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Investigation of Construction and Demolition Waste Causes Toward Comprehensive Taxonomy

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Abstract

Construction and Demolition Waste (C&DW) is a worldwide concern considering its substantial impacts on environmental, economic and social sustainability. Yet, C&DW accounts for 40% of the globally generated waste and is expected to increase due to global urbanization and population growth and the upsurge of elderly buildings. This imposes a huge pressure on concerned bodies to eliminate or lessen the waste causative factors (WCFs). However, construction and demolition processes are recognized to be complex, multiparametric and dynamic making WCFs identification and management difficult in the absence of structured knowledge. This study aims to fill this gap using a systematic review to build a WCFs inclusive taxonomy. This study revealed that 93% of the existing knowledge is incomprehensive and aspect-oriented and disclosed 125 distinct WCFs that could be structured into 9 families: stakeholders attributes, legal and financial aspects, communication and coordination, design and pre-contract development, procurement and material supply chain, delivery and onsite logistics, onsite planning and management, waste-management-related measures and policies, and contingencies and external risks. This study would provide scholars, policymakers, and practitioners with the fundamental knowledge to develop effective solutions, strategies, and practices to lessen or eliminate C&DW generation and/or related impacts.

Keywords: Construction industry; Waste management; Taxonomy; Standardization; 3Rs principle; Sustainability

[*] Masterminded the paper, collected data and developed the paper.
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1 Introduction

Nowadays, Construction and Demolition Waste (C&DW) is acknowledged to be a substantial concern as it is evaluated at 40% of the global Waste Generation (WG) (Naji et al., 2022) and expected to increase significantly due to the uptrend of the worldwide urbanization and population as well as the upsurge of aged buildings needing either to be retrofitted, renovated or demolished (Park et al., 2014). Indeed, the world population growth is expected to reach 9.7 billion by 2050 (Autodesk and SRD, 2018) with 68% in urban zones (Bajjou and Chafi, 2022) leading thereby to the construction and building industry boom as an additional 315.5 billion m^2 built floor area would be needed by 2030 and an another 415.1 billion m^2 by 2050 (SRD, 2016). As a result, it is expected that the annual global C&DW will escalate from 12.7 to 27 billion tons by 2050 (Wang et al., 2022).

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However, beyond that C&DW Management (C&DWM) adoption is highly connected to decision makers' buy-in, in-force regulation and incentives (Wang et al., 2019; Zhao, 2021), executing an efficient C&DWM is a complex and dynamic process (Al-Rifai and Amoudi, 2016) due to 3 key factors. First, it involves multiparametric activities such as design, planning, work execution, materials procurement and supply chain, workforce and machinery management, and coordination. Each of these activities could either cause or reduce WG depending on the performance of decision-making and used tools and methods. Second, construction projects cover a wide range of project types (e.g., residential, industrial, and roads), which result in wider range of wasted Materials and Components (MCs) types and diverse construction and demolition methods. Then, C&DW causes are highly affected by the construction industry fragmentation where various stakeholders and scopes are included and also vary throughout building life cycle (BLC) stages.

Thus, C&DWM involves intricate and voluminous knowledge, namely Waste Causative Factors (WCFs) that are still vague and unstructured. This study aims to fill this gap by identifying existing WCFs and mapping them into a comprehensive taxonomy that would enable scholars, decision makers and practitioners to have a wider understanding of C&DW-generating causes as well as their roots and thereby facilitate development of more effective approaches, strategies and technological solutions to considerably lessen C&DW amounts and/or their impacts.

2 Research Background

Construction Waste (CW) materials are generated when new buildings are constructed (Khaleel and Al-Zubaidy, 2018) or existing buildings are renovated and whose amount is limited compared to demolition waste (Chen and Lu, 2017). Demolition waste stands for wastes resulting from dissembling or destructing the whole or a part of existing buildings or infrastructures either due to a controlled decision, deterioration or force majeure. The WG is gaining extensive attention considering the resulting harmful impacts on the three pillars of sustainable development (environmental, economic, and social sustainability) (Li et al., 2022). C&DW has historically posed significant environmental threats, namely natural resource depletion (Chen and Lu, 2017), energy consumption and carbon emissions (Chellappa et al., 2023) due to transportation, landfilling, and processing.

