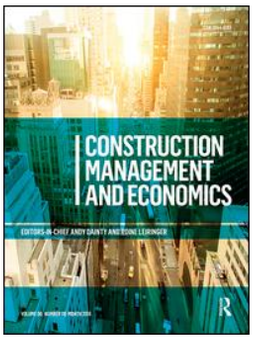

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Revisiting the concept of waste and its causes in construction from analytical and conceptual perspectives

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ABSTRACT

The phenomenon of waste in the construction industry has received considerable attention from the project professionals since the emergence of lean construction. In the research community, however, identifying causes of waste together with waste detection and elimination in the context of construction have been addressed in a limited manner. Moreover, there are very few studies, if any, which have tried to revisit the concept of waste ontologically and to look into the causes of waste through the lens of their relation to other elements in construction projects such as delivery elements and lifecycle phases. Therefore, this study aims to fill this knowledge gap through developing a novel conceptualization of waste and exploring causes of waste in construction projects to reveal their connection to various project attributes. To do so, a systematic literature study was conducted through which relevant studies were located and analysed to achieve the purposes of this study. The findings propose a novel conceptualization of waste and value based on their overlooked components. Moreover, the results present a model which reveals the connection between the identified causes of waste and project attributes (life cycle phases, relevant party, project delivery element, and waste categories in general). The obtained results can be insightful for project practitioners and the research community to reach in-depth understanding of the waste concept.

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Causes of waste; waste; lean construction

Introduction

The emergence of lean construction has played a significant role in the perspective of project professionals toward waste which is known to be one of the major causes for low productivity (Khan and Tzortzopoulos 2018, Watkins and Sunjka 2020). Lean construction ideal is to understand the value from the customer's perspective and then deliver fit for purpose product/-services with low waste (Oakland and Marosszeky 2017). Lean construction can be defined as the application of lean production principles and practices in the context of construction projects for minimizing waste, maximizing value, and pursuing continuous improvement throughout the project by establishing a long-term philosophy, investing in design and planning, developing people and partners, and joint design of processes and products (Koskela and Leikas 1997, Mao and Zhang 2008, Sacks *et al.* 2010, Vilasini *et al.* 2011, Oakland and Marosszeky 2017, Mossman 2018).

Theoretically, it can be said that the origin of lean construction concept and its ideal for waste elimination is rooted in Transformation (production of inputs into outputs)-Flow (Movement that is smooth and uninterrupted)-Value (what the customer is actually paying for the project to produce and install) theory (Koskela 1992). According to Koskela (2020, p. 7),

> a key component in the flow model theory of production is time. This refers to the status of the objects and subjects of production in the timeline. When addressing this, it is understood that not all time is used for transformation. Objects of production are stored, or they are transferred, or inspected. Correspondingly, subjects of production may be waiting, moving, or redoing. Such non-transformation stages are called waste, as such stages do not add value for the customer.

The concept of waste in lean production has been commonly defined as an activity which absorbs resources but does not produce value (e.g. Womack and Jones 2003). This understanding of the waste has been the main basis for categorizing it into seven clusters of (i) defects, (ii) delays, (iii) over-processing, (iv) over-production, (v) excess inventory, (vi) unnecessary transport and conveyance of materials and equipment, and (vii) unnecessary movement of people (Al-Aomar 2012,

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Ahuja 2013, Banawi and Bilec 2014, Yin *et al*. 2014). The mentioned definitions of waste and its categories have been dominant also in construction context, despite of the fact that lean production is the flowing products and fixed people to produce while buildings are the fixed products and the flow of personnel. Thus, waste definition in the context of construction is an area which requires further attention.

In terms of the research efforts concerning waste, a few studies have addressed waste identification and elimination methods in the context of construction projects (Broft 2017, Hossain *et al*. 2019, Cruz *et al*. 2020, Issa and Alqurashi 2020). For example, in a recent study carried out by Demirkesen and Bayhan (2020), it has been mentioned that only 12% of the production time is waste in the manufacturing industry whereas the percentage is 57% for construction projects with traditional delivery models (e.g. design-bid-build). In addition, Yin *et al*. (2014) stated that 46% of wasteful working time in construction projects is due to late arrival or early departure (3%), waiting and idling (32%), waiting for tools or material (5%), and waiting for instruction (6%).

Moreover, there have been few studies looking into the causes of waste in construction to explore what is behind those seven categories of waste (e.g. Singh *et al*. 2017, Besklubova and Zhang 2019, Bajjou and Chafi 2020). The studies addressing waste itself in terms of identification, minimization, and elimination, and also exploring cause of waste have contributed toward broadening our understanding on what is waste and how to deal with it.

Despite great contribution of previous studies, the existing literature on waste in construction still seems to be struggling with providing a clear definition of waste with an ontological perspective (Formoso *et al*. 2020). Moreover, the major focus on the identification and elimination of waste in different construction categories in previous studies has led to the lack of a holistic perspective toward this topic. Such holistic perspective can be an efficient way through which the relevance of different causes of waste to various attributes of construction projects and their impact can be explored. Hence, our understanding is still limited on the waste phenomenon, causes of waste in different life cycle phases of a construction project, and their relation to project delivery elements and project parties.

According to the explained gaps, this study aims to revisit the concept of waste from analytical and conceptual perspectives. This approach toward waste and its causes in construction can be mentioned as the main difference between this study and the previous ones. The expected contribution of this study is to be achieved through answering the following research questions:

- *RQ1*. Is it the correct way to define waste based on the concept of value? What would be meaningful definition for waste and value?
- *RQ2*. How can we objectively measure waste and value of an activity?
- *RQ3*. What are the causes of waste in construction projects?
- *RQ4*. How do the causes of waste in construction relate to different phases of project life cycle, project parties, project delivery element, and seven categories of waste?

The resultant article is structured in six sections. The introduction is followed by discussing the theoretical background on lean construction and waste. Then, research methodology is explained which is followed by presenting the results. Next, the obtained results are discussed, and the conclusion are stated.

