B books	Books with more than 100 citations
5	Conference proceedings	Articles published in conference proceeding about value-adding frameworks
6	Theses	Published theses that address value-adding frameworks
7	Government reports and manuals	Reports and manuals published by governmental authorities pertaining to value-adding frameworks
8	Commercial reports	Reports that are published by commercial entities in regard to the value-adding frameworks
9	Online articles	Nonrefereed articles that discuss value-adding frameworks

literature that discusses the principles and limitations of the selected concepts. For this purpose, Osei-Kyei and Chan (2015) argued that the Scopus search engine has broader and more accurate access to publications compared to other specialized engines; consequently, Scopus was used in the present research for this purpose. Due to the nature of this research, which spans several subtopics—in contrast to the case discussed in Chan and Owusu (2017)—limiting the scope to the journals that received the highest ranks may compromise the comprehensiveness of the retrieved literature. Thus, the search approach was modified to ensure access to the desired information. After searching the short-listed journals for publications that address the principles and limitations of the considered concepts using Scopus, as proposed by Chan and Owusu (2017), the retrieved publications were perused to determine whether they contain the desired information. The number of publications with suitable content was then assessed. In the cases where the number of usable publications was greater than or equal to 10, the search for literature stopped. Otherwise, the search for literature was expanded beyond the six chosen journals and Scopus, with the authors using Google Scholar to perform the search. To maintain a systematic approach when searching for the literature, a system was developed for ranking the sources (Table 1) in order to determine their priority in the search. In this manner, the search began with sources of Priority 1, followed by Priority 2, all the way to Priority 9.

The retrieved literature was then investigated to determine the principles and the limitations of the considered concepts, which were analyzed in the second step. Hence, the deliverables of this step were two lists: one that contained all the principles of the considered concepts, and another that contained their limitations.

Step 2: Analyzing the Retrieved Literature

The second step of the proposed approach analyzes (1) the principles of considered concepts in order to measure their similarly, and (2) the limitations in order to determine the potential improvements in the considered field of research and their priority. This step has three phases, i.e., code development, similarity measure, and prioritization of improvements.

Code Development

Achieving mutual assimilation pertaining to the studied concepts (e.g., VE, LC, and TC) requires a deep analysis of the existing literature in order to uncover the underlying patterns in regard to the principles and the limitations of these concepts. In the 1960s, Glaser and Strauss (1967) suggested a systematic approach for analyzing the qualitative data collected in sociology in order to recognize patterns in data and ultimately develop a theory that explains these patterns (Walsh et al. 2015). This approach, called grounded theory, is widely recognized by researchers from different disciplines as a credible framework for conducting qualitative research (McCallin 2009). Because GT theory can be used with many types of qualitative data, researchers in the construction industry also employ GT for their qualitative research. For example, Dainty et al. (2000) used GT to understand the factors that may hinder women from advancing their careers in the construction industry. Kulchartchai and Hadikusumo (2010) used GT to analyze transcribed interviews to reveal the obstacles that may hinder the development of a culture of safety in the construction industry. Accordingly, GT can be used to analyze the literature related to value-adding frameworks in the construction industry in order to achieve mutual assimilation of the frameworks.

In Phase 1 of Step 2, GT was used to analyze the collected literature, with the purpose of revealing the commonalities in the principles and limitations in order to better understand the studied concepts. In this regard, Hamilton (2011) identified the assumptions underlying GT as follows: (1) theory exists in data; (2) "everything related to the subject of study is data"; (3) develop the theory from data; (4) move from data to hypothesis; (5) answer the question of what is going on, and how; and finally (6) start the analysis once data are collected. The analysis of the collected data (i.e., the text from the literature in this research) follows a three-step approach as suggested by Kulchartchai and Hadikusumo (2010) as follows:

1. Open coding, where the text is replaced by a tentative label of a few words that summarizes the text based on its meaning. For instance, a review of the literature yields the following TC principle: TC philosophy is built on the notion of allotting more time to the design process since this is the phase that is the least costly and most influential on the total cost of the product (Ansari and Bell 1997; Ellram 2006; Everaert et al. 2006; Ax et al. 2008; Kato 1993). The key message of this text is the need to focus on the design of the product; as such, the open code for this text is *focus on design*.
2. Axial coding, where the researcher defines the connections among the developed open codes. To elaborate on how to perform the axial coding, we assumed the following open codes: smallest delivery cost, life-cycle cost, price-led costing, life-cycle cost oriented, and budget oriented. All these codes are concerned with cost, which represents the nature of the assessed value, so the connection between them is that they are all addressing the nature of value. Therefore, the axial code for the open codes is *value nature*.
3. Selective coding, where the goal is to find the core code that categorized the axial codes. This is the step in which the theory that is grounded in the data is formulated. The researcher in this step investigates the underlying collective concept behind all the identified axial codes.