Along with the groundwater, air and soil contamination (Chinda, 2016; Zhao, 2021) resulting in a high danger for the flora and fauna, C&DW disposal occupies valuable land that could be used either for more profitable purposes or returned to nature (Cha et al., 2009), harms human health (Begum et al., 2009); depreciates the image of the surrounding zones (Yuan et al., 2018); and thereby causes significant social and economic losses resulting from wasted materials and lands, C&DWM processes costs and impacts, and avoidance of the community settlement due to deterred anesthetic, noise, smog and olfactory nuisance caused by dumping areas.

Reduce, Reuse, Recycle then Disposal (3RDs') principle is considered as important guidance for C&DWM (Yuan et al., 2018). Waste reduction strategies consist of upstream prevention of waste generation especially during design and construction processes where elimination or reduction of WG is significant and more economical (Fitriani et al., 2023). Meanwhile, waste recovery (Recycling or Reuse) refers to downstream strategies aiding in reinserting wasted MCs into the supply chain of industries' markets rather than sending them to disposal at landfills. Reuse of C&DW means using MCs for the same or different purpose, which makes this option the most direct waste recovery strategy to save resources, protect the environment and have the best economy (Nawaz et al., 2023). Recycling refers to reprocessing recovered MCs at the end of a product's life cycle to new MCs, which decrease the need for new resources, reduce energy costs, and value waste that could end up in landfills (Zhao, 2021). However, selecting the right strategies category assumes a good knowledge of WCFs.

3 Research Methodology

To build an efficient taxonomy, this research adopts a 3-stage design using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach: Preparation of included papers, systematic review and taxonomy development.

3.1 Preparation of included papers

In accordance with the PRISMA approach, preparation of included papers' database comprises 3 steps: ***Papers identification:*** Scopus, Web of Science (WoS) and Google Scholar (GS) were considered to collect papers related to the discussed topic in this study. 2 sets of keywords were used: S1 {Construction waste, Demolition waste, Construction and demolition waste} and S2 {Cause, Factor} whereby 5 searches were conducted for each database based on combining 2 keywords, one from each set: [TITLE{set1}]AND [TITLE{set2}]. Unlike Scopus and WoS, GS is an unstructured database hence the "Publish and Perish" software (Harzing, 2021) was used. As a result, 504 papers were collected.

Papers eligibility: To sift the relevant publications, the following eligibility criteria were applied: (0) No time limits were defined, (1) Refine English language papers, (2) Remove the unfitted Categories and Research areas; (3) Refine peer-reviewed articles and conference papers; and (4) Remove citations and parents for GS database. Consequently, 267 papers were shortlisted. ***Screening and Including:*** consist of (1) Eliminating redundant papers, (2) Refining fully available papers as those with only available abstracts were removed, and (3) Screening abstracts of the remaining to keep only topic-fitted papers. Thus, 73 relevant papers were included in this study.

In the meantime, the same process has been undertaken to identify previously developed taxonomies in the C&DW research using the following 2 keyword sets: S1 and S3 {Taxonomy, Taxonomies}. As a result, only one paper was found but was related to nonphysical waste, i.e., non-adding activities values, within the transportation process. Which confirms the novelty of this paper.

3.2 Systematic review and Taxonomy Development

Systematic review is one of the most performant qualitative methods to efficiently build and connect data collected from literature toward thoughtful and well-founded knowledge. In this paper, the systematic review was used to investigate both the consistency and comprehensibility of existing topic-related results and contributing causative factors to WG to be able to organize the findings into a structured knowledge under the form of a comprehensive taxonomy.