Theoretical background

Definition

Waste has been a critical and recognized issue in the construction industry for more than three decades. The proposition of TFV (Transformation-Flow-Value) theory by Lauri Koskela in 1992 and the emergence of lean construction in 1993 were the starting points and also the origin of addressing waste issue in construction industry in a systematic manner (Koskela 1992, 2020). Koskela explained waste as "any inefficiency that results in the use of equipment, materials, labour or capital in larger quantities than those considered as necessary in the production of a building" (Koskela 1992). In addition, Womack and Jones (2003) defined waste "as any human activity which absorbs resources but creates no value.

In the context of construction, like production, waste is primarily understood in seven categories which are (i) Transport—moving products or materials around, (ii) Waiting—waiting in any form, (iii) Overproduction—producing more than what the customer needs, (iv) Defect—any process that fails to transfer inputs to desired outputs, (v) Inventory—Any inventory is considered a non-value-added commodity, even though it may be needed, (vi) Motion—any physical movement by people that does not add value to the process, (vii) Extra processing—any processing that does not add

value to the product (Al-Aomar 2012, Ahuja 2013, Banawi and Bilec 2014, Yin *et al*. 2014).

Looking into waste through the lens of value has been a common practice in the research community. For instance, several scholars have referred to the mentioned definition of waste by Womack and Jones (2003) and have developed relevant conceptualizations such as value adding and non-value adding activities or main and normal activities (Mao and Zhang 2008). However, the current definitions of waste based on value seem to be incomplete (both theoretically and practically) in the context of construction. An important reason for this is the variety of interpretations which different individuals make from the concept of value itself based on which waste is primarily defined. In other words, the term "value" in the definition of waste brings up curiosity on its meaning in different activities, and subsequently questions the common understanding toward waste. Some scholars have argued that value is what the client is willing to pay for it as a service to be delivered (e.g. Forbes *et al*. 2018). If we return to the common definition of waste, there are also two elements (activity & resource) which are closely connected with the concept of cost and time and there is no clear understanding of the components of value, activity and resource and their relationship with each other in the definition of waste. Hence, it seems that a thorough definition of waste is required to enhance simplicity of measuring waste and value in an objective manner. This study's proposal for the defining and measuring waste and value (as the response to RQ1 and 2) are presented in the results section as the first group of findings.

Previous research

Analysing literature in field of lean construction and particularly waste shows that previous studies have been mainly focused on micro level studies to address waste through exploring its typology, root causes, and the techniques and tools for minimizing/eliminating waste in construction projects. In terms of the studies focused on causes of waste, the research conducted by Issa and Alqurashi (2020) in Egypt identified 20 causes of waste in construction projects of which client's slow response and slow decision-making mechanism, problems in client's organization such as bureaucracy and lack of specialists, delay in running bill payments to the contractor or consultant, client's special needs such as additional works and change order, contractor selection before design team, unfairness in tendering or method of contractor choice, lack in project financing, and delay in reviewing or approving design documents can be mentioned as the examples. In other effort, Bajjou and Chafi (2020) conducted a study in Morocco to explore the causes of waste in construction. They stated that inefficient site management, improper planning and poor communication, rework and poor quality, human-related factors are the sources for 24 critical waste factors. Moreover, in the study carried out by Besklubova and Zhang (2019), 28 causes of waste were explored of which improper sequencing of activities, poor workflow planning, waiting for information or resources, ineffective work because of worker moral problems, ineffective work because of physical problems, ineffective work because of worker unavailability, ineffective work because of unqualified workers, lack of worker involvement in process, lack of collaboration with supplier, lack of collaboration among project parties, change orders, and design errors can be mentioned as the examples.

Another focus area in the studies addressing waste is the identification of ways to eliminate it. The study conducted by Cruz *et al*. (2020) in Peru found out that Kanban, 5S and JIT techniques help to eliminate waste (time, movement and inventory). In other study performed by Ko and Kuo (2015) in Taiwan, it became clear that improving quality depends on adopting a culture of continuous learning and improvement and the andon culture and kanban system can then be used to eliminate waste. In addition, some of the studies have looked into the waste issue by conceptualizing different types of activity. For instance, the study conducted by Mao and Zhang (2008) in Canada, proposed classifying activities into main and supportive activities and/or into normal and interactive activities instead of classifying them into value-adding and non-value-adding activities, or into conversion and flow activities as is common in lean production practices. They defined "main activity" as the one that directly consumes construction materials and contributes "physically" to the final project. On the other hand, a "supportive activity" is one that supports and facilitates the execution of main activities but may not contribute "physically" to the final project. Main activities have to be kept in the construction process whereas supportive activities may not be necessary. They also defined a normal activity as the one that serves only one workflow. It is the basic element of a workflow that may link upstream activities to downstream activities. An interactive activity is one that serves more than one workflow. Interactive activities

join different workflows together so that these workflows can interact with each other. They stated that this classification makes it more effective in modeling the construction workflow and reengineering the construction process. It also avoids the confusion of the classification of activities into value-adding and non-value adding activities encountered in the construction industry.

Notwithstanding previous research on the waste, there is still a need for macro-level studies addressing waste in a manner that results in a comprehensive analysis of causes of waste in construction and their relation to project attributes (e.g. project delivery elements). Thus, this study aims to fill the mentioned knowledge gap through answering the third and fourth research questions which were outlined earlier in the introduction section.

Methodology

Research design

The systematic literature study behind this article aimed to explore causes of waste and to reveal their connection to project attributes (e.g. project party, project delivery element) in construction projects. In this regard, locating the relevant studies from Scopus database was followed by excluding irrelevant ones and repetitions through abstract review. Then, the full texts of the relevant studies were reviewed, and the obtained research data were analysed through thematic and content analysis methods (Saunders *et al*. 2019). The whole process of data collection and analysis in this research is illustrated in Figure 1 and explained in detail in the following.