The present research utilized the first two steps (i.e., open coding and axial coding), where the lists (i.e., the principles list and the limitations list) previously developed were analyzed to define the open codes and axial codes for the principles and limitations of the considered concepts. Then, instead of proceeding to selective coding, the axial codes of principles were analyzed quantitatively to measure the similarities among the considered concepts, while the axial codes of limitations were analyzed (also quantitively) to determine the urgency of the issues to be addressed in the considered field of study.

Measure Similarity

The developed axial codes of the principles represent the core ideas that all the studied concepts share despite their differences in terminology. These core ideas demonstrate the similarities between the considered concepts. In order to evaluate the resemblance between the selected concepts in an objective manner, this paper introduces the similarity index (SI_{ij}) of two concepts i and j, a metric that measures the degree of similarity between two given concepts. In this context, $SI_{ij} > SI_{il}$ means that concept j is more similar to concept i than to concept l. The assessment of the similarity index begins with calculating the contribution of concept i to an axial code j or C_{ij} as follows:

$$C_{ij} = \frac{N_{OC_{ij}}}{NP_i} \tag{1}$$

where $N_{OC_{ij}}$ = number of open codes of concept i that have axial code j; and NP_i = number of listed principles of concept i. Note that $C_{ij} \in [0, 1]$.

The similarity index SI_{ij} of concepts i and j is then calculated as per Eq. (2)

$$SI_{ij} = \sum_{k=1}^{n} C_{ik} \times C_{jk} \tag{2}$$

where C_{ik} and C_{jk} = contributions of concepts i and j, respectively, to the axial code k. It should be noted that $SI_{ij} = SI_{ji}$ and $i \neq j$. SI is evaluated for each pair of concepts to assess how close the selected concepts are to one another.

Prioritization of Improvements

While analyzing the principles highlights the similarities among the studied concepts, analyzing their limitations, as described in the literature, underscores the shortcomings in general practice in the field of research to which the considered concepts belong, and therefore gives direction as to where further research should be pursued. Developing the axial codes of a limitation's open codes describes problematic issues that span over several concepts, where no comprehensive solution is provided by any of the considered concepts. The present research used the priority index (PI_i) of an axial code i to measure how urgent the need is to address issue i. After assessing the contribution of each of the considered concepts toward the axial codes as per Eq. (1), the priority index is calculated using Eq. (3). Here, the higher the priority index, the more urgent is the need to address the corresponding issue

$$PI_i = \sum_{j=1}^{n} C_{ji} \tag{3}$$

The application to the discussed steps in a real-life scenario is explained in the following section.

Case Study

To demonstrate the application of the proposed approach, this research used value-adding practice in the construction industry as a case study. For this purpose, the frameworks described in

Table 2. Leading construction journals publishing articles on value-adding frameworks

Rank	Journal	Number of published articles on selected frameworks
1	*Engineering, Construction and Architectural Management*	64
2	*Construction Management and Economics*	27
3	*Construction Innovation*	21
4	*Journal of Construction Engineering and Management*	21
5	*Journal of Management in Engineering*	10
6	*Journal of Engineering, Design and Technology*	9

the "Origins of the Value-Adding Frameworks under Consideration" section (i.e., VE, VM, TC and TVD, LPS and LC, and VDD) were investigated to measure their similarities and define avenues for improvement in value-adding practice in the construction industry. VE and VM were considered separately following the fundamental difference stated by Barton (2012). The application of the proposed approach is detailed as follows.

Step 1: Defining the Principles and Limitations of the Considered Frameworks

As discussed previously, the application of the proposed approach began with a systematic review of the literature to define the principles and limitations of each of the considered concepts. The systematic review of the literature began, as explained, with defining and ranking the leading journals in the area of research (i.e., value-adding practice in the construction industry). For this purpose, the search criteria mentioned previously led to the results shown in Table 2.