Shen et al. (Shen et al., 2018) pointed out that most existing approaches to taxonomy construction focus on *"building hypernym-hyponym taxonomies wherein each parent-child pair expresses the 'is-a' relation. Typically, they consist of two key steps: (1) hypernymy relation acquisition (i.e., obtaining hypernym-hyponym pairs), and (2) structured taxonomy induction"*. In this vein, using bottom-up approach based on thematical analysis, the roots of the identified WCFs would be investigated to organize hypernymy relations into a comprehensive tree structure.

4 Findings

4.1 Investigation of Existing WCF-related Knowledge

The systematic review revealed that 64% of studies addressing WCFs are aspect-oriented studies where they address either a specific topic (waste stage/type and waste treatment strategy) or region. As shown in Figure 1-a, 41% of the studies focused on CW considering the complexity and multi-parametricity of construction processes whereas only 1% discussed factors causing the imminence or persistence of demolition waste. As shown in Figure 1-b, the research addressed either WG causes (Reduce, 13%) resulting in damaged or left-over MCs; waste persistence (WP) causes that would hinder recovering (Recycle, Reuse and Recover, 11%) wasted MCs, and instead direct them to the disposal at landfills (Sorting and Disposal, 8%) with or without an appropriate treatment; or general WCFs (not specified and R3sD, 67%) such as these caused by either human, machinery or others.

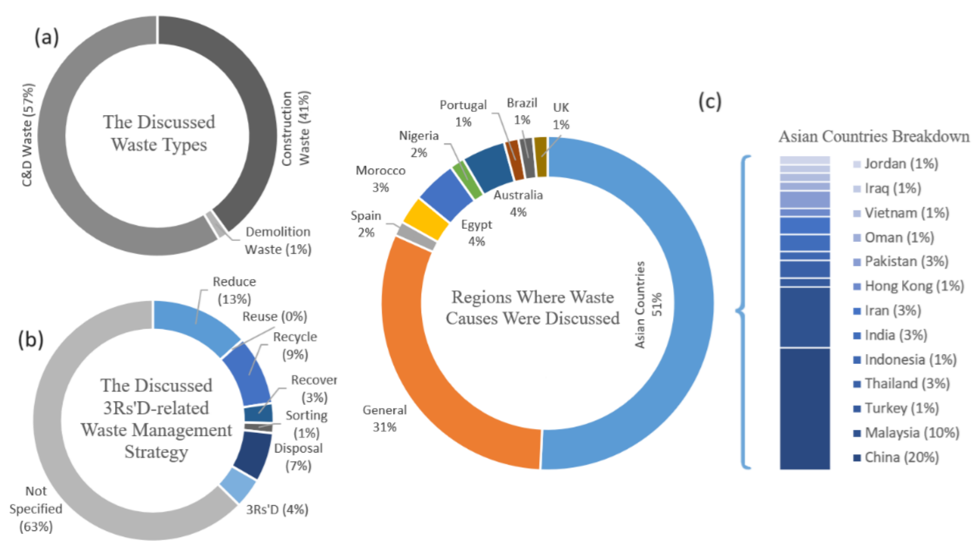

Figure 1: Breakdown of WDF-related studies according to discussed aspects and regions.

On the other hand, 69% of included papers are region-oriented studies (see Figure 1-c) where WCFs are discussed in a particular region with a quasi-dominance of Asian countries (49%), headed by China (20%) and Malaysia (10%), tailed by African then European countries with 9% and 4% of regions where WCFs were investigated, respectively. Overall, the triangulation of three forms of findings illustrated in Figure 1 disclosed that 93% of the topic-related studies are either aspect-oriented, region-oriented or both hence the existing knowledge is fragmented and needs to be organized.

4.2 Investigation of Waste Causative Factors

Identifying and understanding WCFs throughout the BLC stages is the foundation for decreasing BLC WG and/or WP. In the last decade, many efforts have been made for this purpose. Al-Rifai and Amoudi (2016) identified 39 WCFs and stressed that lack of skilled workers and subcontractors, rework due to workers' errors, and lack of quality management systems are the most impactful ones. Ikau et al. (2016) revealed that key WCFs roots are: design, procurement, handling, and onsite construction and disclosed 10 main WCFs of each root.