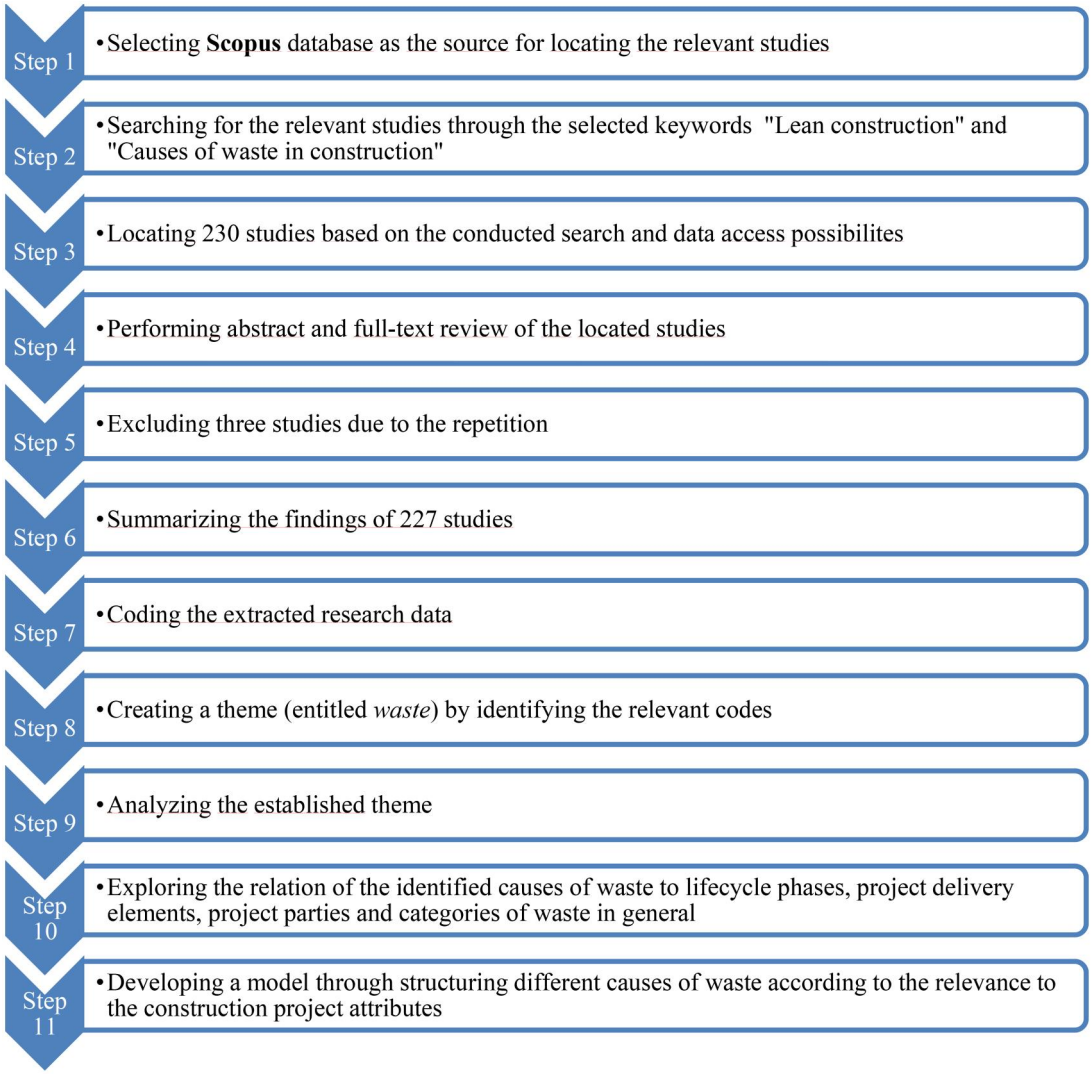


Figure 1. Research process.

Keyword selection

In this study, Scopus database was selected as the main source for locating the relevant studies, as it contains most of the relevant and well-known journals in the field of construction and project management. "Lean construction" and "Causes of waste in construction" were selected as the keyword due to the focus of this study on the previous research addressing causes of waste in the context of construction, and because the concept of waste in construction has been mainly a part of lean construction research. This means that using the mentioned keywords deemed sufficient for locating those studies focused on waste in construction.

Descriptive statistics

The conducted search was primarily resulted in locating 230 studies of which 127 ones were journal articles and 103 ones were conference proceedings. The publication period of 206 (more than 90%) out of the 227 analysed studies was between 2011 and 2022. This can be of importance as the relevance of recent publications is usually higher. No specific time span was applied in locating the relevant studies to ensure the comprehensiveness of the search. Three out of 230 studies were excluded in results of abstract review due to the repetition. Analysing full text of those 227 studies through thematic analysis and resulted in discovering five studies which have specifically addressed causes of waste in construction projects.

Conceptualization: thematic analysis and model development

After locating the relevant studies, they were analysed through thematic analysis (Saunders *et al*. 2019). This was undertaken by inductively coding the extracted research data as a result of reviewing the relevant studies. The labels of the codes were data derived by the researcher. According to the purpose of this study, the codes representing "waste" were structured under a theme entitled "Waste in Construction." Then, the codes under the developed theme were further analysed for three main purposes: first, to identify and compile a list of causes of waste in construction and to prioritize them based on their frequency of appearance in the literature, second, to discover their relevance to different lifecycle phases of the project, project delivery elements, project parties, and categories of waste in general, and third, to develop a model for causes of waste in construction projects, mapping their relevance to different attributes of construction projects.