Once the leading journals were identified, Scopus was used to retrieve articles in those journals with content pertaining to the principles and limitations of VE, VM, TC and TVD, LPS and LC, and VDD. The retrieved articles were then assessed to determine if they list and/or discuss the principles and limitations of the mentioned frameworks. If the relevant content was sufficient (as stated in "Methodology"), the search process stopped. If not, the search was expanded to other sources that comply with the priories defined in Table 1. In this regard, the founders and pioneers were identified as Miles and Dell'Isola for VE and VM; Ohno and Womack for LPS; Koskela, Ballard, and Howel for LC; and Collopy for VDD. Tables 3 and 5 show the principles and limitations, respectively, of each of the considered value-adding frameworks, indicating where the reader can find the principle and limitations as stated in the retrieved literature. The sources from which these principles and limitations are obtained are also listed. The principles and limitations of considered frameworks that were obtained from the literature are the row data that will be analyzed using GT in Step 2.

Step 2: Analyzing the Retrieved Literature

Following the explanation provided in the "Methodology" section, the retrieved literature was analyzes according to the following phases.

Code Development

Table 3 shows the principles (categorized according to the considered value-adding framework) and their corresponding open codes formulated by summarizing the sentences that describe a given principle using few words that succinctly capture the full meaning of the sentences. Each principle was given an ID consisting of three parts: the method code (i.e., VE for value engineering, VM for value management, LC for lean construction, TC for target costing, TVD for target value design, and VDD for value-driven design), the letter P, which stands for principle, then a serial number. For instance, the first principle of value engineering was assigned the ID VEP1. This ID is used to indicate the corresponding principle in Table 4. These open codes were further analyzed (as described in the "Methodology") in order to develop the axial codes that are shown in Table 4. In Table 4, the reader can see the developed axial codes, their IDs, description, and corresponding open codes.

Similarly, the limitations of value-adding frameworks collected from the retrieved literature undergo the coding process, with the results presented in Tables 5 and 6. Each limitation is given an ID, which can be seen in Table 5, following the same logic as the principles' IDs, but using the letter L to refer to limitation (corresponding to the use of the letter P for the principles).

After the code development phase is finished, it is possible to measure the similarity among the considered value-adding frameworks and define the issues in order to improve the value-adding practice in the construction industry.

Measure Similarity

Based on the information in Tables 3 and 4 and using Eq. (1), the contribution of each framework to each axial code can be assessed. For example, there are two open codes (VEP1 and VEP4) of VE that belong to the representation of values axial code, and there are seven principles for VE. Thus, the contribution of VE to the representation of values is $2/7 = 0.29$. Table 7 shows the rest of the calculated contributions.

Using Table 7 and Eq. (2), the similarity between each pair of frameworks can be assessed. For example, the similarity index of VE and LC is calculated as follows: $SI_{\text{VE-LC}} = 0.29 \times 0 + 0.29 \times 0 + 0 \times 0 + 0 \times 0.09 + 0 \times 0 + 0 \times 0.27 + 0.14 \times 0 + 0.14 \times 0.09 + 0.14 \times 0.36 + 0 \times 0.18 = 0.0649$. Table 8 shows the rest of the similarity indexes for each pair of frameworks.

Prioritization of Improvements

Based on Tables 5 and 6 and Eqs. (1) and (3), Table 9 demonstrates the priority index for each of the limitations.

Results Discussion

As can be observed from Table 8, TC and VE are the two frameworks that are most similar to one another (SI = 0.1633), despite the fact that TC was adopted by lean practitioners and incorporated into their practices. This implies that, despite the modifications, TC has maintained the essence of VE. Two interesting observations can be made in regard to the information in Table 8. The first is that TVD, which is considered the application of TC in the construction industry, carries more resemblance to LC than to the original TC ($SI = 0.1515$ with LC versus $SI = 0.127$ with TC), which indicates that the tailoring process of TC carried conceptual changes that distanced the manifestation of TC in construction (i.e., TVD) considerably from the original TC. The other observation is that VM is not the most similar to VE (despite VE being the most similar to VM of the studied frameworks) because TC is more similar. This can be attributed to the tailoring of VM to fit managerial processes, whereas VE is more suited for design. As for VDD, which Collopy and Hollingsworth (2011) consider an improvement to VE, the observation is that it shows only a small resemblance to the original version ($SI = 0.0714$), only slightly larger than the resemblance

Table 3. Principles of considered value-adding frameworks and their corresponding open codes