Similarly, Umar et al. (2016) revealed 40 WCFs but affected them to 5 slightly different roots: site operation, onsite management and planning, material storage and handling design and documentation, and transportation. Bajjou and Chafi (2022) listed 28 WCFs structured into 6 clusters related to design and documentation, people, contractors, management/ finance/ administration, execution/ performance, and external factors. Fitriani et al. (2023) listed 47 WCFs that were divided according to 8 themes: site and human resource management approaches, inadequate collaboration and support among stakeholders, material logistics management, equipment management approach, poor working environment, incompetency and waste behavior, poor communication on the construction site, and lack of training and experience.

Some studies focused on WP-related WCFs. Examples include Cha et al. (2009) that listed 57 WP-CFs and clustered them into 5 sets according to workforce, material and equipment, industry policy, management practice, and construction method. Likewise, Chinda (2016) presented 18 WP-related WCFs, mainly affecting recycling decisions, and suggested another clustering: economics including the need for specific machines for sorting, and time constraints; market and site activities such as lack of mature market and limited site space; and environment mainly lack of standard of recycled waste. As a result of the systematic review of all included papers, the following 125 various WCFs were identified.

X01 -Change in design and specification
X02 -Delays in passing information.
X03 -Lack of consistent interaction between involved specialists
X04 -Lack of clearly allocated responsibility for decision-making.
X05 -Lack of attention paid to dimensional coordination.
X06 -Lack/Poor coordination and communication.
X07 -Last-minute client requirements
X08 -Poor coordination due to absence of early stakeholders' involvement in the project
X09 -Slow drawing revision and distribution
X10 -Theft and lost.
X46 -Lack of on-site material control
X47 -Lack of supervision
X48 -Workers' fatigue.
X49 -Off-cuts from cutting materials.
X52 -Waste from execution processes (over-preparation of mortar…)
X53 -Effect of new technologies and methods
X54 -Errors in detection and prediction of proper decisions before execution
X55 -Absence of incentives and proper standards and guidelines.
X56 -Improper planning for required quantities.
X57 -Incomplete or insufficient
X86 -Political Conditions (War, Urbanization change…),
X87 -Building aging
X88 -Building removal decision by public authorities or owners.
X89 -Illegal dumping
X90 -Lack of heavy coercive measures and penalties for C&DWM
X91 -Lack of training
X92 -Low cost due to illegal dumping
X93 -Ambiguity due to frequent revisions and/or information latency
X94 -Waste accepted as inevitable.
X95 -Low budgets due to fierce competitivity
X96 -Lack of awareness and publicity of C&DWM benefits
X97 -Lack of WM profitability

X11 -Vandalism
X12 -Natural Conditions (Weather, Earthquake, Tornedo, Tsunami…)
X13 -Contract documents incomplete at commencement of construction
X14 -Errors in contractual documents
X15 -Inadequate/unclear/incorrect specification
X16 -Long contract/project duration
X17 -Confusing requirements
X18 -The practice of assigning the contract to the lowest bidder.
X19 -Waste client-driven/enforced.
X20 -Absence of detailed information in drawing
X21 -Design complexity
X22 -Different methods used in estimating.
X23 -Errors in design including drawings/detailing/Tech documents.
X24 -Failure to identify client needs.
X25 -Inaccurate quantity take-off
X26 -Incorrect standard specification
X27 -Material waste due to rework and change orders.
X28 -Over or under designing
X29 -Lack of proper Packaging
X30 -Poor design management
X31 -Poor design quality
X32 -Deficiencies in cost estimates
X33 -Low and/or heterogenous experience of designers
X34 -Low and/or heterogenous experience of onsite workforce
X35 -Poor craftsmanship.
X36 -Ignorance of changes' needs
X37 -Poor quality control
X38 -Poor workers' ethics.
X39 -Accidents due to negligence
X40 -Negligence attitude
X41 -Poor synchronization of procurement and construction planning X42 -Equipment malfunction.
X43 -Errors amongst parties' plannings
X44 -Improper program of work
X45 -Inefficient methods of unloading.