Matching the causes of waste to project attributes (project delivery elements, project parties, life cycle phases) and seven categories of waste was accomplished in three steps. First, the definitions of project delivery elements by Mesa *et al*. (2019) were utilized as the reference to the identify the relevant causes of waste to each project delivery element. According to Mesa *et al*. (2019), organizational structure refers to the roles and relationships between the participants, operational system refers to the timing and sequence of events and practices and techniques of management, and the contractual relationships involve defining, designing and constructing a project. In the second step, exploring the relevance of identified causes of waste to project parties and life cycle phase were undertaken based on their meaning and conceptual relevance. Finally, in the third step, mentioned definitions of the seven categories of waste in the theoretical background section was utilized as the source for exploring their relevance to the identified causes of waste in this study.

Results

Proposal for defining and measuring waste and value in construction

In this section, the RQ1 and RQ2 which were mentioned in the introduction section are answered. Let's start by answering RQ1. To do so, it is necessary to see how the concept of value has been defined in the literature. The term "value" in the context of construction has been defined as what the customer is actually paying for the project to produce and install. Now, if we return to the common definition of waste (as an activity which absorbs resources but does not produce value), there are two elements, activity and resource, which are closely connected with the concept of cost and time. So far, it is pretty much obvious that in addition to the value, "cost" and "time" seem also to be a part of the waste concept. Thus, it can be argued that basing the definition of waste simply on the value concept seems to be incorrect or insufficient.

How can then we define value and how is it related to the concepts of "Cost" and "Time"? Time and Cost in the context of waste seem to imply expense and benefit of an activity in short/mid/long term. The role of value in the relationship of Cost and Time with Waste, is a measurement of the worth which can be characterized by its two attributes which seem to

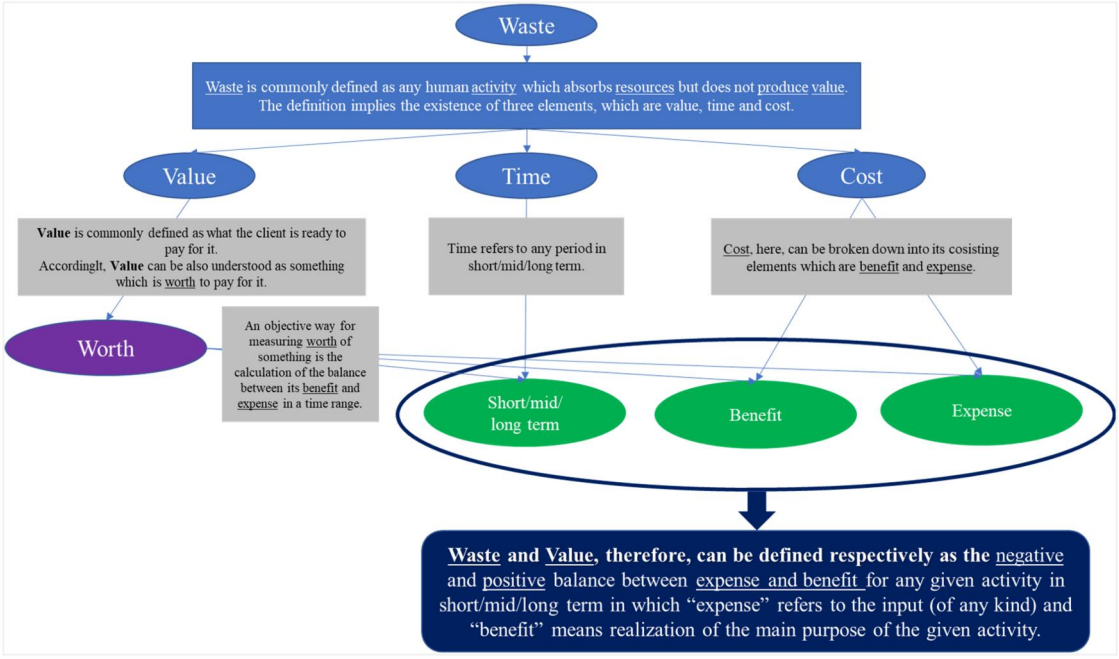


Figure 2. Novel conceptualization of waste in construction.

be the expense and benefit in a given time range. Thus, value can be understood as the worth of an activity which can be objectively measured through calculation of the benefits and expenses in a given time range.

Therefore, *Waste* can be better understood as the negative balance between expense and benefit for any given activity in short/mid/long term in which "expense" refers to the input (of any kind) and "benefit" means realization of the main purpose of the given activity. Accordingly, *Value* can be explained as the positive balance between expense and benefit for any given activity/decision in short/mid/long term in which "expense" refers to the input (of any kind) and "benefit" means realization of the main purpose of the given activity. Figure 2 provides the novel conceptualization of waste and value.

Objective measurement of waste and value

In order to provide an objective way for conceptualizing "waste" the following framework is proposed in which waste and value judgment of an activity can be guided through the calculation of benefit and expense and their balance in short-term and/or mid-term and/or long term (see Table 1). If the quantified value of activity's benefit is more than activity expense, then that activity can be considered as value adding one, but if the calculated expense is more than the benefit, then the activity would be considered as a waste. The proposed framework can be also utilized for evaluating waste or value nature of decisions in construction projects.

Table 1. Framework for objective measurement of waste and value of activity.

	Activity			
	Benefit	Expense	Balance	Waste/Value
Short-term				
Mid-term				
Long-term				

Next step was the development of formulas for calculating (quantifying) the benefit and expense an activity and their balance in a given time range. Accordingly, the following formulas were developed based on the novel conceptualization of the waste and are proposed for (quantifying) the benefit and expense of an activity and their balance in short/mid/-long term:

- *Activity benefit (quantified)* = (activity budget) * activity duration (for short-term), or project duration (for mid-term), or operational life of the project after completion (for long-term).
- *Activity Expense (quantified)* = (activity's actual cost) * activity's actual duration (for short-term) or project's actual duration (for mid-term) or operational life of the project after completion (for long-term).