ID	Description	Source	Open code
Value engineering			
VEP1	Function: Describes the utilization of the developed product, service, or process, thereby defining the goal of performing VE	Rajiv et al. (2014) and US Department of Defense (1983)	Define the goal
VEP2	Worth: The minimum monetary value needed to deliver a certain function	US Department of Defense (1983)	Smallest delivery cost
VEP3	Cost: The total monetary value needed for a certain function, which includes the cost of production or construction and operation and can be extended to the cost of replacement	Dell'Isola (1982), NEDA (2009), US Public Buildings Service (1992), and US Department of Defense (1983)	Life-cycle cost
VEP4	Value: The relationship between the worth and the cost of a given function	US Department of Defense (1983)	Definition of the function
VEP5	Cross-functional teamwork, which implicitly requires proper communication among project participants	USDOT (1997) and WVDOH (2004)	Multidisciplinary teamwork
VEP6	Continuous resolution of any issues arising until the final deliverable is ready	Mudge (1971), USDOT (1997), and WVDOH (2004)	Continuous assessment
VEP7	Job plan: Systematic and organized plan of action for conducting a VE analysis and assuring the implementation of the recommendations	NEDA (2009) and USDOT (1997, 2015)	Systematic planning for application
Target costing			
TCP1	The cost of the product is a target of the design process; this target is determined based on the competitive market price and target profit	Ansari and Bell (1997), Ax et al. (2008), Glaser and Strauss (1967), and Kato (1993)	Price-led costing
TCP2	The requirements of the end users are an essential component in the design process; designers must not compromise the desires of the customer in terms of quality, reliability, and low price in their efforts to lower the production cost		Focus on customer requirements
TCP3	TC philosophy is built on the notion of allotting more time to the design process since this is the phase that is the least costly and most influential on the total cost of the product		Focus on design
TCP4	In TC the design is carried out using a cross-functional team from different departments of the organization that contribute to the design and production; this allows the team to capture the various aspects that affect designs		Multidisciplinary teamwork
TCP5	TC aims to reduce the cost of the production throughout its entire life cycle, including the deposition cost; TC considers the cost from the perspective of the user, and thus aims to reduce the operation and maintenance cost; it also focuses on reducing production cost, including deployment and marketing		Life-cycle-cost orientated
TCP7	TC considers all the parties involved in the process of creating value for the product, including suppliers and dealers		Inclusiveness
TCP7	The company strives for continuous improvement of the product until it reaches the targeted cost; the product should not be introduced to the market prior to the fulfillment of the targets		Continuous assessment
Value-driven design			
VDDP1	Functional representation of value that links the economics and the operational features	Bertoni et al. (2015), Cheung et al. (2012), Collopy and Hollingsworth (2011), Isaksson et al. (2013), and Zhang et al. (2013)	Value model
VDDP2	Define the needs of the customer (values) through focus groups, questionnaires, or any other method that can capture the users' requirements and assign weights for these requirements and values		Define customer needs
VDDP3	Focus on the technical performance of the engineering systems in the products		Focus on the technical performance
VDDP4	Value-driven design is value-adding methods that are dedicated to the engineering design on the product		Focus on design

Table 3. (*Continued.*)