procurement documents
X58 -Lack of C&DWM system
X59 -Residues due to over-ordering
X60 -Materials supplied in loose form.
X61 -Ordering errors (i.e., ordering items not in compliance with specification: Quality, Quantity...)
X62 -Over allowances (i.e., difficulties ordering small quantities).
X63 -Shipping and suppliers' errors.
X64 -Unused materials and products.
X65 -Use of wrong materials.
X66 -Difficulties for delivery vehicles accessing construction sites.
X67 -Improper plan for site organization and layout
X68 -Inadequate material handling.
X69 -Inadequate site investigation
X70 -Improper onsite storage and delivery conditions.
X71 -Improper protection during transportation, handling, and storage.
X72 -Improper maintenance
X73 -Material waste due to lack of proper warehousing system
X74 -Materials stored far away from point of application.
X75 -Damage during transportation
X76 -Material waste due to improper transportation
X77 -Improper moving methods from storage to the point of application.
X78 -Effect of checking the recyclability of materials on the throwing of materials due to rework.
X79 -Lack of clear goal for waste management (WM)
X80 -Lack of inclusion of WM in the bidding process
X81 -Lack of on-site waste management plans (WMPs)
X82 -Lack of waste feasibility studies
X83 -Lack of waste responsibility
X84 -Lack/poor investigation of the recyclability of materials.
X85 -Material waste due to non-recyclability after demolition

examples
X98 -Aggressive or excessive use of B&Is leading to early degradation.
X99 -Absence of proper maintenance during operation stage
X100 -Lack of motivation
X101 -Adoption of high-waste architecture and construction methods
X102 -Use of destructive methods for demolition
X103 -Manufacturing defects
X104 -Companies size and policies
X105 -Recovery needs specific machinery and competencies.
X106 -Government non-commitment
X107 -Lack of decision-makers buy-in
X108 -Errors and defects in execution
X109 -MCs waste due to improper maintenance on the site
X110 -Immature market for recovered materials and components.
X111 -Improper energy supply to the worksite (e.g., lighting issues)
X112 -Poor materials quality
X113 -Scarcity and/or failure of equipment / machinery
X114 -Lack of C&DWM regulation and guidelines
X115 -Short-term profit-driven nature of the construction industry
X117 -Unawareness or no-commitment of workers to waste optimization.
X118 -Improper waste collecting and sorting processes.
X119 -Absence of early waste sorting systems
X120 -Lack of quality management system
X121- Improper onsite materials management and inventory
X122 -Poor immediate profitability from the WM at the project level
X123- WM needs extra time and costs.
X124 -On-site waste contamination
X125 -Complex legal procedure to install recycling station

Table 1: Causative Factors of the BLC waste generation and/or persistence

5 Taxonomy and Discussion

Due to the increasing amount and complexity of data, willing stakeholders and scholars to consider C&DWM would face major difficulties since up to 93% of existing data related to the WCFs is restricted and multi-dimensional (see § *Investigation of Existing WCF-related Knowledge*). Analysing, processing, interpreting, and transforming this data into taxonomies constitutes the main shift from large to smart data as it enables the mutation from initially unstructured mass data to the intelligent processing of data and its conversion into clear knowledge, which represents the basis for further technological innovations and efficient strategies in almost all domains and industries (Lenk et al., 2015).

Among transversal roots of WCFs, a high importance was given to legal and financial aspects and a much higher one to stakeholders' attributes (F1). It was disclosed that the absence of severe penalties, attractive incentives, explicit contractual terms, and mandatory regulation allied to waste management would significantly increase C&DW. Begum et al. (2009) showed that due to this absence 70% of contractors assume no waste management action including sorting, 65% directly dispose CW at landfills and 9% dump the waste at illegal dumpsites, but reported that adoption of incentives prevents up to 23% of WG. Wang et al. (2010) stated that financial factors have significant weight on WP where the revenue of the recovered materials and costs of the needed machines for waste sorting affect the decision to recycle, with weights of 57.6% and 58.8%, respectively.