Discovered causes of waste in construction projects

Analysing previous studies resulted in the identification of 64 causes of waste in construction projects. These causes of waste were then synthesized, and a list of 31 causes of waste was compiled. The top ten ones from that list are presented here in Table 2 (see Appendix 1 for more details including references). As can be seen, poor site management, improper planning, scheduling, improper communication and coordination, client's special needs such as additional works and change order, and delay in preparation, reviewing or approving design documents are the top five causes of waste in construction.

Relation of causes of waste in construction to project attributes

After synthesizing the identified causes of waste, the final list was analysed to explore the relevance of each cause of waste to different project attributes which included life cycle phase, project delivery element, project party, and seven categories of waste in general. This analysis was resulted in the identification of two new categories of waste, entitled "inadequate processing" and "excessive processing" which are defined as any shortage or extravagance in processing which causes one or more types of waste. For instance, failure in preparing risk management or project management plans can lead to reword or waiting in the construction phase. Table 3 shows the results.

A novel model for causes of waste in construction projects

The mentioned results in Table 3 provided a basis for modelling the identified causes of waste based on their conceptual relevance to the mentioned attributes of construction projects (see Figure 3). The developed model illustrates various causes of waste in three phases of project life cycle (definition, design and planning, and construction) and also reveals the relevant project party and project delivery elements representing each cause of waste in different life cycle phases. The order of listing causes of waste in each life cycle phase is based on their significance, determined according to their frequency of appearance in the literature (see Appendix 1).

As shown in Figure 4, the percentage of related causes of waste to project organization, contractual relationships and operational system are respectively 16%, 13%, and 71%. In terms of the categories of waste it looks obvious that majority (58%) of the identified causes of waste in this study represent "defect" category of waste in general (see Figures 3 and 4). In terms of the project parties, it is interesting, but not surprising, to see that contractor and design team (34%), contract alone (30%), and contractor and client (13%) altogether account for 77% of the identified cause of waste (see Figures 3 and 4).

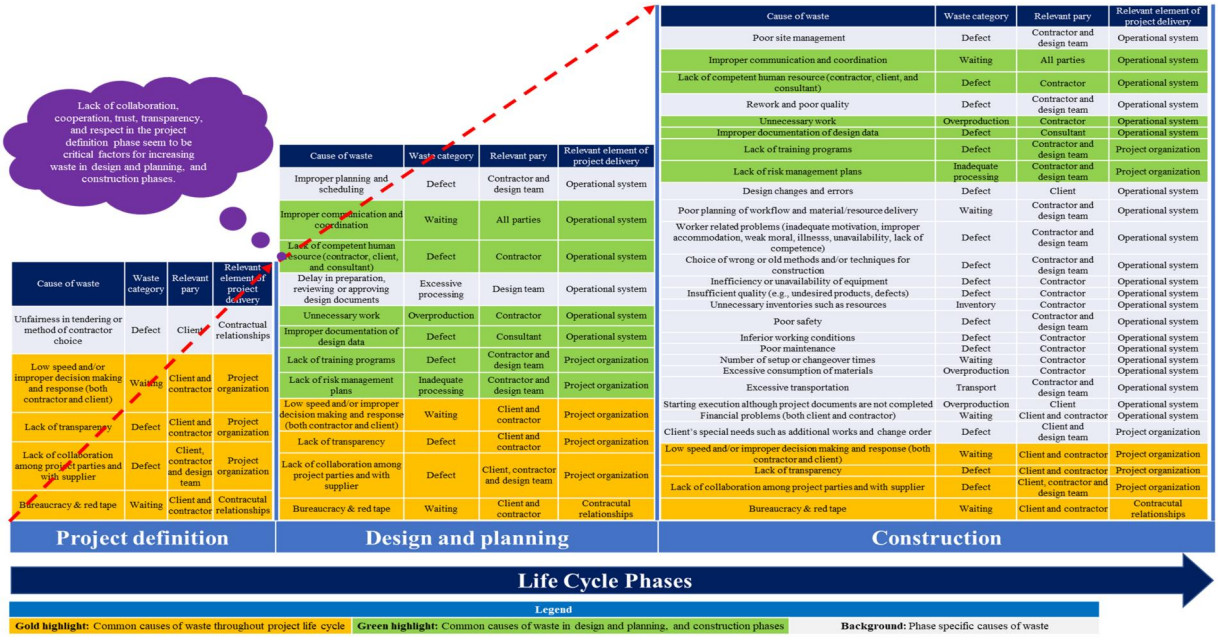
An interpretation of the shown information in Figures 3 and 4 is that the fragmentation of construction projects and lack of integration play a critical role in this regard. In other words, constructive collaboration and cooperation between client, contractor and design team can led to elimination of 71% of causes of waste in construction projects. Another interesting but again not surprising finding regarding project life-cycle phase and causes of waste is that execution phase of the construction projects includes majority of the identified causes of waste while, in a backward perspective, the number declines as we move back to design and planning and project definition and finally project definition phase. Hence, it can be argued that collaboration, cooperation, trust, transparency, and respect in the project definition phase could lead to less waste in design and planning, and construction phases. Of course, this is just a hypothesis which needs to be tested in future studies. The last, but not the least, point to notice is that four of the identified

Table 2. Top 10 causes of waste in construction projects.

Causes of waste	Frequency of appearance in the literature
Poor site management	4
Improper planning, scheduling	4
Improper communication and coordination	4
Client's special needs such as additional works and change order	3
Delay in preparation, reviewing or approving design documents	3
Rework and poor quality	3
Design changes and errors	3
Waiting (poor planning of workflow and material/resource delivery)	3
Low speed and/or improper decision making and response (both contractor and client)	3
Worker related problems (inadequate motivation, improper accommodation, weak moral, illness, unavailability, lack of competence)	3

Table 3. Relation of causes of waste to different project attributes which include life cycle phase, project delivery element, project party, and seven categories of waste in general.