ID	Description	Source	Open code
Target value design			
TVDP1	Designers and clients should work closely and openly with one another throughout the design phase to clearly define value and streamline the design to satisfy the value	Macomber et al. (2007)	Collaborative work
TVDP2	The team should come up with an innovative solution for design and construction		Innovation
TVDP3	The design must be evaluated against a set budget, with the design to be executed within this budget		Budget orientated
TVDP4	All stakeholders must be incorporated in the planning and replanning of the project		Inclusiveness
TVDP5	The project should be designed in smaller batches, while developing a procedure to approve the overall design as it proceeds		Design in small batches
TVDP6	The design process should be directed toward what stakeholders value, and in the same sequence as it will be carried out; this will reduce rework		Customer focus
TVDP7	A small design group should be maintained		Small groups of designers
TVDP8	Design should be carried out in large spaces to encourage team involvement		Design in large spaces
TVDP9	An assessment meeting should be held following the completion of each phase		Continuous assessment
Value management			
VMP1	VM functionally assesses the problems it's utilized to solve	Che'Mat (2006), Fraser (1989), Ghazali and Anuar (2017), and Thiry (2013)	Functional assessment
VMP2	VM is utilized by a team formed from different disciplines	Fraser (1989), Kelly et al. (2014), and Thiry (2013)	Multidisciplinary teamwork
VMP3	The team has to evaluate the cost of alternatives over the life cycle of the problem	Che'Mat (2006)	Life-cycle-cost orientated
VMP4	Develop a system plan for the application, which is called the job plan	Che'Mat (2006), Fraser (1989), and Thiry (2013)	Systematic planning for application
VMP5	Analyze the organization value and the managerial consequences that stem from the potential change	Kelly et al. (2014)	Assess the influence on management
Lean construction			
LCP1	Reduce waste by eliminating non-value-adding tasks	Al-Sudairi (2007), Dunlop and Smith (2004), Freire and Alarcón (2002), Gambatese et al. (2016), Gudem et al. (2013), Nahmens and Mullens (2009), Koskela (1997), and Ogunbiyi et al. (2014)	Reduce waste
LCP2	Systematically assess the requirements of customers to enhance the delivered value	Bryde and Schulmeister (2012), Koskela (1997), and Ogunbiyi et al. (2014)	Systematic assessment of customer requirements
LCP3	Increase stability in the construction task	Koskela (1997)	Increase task stability
LCP4	Decrease the time required for performing tasks	Al-Sudairi (2007), Dunlop and Smith (2004), Freire and Alarcón (2002), Gambatese et al. (2016), Gudem et al. (2013), Koskela (1997), Nahmens and Mullens (2009), and Ogunbiyi et al. (2014)	Reduce task time
LCP5	Reduce the number of components and connections to reduce complexity	Dunlop and Smith (2004), Gudem et al. (2013), and Nahmens and Mullens (2009)	Reduce product complexity
LCP6	Enhance the flexibility of deliverables	Freire and Alarcón (2002) and Koskela (1997)	Enhance product flexibility
LCP7	Improve transparency	Bryde and Schulmeister (2012) and Koskela (1997)	Improve transparency
LCP8	Keep the focus of the control process on finished tasks	Al-Sudairi (2007), Freire and Alarcón (2002), and Koskela (1997)	Focus on finished tasks
LCP9	Continuously improve the processes	Koskela (1997), Meiling et al. (2012), and Ogunbiyi et al. (2014)	Continuous assessment

Table 3. (*Continued.*)

ID	Description	Source	Open code
LCP10	Achieve balance in flow and conversion	Bryde and Schulmeister (2012), Dunlop and Smith (2004), Koskela (1997), Ogunbiyi et al. (2014), and Thomas et al. (2002)	Balance flow
LCP11	Benchmark	Koskela (1997)	Benchmark

Table 4. Developed axial codes for the principles of the considered frameworks

Category (axial code)	ID	Explanation	Open codes
Representations of values	P.AX.1	Value is represented using a mathematical function and/or model to allow for the objective assessment of the alternatives	VEP1, VEP4, TCP1, VDDP1, VMP1
Value nature	P.AX.2	Product cost is in the core of the assessment process	VEP2, VEP3, TCP1, TCP5, TVDP3, VMP2
Incorporating customer feedback	P.AX.3	Customers are consulted for their requirements in the product	VDDP2
Customer focus	P.AX.4	Give the higher priority to the requirements of the customer	LCP2, TCP2, TVDP6
Technical performance focus	P.AX.5	Focus the design effort on increasing the technical performance of the engineering systems in the product	VDDP3
Value-adding practices	P.AX.6	Define practices to increase the obtained value	LCP1, LCP3, LCP4, TVDP6, VMP5
Team organization	P.AX.7	Define practices to better organize the team(s) involved in value-adding practice	VEP5, TCP4, TCP6, TVDP1, TVDP4, TCDP5, VMP3
Assessment process	P.AX.8	How the team is managing the evaluation process to ensure achieving the goals	VEP6, LCP9, TVD9, TCP7
Application process	P.AX.9	How the team is planning to apply the selected method	VEP7, LCP7, LCP8, LCP10, LCP11, TVDP7, TVD8, VMP4
Focus on design	P.AX.10	Where the method has allocated higher importance for the design phase	LCP5, LCP6, TCP3, TVDP2, VDDP4

Table 5. Limitations of considered value-adding frameworks and their corresponding open codes