Several studies revealed that stakeholders attributes were the focus of most discussed WCF-related topics among scholars, either in general (Chellappa et al., 2023; Wei et al., 2023; Zhao, 2021) or specific to a certain role, including designers (Osmani et al., 2008; Wang et al., 2019), contractors (Begum et al., 2009, 2007; Li et al., 2022), and managers (Yuan et al., 2018). The investigation of this WCFs family revealed that skills, ethics, commitment, and decision-making of involved stakeholders have severe impacts on both WG and WP since they either directly cause WG and WP, due to negligence, unawareness, and incompetency for instance; or considerably help increase the likelihood of WG and WP due to the other families. Li et al. (2022) proved that governments commitment to waste reduction through mandatory measures, and rigorous supervision including penalties and incentives would decrease contractors' waste behavior by 30.7%, 29.9%, and 23.1%, respectively.

It has been confirmed that WCFs related to design and pre-contract stage (F4) have devastating effects on the WG where an inappropriate design results in up to 33% of the CW (Chellappa et al., 2023) and adoption of sustainable design mainly prefabrication could enable 52-84.7% cut of the CW (Fitriani et al., 2023) and almost 100% recovery of the demolition waste (Begum et al., 2009). Eze et al. (2022) reported that 96.88% of F3-related WCFs are equally sources of cost overrun.

Likewise, procurement and onsite construction stages are highly contributing to the CW and are influenced by transversal WCFs families. Fitriani et al. (2023) showed that 25.96%, 19.96%, 14.25%, and 11.59% of CWs could be explained by improper management of equipment, onsite material logistics, and working milieu (F6); onsite-related inadequate collaboration and communication on the construction site (F3); improper site planning and workforce management (F6), and F1 due to involved stakeholders in the construction operation (waste behavior, incompetency, and lack of training and experience), respectively. Based on risk severity and occurrence analyses, Bachayo et al. (2022) revealed that among 8 WCFs related to procurement and supply chain, 7 fell in the red zone with orders variation as the most occurrent, incompliant materials with specifications as the severest, and mistakes in quantity surveys as the most impactful on the cost.