Causes of waste	Relevant delivery element	Relevant party	Lifecycle phase	Relevant category of waste in general
Poor site management	Operational system	Contractor and consultant	Construction	Defect
Improper planning, scheduling	Operational system	Contractor and consultant	Design and planning	Defect
Improper communication and coordination	Operational system	All parties	Design & planning, and construction	Waiting
Client's special needs such as additional works and change order	Project organization	Client and consultant	Construction	Defect
Delay in preparation, reviewing or approving design documents	Operational system	Consultant	Design and planning	Excessive processing
Rework and poor quality	Operational system	Contractor and consultant	Construction	Defect
Design changes and errors	Operational system	Client	Construction	Defect
Waiting (poor planning of workflow and material/resource delivery)	Operational system	Contractor and consultant	Construction	Waiting
Low speed and/or improper decision making and response (both contractor and client)	Project organization	Client and contractor	Whole lifecycle	Waiting
Worker related problems (inadequate motivation, improper accommodation, weak moral, illness, unavailability, lack of competence)	Operational system	Contractor and consultant	Construction	Defect
Lack of competent human resource (contractor, client, and consultant)	Operational system	Contractor	Design & planning, and construction	Defect
Starting execution although project documents are not completed	Contracutal relationships	Client	Construction	Overproduction
Unnecessary work	Operational system	Contractor	Design & planning, and construction	Overproduction
Choice of wrong or old methods and/or techniques for construction	Operational system	Contractor and consultant	Construction	Defect
Inefficiency or unavailability of equipment	Operational system	Contractor	Construction	Defect
Insufficient quality (e.g. undesired products, defects)	Operational system	Contractor	Construction	Defect
Financial problems (both client and contractor)	Contracutal relationships	Client and contractor	Construction	Waiting
Bureaucracy & red tape	Contracutal relationships	Client and contractor	Whole lifecycle	Waiting
Unnecessary inventories such as resources	Operational system	Contractor	Construction	Inventory
Unfairness in tendering or method of contractor choice	Contracutal relationships	Client	Project definition	Defect
Lack of transparency	Project organization	Client and contractor	Whole lifecycle	Defect
Improper documentation of design data	Operational system	Consultant	Design and planning	Defect
Lack of training programs	Project organization	Contractor and consultant	Design & planning, and construction	Defect
Lack of risk management plans	Operational system	Contractor and consultant	Design & planning, and construction	Inadequate processing
Poor safety	Operational system	Contractor and consultant	Construction	Defect
Inferior working conditions	Operational system	Contractor	Construction	Defect
Poor maintenance	Operational system	Contractor	Construction	Defect
Number of setup or changeover times	Operational system	Contractor	Construction	Waiting
Excessive consumption of materials	Operational system	Contractor	Construction	Overproduction
Lack of collaboration among project parties and with supplier	Project organization	Client, contractor and consultant	Whole lifecycle	Defect
Excessive transportation	Operational system	Contractor and consultant	Construction	Transport



Cause of waste	Waste category	Relevant pary	Relevant element of project delivery
Unfairness in tendering or method of contractor choice	Defect	Client	Contractual relationships
Low speed and/or improper decision making and response (both contractor and client)	Waiting	Client and contractor	Project organization
Lack of transparency	Defect	Client and contractor	Project organization
Lack of collaboration among project parties and with supplier	Defect	Client, contractor and design team	Project organization
Bureaucracy & red tape	Waiting	Client and contractor	Contractual relationships

Cause of waste	Waste category	Relevant pary	Relevant element of project delivery
Improper planning and scheduling	Defect	Contractor and design team	Operational system
Improper communication and coordination	Waiting	All parties	Operational system
Lack of competent human resource (contractor, client, and consultant)	Defect	Contractor	Operational system
Delay in preparation, reviewing or approving design documents	Excessive processing	Design team	Operational system
Unnecessary work	Overproduction	Contractor	Operational system
Improper documentation of design data	Defect	Consultant	Operational system
Lack of training programs	Defect	Contractor and design team	Project organization
Lack of risk management plans	Inadequate processing	Contractor and design team	Project organization
Low speed and/or improper decision making and response (both contractor and client)	Waiting	Client and contractor	Project organization
Lack of transparency	Defect	Client and contractor	Project organization
Lack of collaboration among project parties and with supplier	Defect	Client, contractor and design team	Project organization
Bureaucracy & red tape	Waiting	Client and contractor	Contracutal relationships

Cause of waste	Waste category	Relevant pary	Relevant element of project delivery
Poor site management	Defect	Contractor and design team	Operational system
Improper communication and coordination	Waiting	All parties	Operational system
Lack of competent human resource (contractor, client, and consultant)	Defect	Contractor	Operational system
Rework and poor quality	Defect	Contractor and design team	Operational system
Unnecessary work	Overproduction	Contractor	Operational system
Improper documentation of design data	Defect	Consultant	Operational system
Lack of training programs	Defect	Contractor and design team	Project organization
Lack of risk management plans	Inadequate processing	Contractor and design team	Project organization
Design changes and errors	Defect	Client	Operational system
Poor planning of workflow and material/resource delivery	Waiting	Contractor and design team	Operational system
Worker related problems (inadequate motivation, improper accommodation, weak moral, illness, unavailability, lack of competence)	Defect	Contractor and design team	Operational system
Choice of wrong or old methods and/or techniques for construction	Defect	Contractor and design team	Operational system
Inefficiency or unavailability of equipment	Defect	Contractor	Operational system
Insufficient quality (e.g., undesired products, defects)	Defect	Contractor	Operational system
Unnecessary inventories such as resources	Inventory	Contractor	Operational system
Poor safety	Defect	Contractor and design team	Operational system
Inferior working conditions	Defect	Contractor	Operational system
Poor maintenance	Defect	Contractor	Operational system
Number of setup or changeover times	Waiting	Contractor	Operational system
Excessive consumption of materials	Overproduction	Contractor	Operational system
Excessive transportation	Transport	Contractor and design team	Operational system
Starting execution although project documents are not completed	Overproduction	Client	Operational system
Financial problems (both client and contractor)	Waiting	Client and contractor	Operational system
Client's special needs such as additional works and change order	Defect	Client and design team	Project organization
Low speed and/or improper decision making and response (both contractor and client)	Waiting	Client and contractor	Project organization
Lack of transparency	Defect	Client and contractor	Project organization
Lack of collaboration among project parties and with supplier	Defect	Client, contractor and design team	Project organization
Bureaucracy & red tape	Waiting	Client and contractor	Contracutal relationships

Figure 3. Modelling causes of waste based on waste category, life cycle phases, project delivery elements, and relevant party.