ID	Description	Source	Open code
Value engineering			
VEL1	The traditional practice of VE does little to assist in the clear definition of value in exploration projects, and, despite defining the functional attributes and following a logical approach to maximize value in the product, fails to satisfy the expectations	Maniak et al. (2014)	Vagueness in the definition of value
VEL2	The lack of a structured framework is the major shortcoming of VE		Lack of structured framework
VEL3	VE does not support further processes such as design and performance optimization	Soban et al. (2012)	Lack of support for design and optimization
VEL4	In the application of VE, there is a discrepancy between clients and VE practitioners	Fong (2004)	Client–practitioner discrepancies
VEL5	In education, there are insufficient training programs, materials, and educators		Training insufficiency
VEL6	In research, there are inadequate research activities and funding		Research fund insufficiency
VEL7	There is a gap between university research and application of VE		Academia–industry discrepancy
Target costing			
TCL1	TC fails to incorporate the cost of capital into production-related decisions, and thus may not yield the best alternative in terms of economic considerations	Kee (2010)	Overlocking the cost of capital
TCL2	The utilization of TC is limited in products with interdependencies due to the complex interactions among the constituent components that influence the overall value of the end product		Limited in complex products
TCL3	TC tends to give less consideration to the technical realism—that is, the technical attributes and performance—of the designed product	Bertoni et al. (2015) and Gerst et al. (2001)	Less consideration of technical performance
TCL4	The manner in which this method has been applied suggests that cost reduction is the principal benefit to be derived from its implementation	Dekker and Smidt (2003)	Singularity of value
TCL5	TC requires more planning time compared to traditional cost-reduction methods	Everaert (1999)	Long planning time
TCL6	Companies with a less responsive management style have less success implementing TC	Huh et al. (2008)	Requires dynamic companies
Lean production systems			
LL1	LPS application is dependent on both the clarity and stability of customer value; therefore, ambiguous and inconsistent customer definitions of values can limit the effectiveness of LPS	Anvari et al. (2011)	Effectiveness is dependent on value clarity
LL2	The application of lean may have a negative effect on the producer in cases of demand fluctuation	Cusumano (1994), Chicksand and Cox (2005), and Hines et al. (2004)	Effectiveness is dependent on demand stability
LL3	Shortage in the required materials can cause a slowing or even a complete shutdown of the production line	Curran (2010)	Effectiveness is dependent on material availability
LL4	Despite the discussion about incorporating automation, lean practices do not fully support automation	Hines et al. (2004)	Lack of automation support
LL5	Overlooking the dynamic features of the systems		Overlooking system dynamics
LL6	Little support to integration on both a macro level (across organizations) and a micro level (across processes in the same organization)		Lack of support for integration
LL7	LPS leads to an organization that is less responsive to variability		Less responsive to variability
Value management			
VML1	Providing a practical solution for the problem in consideration is time consuming, which limits the number of evaluated options and jeopardizes optimality	Norton and McElligott (1995), Omran and Suliman (2017), and Noor et al. (2015)	Time restricted
VML2	VM lacks a standard methodology for application	Omran and Suliman (2017)	Lack of structured framework

Table 5. (*Continued.*)

ID	Description	Source	Open code
VML3	VM lacks a mechanism to deal with values of qualitative nature (i.e., the social impact of buildings)	Thomas et al. (2003)	Lack of support for qualitative values
VML4	The success in VM implementation is dependent on the team knowledge and objectivity, and the support it gets from management	Norton and McElligott (1995) and Senarathne et al. (2014)	Effectiveness is team dependent
VML5	Client commitments, which are not always available, are major factor to VM success	Omran and Suliman (2017)	Effectiveness is client dependent
Value-driven design			
VDDL1	The monetary assessment of VDD limits its efficiency when it is used to evaluate other values such as *life saving*	Surendra et al. (2012)	Singularity of value
VDDL2	The transformation of the process of value definition into practical application (i.e., developing the value model) is inherently challenging	Curran (2010) and Hines et al. (2004)	Challenging value definition
VDDL3	VDD focuses on performance as the driver of value rather than streamlining the customer requirements into the design process	Chan and Owusu (2017) and Curran (2010)	Less consideration of customer demand

Table 6. Developed axial codes for the limitations of the considered frameworks

Category (axial code)	Description	Open codes
Value definition process	Includes all limitations that are related to the definition of value to be added to the practice or design	VEL1, VEL4, LL1, LL2, TCL1, VDDL2
Single nature of value	Where the method considers values of one nature only such as only economic or only environmental	TCL4, VDD1, VML3
Focus	Where the method focuses on one aspect over the others	VEL3, TCL3, VDDL3
Methodology	Limitations related to the steps and process involved in the method	VEL2, LL3, LL4, LL5, LL6, VML2
Application	Involved limitations that are related to the application of the methods	VEL5, LL7, TCL5, TCL6, VML1, VML4, VML4
Reach out	Limitations related to promoting the method	VEL6, VEL7

Table 7. Contributions of frameworks under study to the axial codes

Value-adding framework	P.AX.1	P.AX.2	P.AX.3	P.AX.4	P.AX.5	P.AX.6	P.AX.7	P.AX.8	P.AX.9	P.AX.10
VE	0.29	0.29	0.00	0.00	0.00	0.00	0.14	0.14	0.14	0.00
LC	0.00	0.00	0.00	0.09	0.00	0.27	0.00	0.09	0.36	0.18
TC	0.14	0.29	0.00	0.14	0.00	0.00	0.14	0.14	0.00	0.14
TVD	0.00	0.11	0.00	0.11	0.00	0.11	0.33	0.11	0.11	0.11
VDD	0.25	0.00	0.25	0.00	0.25	0.00	0.00	0.00	0.00	0.25
VM	0.20	0.20	0.00	0.00	0.20	0.20	0.00	0.00	0.20	0.00

Table 8. Similarity index of each pair of value-adding frameworks

Value-adding framework	VE	LC	TC	TVD	VDD	VM
VE	N/A	0.0649	0.1633	0.1270	0.0714	0.1429
LC	—	N/A	0.0519	0.1515	0.0455	0.1273
TC	—	—	N/A	0.1270	0.0714	0.0857
TVD	—	—	—	N/A	0.0278	0.0667
VDD	—	—	—	—	N/A	0.1000
VM	—	—	—	—	—	N/A

Table 9. Priority index of shortcomings in the value-adding practice

Limitation	Priority index
Value definition process	1.07
Single nature of value	0.7
Focus	0.75
Methodology	0.91
Application	1.22
Reach out	0.29

between VE and LC ($SI = 0.0649$). VE and LC are two methods that were developed in completely different contexts. This indicates that VDD, even though it carries some of the concepts of VE, is distinct from VE. Finally, LC and VE were found to be significantly different ($SI = 0.0649$), despite the fact that both frameworks emphasize the elimination of process waste. While there is no clear approach for the application of the VE, LC has a very robust application structure that is embodied at the principle level.

As for the analysis of the limitations, as Table 9 shows, the main challenge in the value-adding practice is the applicability of the value-adding frameworks (PI = 1.62), followed by the clear definition of the value (PI = 1.07), where the considered frameworks do not provide a robust approach for determining the value. VE, TC, VDD, and, to some extent, TVD each propose a function to *measure* value, but these functions have led to an overemphasis on monetary value without addressing the issue of value definition. The implementation method of value-adding practice ranked third at PI = 0.91, where the lack of a robust and clear methodology for the value adding is perceived to be among the major obstacles that need to be overcome in order to improve the value-adding practice in the construction industry. Having an imbalanced focus on a particular phase of the project, project stakeholder, or metric of engineering performance is the fourth most influential shortcoming with a PI = 0.75. This aspect is important in particular because it leads the practitioner to overlook some aspects of a given project. On a lower importance level are issues related to the narrow scope of values that could be evaluated by the given framework and the education pertaining to value-adding practice.

Table 10. Comparison between the results of the case study and the FGM

Limitation	Case study order	FGM order
Value definition process	2	1
Single nature of value	5	5
Focus	4	4
Methodology	3	3
Application	1	2
Reach out	6	6