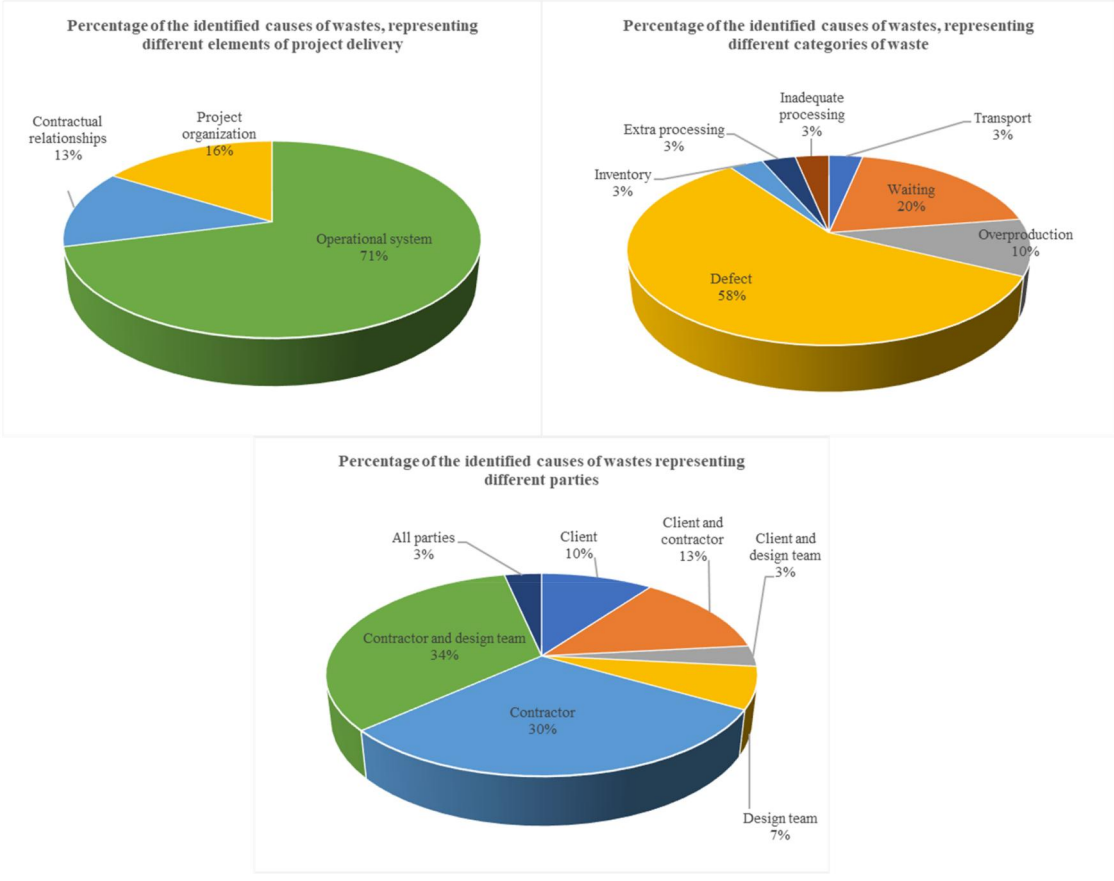


Figure 4. Descriptive statistics concerning the waste model shown in Figure 3.

causes of waste are related to/happens in all phases of project lifecycle. These are low speed and/or improper decision making and response (both contractor and client), lack of transparency, lack of collaboration among project parties and with suppliers, and bureaucracy & red tape. These four causes of waste seem to be result of adopting traditional project delivery systems (e.g. design-bid-build), as they clearly represent characteristics and elements of those delivery systems (Moradi *et al*. 2022). This, in turn, highlights the significance of collaborative construction.

Discussion

Wrap-up and interpretation of findings (while positioning the previous research)

This study, with a novel perspective, revealed the relevance of the identified causes of waste to project delivery elements, project party, life cycle phase and categories of waste in general. The high number of the appearance of causes of waste in construction phase and low number in project definition phase, not only shows the alignment of the finding with the previous studies (Yin *et al*. 2014) but also contains an important message. The main message of the developed model in Figure 3 is that the lack of collaboration, cooperation, trust, transparency, and respect in the project definition phase seem to be critical factors for increasing cause of waste and subsequently the waste itself in design and planning, and construction phase. This negative consequence subsequently threatens the realization of sustainability throughout construction projects.

Moreover, it seems that interface between client, contractor, and design team, particularly in the design and planning, and construction phase contribute to increasing or decreasing causes of waste in a considerable manner. In other words, constructive collaboration and cooperation between client, contractor, and design team seems to be hidden but very effective tool for decreasing cause of waste, thereby minimizing and eliminating the waste itself. This effect can be easily seen in the context of construction projects with collaborative delivery models (alliance, lean project delivery, partnering) in which high productivity and lower waste are achieved through trust-based working relationships, fair share of risk-reward, early involvement of contractor, joint design, planning and control of project, anonymous decision making, and aligned interests of project stakeholders (e.g. Ibrahim *et al*., 2016, Moradi *et al*. 2022).