Validation of the Case Study Findings

The authors sought the opinions of industry experts to validate the findings through focus group meetings (FGMs) that followed the steps proposed by Morgan et al. (1998). The purpose of discussion was to validate the suggestion proposed by the case study as demonstrated in Tables 8 and 9. Prior to conducting the meeting, a list of questions was developed; these questions fall under two categories: questions to assess the knowledge of participants pertaining to the considered value-adding framework (for weighing the response of each participant) and questions related to the findings of the case study. The recommended number of participants of focus group meetings is 8–12 (Morgan et al. 1998). Therefore, eight participants (one director, one research and development lead, three managers, and four project managers) who have demonstrated involvement in all phases of construction projects and who have implemented at least one of the studied value-adding frameworks were recruited. The participants were located in five western Canadian cities (Edmonton, Calgary, Fort McMurray, Kelowna, and Winnipeg); participants who were not located in Edmonton joined via a conference call. The results of the conducted meetings were as follows: 88% of the participants considered VE and VM to be the same; 63% reported that TC and VE are similar to each other, where TC can be regarded as "a specialized version of VE that focuses on reducing the selling price"; finally, less than 15% of the participants reported knowledge of TVD and VDD and none of them reported having implemented either framework; as such, responses pertaining to these frameworks cannot be relied upon. A total of 88% of the participants reported perceiving no similarity between LC, TC, and VE or VM. As for the room for improvement in the value-adding practice, Table 10 shows a comparison of the case study results and FGM results. The process of value definition ranked as the most pressing issue among the participants (ranked second in the case study findings), followed by the applicability (ranked first in the case study findings). No change in the ranking of the rest of the issues was suggested by the participants.

To conclude, the FGM has proven considerable radiality in mapping the similarity among the studied frameworks, despite the reported variation, whereas, in regard to defining the issues that need to be done in order to improve the value-adding practice, the finding of the case study matched the assessment of the industry expert in 83% of the defined issues. The qualitative nature of the problem that the present research addressed (i.e., knowledge discontinuity) makes achieving a 100% success rate nearly impossible, and therefore there is always room for improvement.

General Discussion on the Case Study Finding

The mentioned frameworks tend to focus on the economic aspects of the construction phase of a project (Miles 1961; Mudge 1971; Dell'Isola 1966, 1982; Kim and Lee 2010; Cheung et al. 2012), while giving less attention to the social and environmental aspects or the life-cycle economic aspects. Another important observation in reviewing the mentioned value-adding frameworks is the relatively little support these frameworks provide for accounting for the interdependencies among systems in a developed product (i.e., building, in the case of the building construction industry). The exception to this observation is VDD, which provides an integrated platform outlining how the components of building systems interact with one another.

Based on the previous discussion, it is important to develop a value-adding framework for the construction industry to improve communication among the various disciplines and parties involved in a construction project. This unified framework can ensure cross-disciplinary knowledge transfer among the stakeholders of a construction project. Consequently, it can contribute to improving the overall value of the project. This framework is defined by the following characteristics:

- Flexible to accommodate multiple values (e.g., economic versus environmental);
- Efficient to streamline multiple values throughout the different phases of construction;
- Able to accommodate all the shared principles of the various existing frameworks; and
- Able to account for the interrelations among the various components of building systems.

The development of such a framework will help with establishing shared terminology among the involved parties in construction and will help to ensure the delivery of the value demanded by end users.

Conclusion and Future Recommendations

Construction practitioners often overlook the similarities of value-adding frameworks, and this may hinder communication and shared understanding of the best practices of each framework. This paper provides a common understanding pertaining to the predominant value-adding frameworks in construction in order to improve communication among stakeholders. It also lists the key features in a unified form for the purpose of manifesting value into the deliverables of the construction industry.

This paper seeks to demonstrate that the different frameworks share common core principles. A review of the literature shows that, despite the different nomenclature used for the various value-adding frameworks in the construction industry, they share major fundamental principles.

Based on the reviewed literature, it can be concluded that a framework is needed that is flexible to accommodate multiple values, capable of streamlining the multiple values across the different phases of construction, able to accommodate all the shared principles of other frameworks, and, finally, able to account for the interrelations among the various components of building systems.

It is important for the construction industry to develop universal understanding of terminology to describe problems and streamline solutions. This paper constitutes a step toward achieving this goal. Further research must build upon commonalities rather than creating new names for practices that share the same principles and only differ in application. This will allow the construction industry to adapt to rapid market changes and to secure a competitive position.

The discussion on the findings of the presented case study was tailored to building industry because the intention was to demonstrate how to employ the findings to suggested further enhancement in the value-adding practice in the construction industry. Nevertheless, the proposed approach in its general form helps to establish a collective appreciation of branching concepts with a given area of knowledge and, despite the potential difference in the terminology used, it is capable of measuring similarity among these branches and defining the issues that should be addressed to improve the practice and research in a given field of knowledge.

Data Availability Statement

All data generated or analyzed during the study are included in the published paper. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

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