Contribution of the findings to the literature

This study's results provide a novel and significant contribution to the body of knowledge on construction waste and its causes. The first contribution of this study to the theory was critically revisiting the concept of waste and objectively defining waste and value as respectively negative and positive balance between benefit and expense of any activity in a given period of time. This perspective toward waste is missing in the previous studies. Moreover, a framework was proposed for objectively measuring waste and value of construction activities in a quantitative manner. These findings enrich our current understanding from the waste and value concepts and reveals the significance of cost and time components in the form of benefit and expense. Moreover, the proposed definition and measurement framework covers shortages of current interpretations from waste and value based on qualitative approaches which categorize activities into clusters of value-adding and non-value adding or main and normal (e.g. Mao and Zhang 2008). Another contribution of this study's findings is that employing project delivery elements as theoretical lens seems to be an efficient method for studying waste and sustainability in construction projects (Moradi and Kähkönen, 2022a,b). Finally, the findings suggest that collaborative project delivery models and working practices seem to positively correlate with the minimization and elimination of waste in design and construction phases. This hypothesis needs to be tested in the future studies.

Implications of the findings in practice

The findings have certain practical implications which are explained here. The proposed definition for waste and value and the measurement framework contribute toward more effective management of waste in general because it is obvious that the better we understand a phenomenon, the better we can manage it. In the context of construction, the proposed definition of waste, which is objective and easy to understand, informs project practitioners on what waste is and how it occurs. This insight is then complemented by the measurement framework which provides a very practical and easy to use method to explore the waste and value nature of an activity in the design and execution phase of construction projects. Consequently, the project practitioners can gain more in-depth understanding of what is waste and value, and how to know whether an activity is waste or adds value.

Moreover, the developed model in Figure 3 can be beneficial for construction project practitioners in three different ways. First, it reveals the critical effect of early collaboration between different project parties on the minimization and elimination of waste. This insight can assist project managers to adopt those delivery systems which allow early and close collaboration between project parties. The second benefit of the developed model is that phase-specific identified causes of waste with their revealed relationship to project delivery elements can be a useful source of information for facilitating sustainable value definition and management throughout the project, particularly in the project definition phase. The third benefit of the developed model is for planning activities at all levels (i.e. master, phase, and weekly) and site supervision. This benefit is realized by revealing occurrence of the different causes of waste in different life cycle phases and also by showing which project party is mostly capable of handling (avoiding) those causes of waste.

Conclusions

This study aimed to revisit the concept of waste in construction from analytical and conceptual perspectives. This was realized through developing and proposing a novel conceptualization toward waste and value and identifying as well as modelling causes of waste in construction based on their relevance to project delivery elements, life cycle phases, project parties, and waste categories in general. The obtained results provided the basis for the following conclusions concerning waste and value and causes of waste in construction projects:

- Waste and value are respectively the negative and positive balance between expense and benefit of an activity in a given period of time.
- Lack of collaboration, cooperation, trust, transparency, and respect in the project definition phase seem to be critical factors for increasing waste in design and planning, and construction phases and threating the realization of sustainability.
- Adopting collaborative project delivery models (e.g. alliance, lean project delivery, integrated project delivery) seems to be an efficient solution for avoiding waste, particularly in the design and construction phases.
- Employing traditional delivery models, seem to result in the emergence of repetitive causes of waste (e.g. lack of transparency, lack of collaboration among project parties and with supplier, and bureaucracy & red tape) which are common in all life cycle phases.

This study's findings contribute toward the body of knowledge in lean construction and waste. As the limitation of the study, it is acknowledged that certain keywords were utilized in Scopus database for locating the relevant studies which might have affected the reliability and generalizability of the findings. Further research in case projects is required for validation of the findings. Moreover, the obtained findings provided also a basis for the following recommendations which can be the departure point for the future studies:

- Developing a computerized model based on the proposed definition and framework for waste measurement.
- Testing the hypothesis that collaborative project delivery models and working practices positively correlate with the minimization and elimination of waste in design and construction phases.
- Quantitatively comparing the number and types of causes of waste in construction projects with traditional (e.g. design-bid-build, design-build) and collaborative (e.g. alliance, lean project delivery) delivery models.
- Applying the proposed framework for waste measurement in multiple case projects for enhancing accuracy and efficiency of value definition and management in construction projects.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix 1. Complete list of identified causes of waste and their references

Causes of waste	Issa et al. 2020	Bajjou and Chafi 2020	Singh et al. 2017	Gómez-Cabrera et al. 2020	Besklubova and Zhang 2019	Frequency of appearance
Poor site management	*	*	*	*		4
Improper planning, scheduling		*	*	*	*	4
Improper communication and coordination		*	*	*	*	4
Client's special needs such as additional works and change order	*		*		*	3
Delay in preparation, reviewing or approving design documents	*		*	*		3
Rework and poor quality		*	*		*	3
Design changes and errors	*			*	*	3
Waiting (poor planning of workflow and material/ resource delivery)	*		*		*	3
Low speed and/or improper decision making and response (both contractor and client)	*			*	*	3
Worker related problems (inadequate motivation, improper accommodation, weak moral, illnesss, unavailability, lack of competence)	*		*		*	3
Lack of competent human resource (contractor, client, and consultant)	*		*		*	3
Starting execution although project documents are not completed	*			*		2
Unnecessary work			*		*	2
Choice of wrong or old methods and/or techniques for construction			*		*	2
Inefficiency or unavailability of equipment			*		*	2
Insufficient quality (e.g., undesired products, defects)			*		*	2
Financial problems (both client and contractor)	*			*		2
Bureaucracy & red tape	*		*			2
Unnecessary inventories such as resources			*		*	2
Unfairness in tendering or method of contractor choice	*					1
Lack of transparency			*			1
Improper documentation of design data			*			1
Lack of training programs			*			1
Lack of risk management plans			*			1
Poor safety			*			1
Inferior working conditions			*			1
Poor maintenance					*	1
Number of setup or changeover times					*	1
Excessive consumption of materials					*	1
Lack of collaboration among project parties and with supplier					*	1
Excessive transportation					*	1