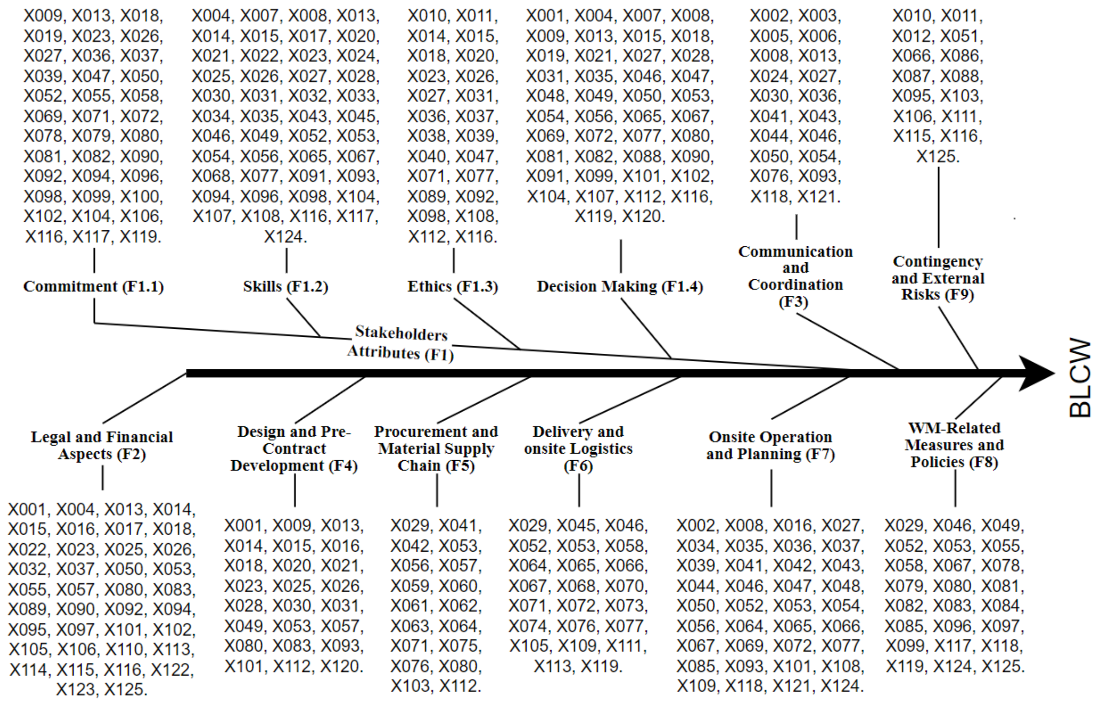

Figure 2: Taxonomy of Causative Factors of BLC waste generation and/or persistence.

Overall, the thematical analysis of the 125 systematically reviewed WCFs revealed that they could be structured into 9 families (see Figure 2): (F1, 82WCFs) Stakeholders attributes including commitment (F1.1, 37), skills (F1.2, 45), ethics (F1.3, 24) and decision making (F1.4, 42); (F2, 38WCFs) Legal and financial aspects (e.g., contracts, standards, costs, regulation, and responsibilities); (F3, 20WCFs) Communication and coordination; (F4, 24WCFs) Design and pre-contract development; (F5, 18WCFs) Procurement and materials supply chain; (F6, 23WCFs) Delivery and onsite logistics; (F7, 36WCFs) Onsite operation and planning; (F8, 24WCFs) Waste Management-related measures and policies; and (F9, 15WCFs) Contingencies and external risks. F1, F2, F3, F8 and F9 are transversal WCFs that influence other families and keep being impactful throughout all BLC stages.

6 Conclusion

The study showed that 93% of the knowledge discussing causative factors of WG and WP through construction and demolition processes is fragmented and needs to be organized. In fact, among the existing studies, 69% are region-oriented with quasi-dominance of Asian countries, 41% focus on the CW, and 33% discuss a specific family of C&DWM strategies. However, considering the harmful impact of C&DW on environmental, economic and social sustainability development and the substantial escalation of the related amounts due to population and urbanization growth and demolition upsurge of the buildings stock due to either aging, aggressive use, wars or natural hazards; enormous efforts are needed to reduce or eliminate WCFs but that would be complicated in absence of comprehensive and structured related knowledge.

To help overcome this limitation, this paper proposed a comprehensive taxonomy of WCFs causing either WG, WP or both that provides scholars, decision makers and practitioners with clear guidance on WCFs and related roots. This study disclosed 125 WCFs that were thematically structured into 9 families: F1. Stakeholders' attributes that include 4 genera: commitment (37 WCFs), skills (45 WCFs), ethics (24 WCFs) and decision making (42 WCFs); F2. Legal and financial aspects including 38WCFs associated mainly with contractual documents, standards, costs, regulation, and responsibilities; F3. Communication and coordination involving 20 WCFs; F4. Design and pre-contract development covering 24WCFs; F5. Procurement and materials supply chain with 18 WCFs. Delivery and onsite logistics with 23 WCFs; F7. Onsite operation and planning including 36 WCFs; F8. Waste management-related measures and policies with 24 WCFs; and F9. Contingencies and external risks involving 15 WCFs. While F4 to F7 are mostly associated with specific construction projects' stages; F1, F2, F3, F8 and F9 are transversal WCFs that influence other families and keep being impactful throughout all BLC stages. Among all families, F1 represents the most impactful one as it either directly causes WG or WP or increases the intensity of other WCFs families due to one of its related genera.

From research and industry perspectives, this paper contributes to helping establish construction sustainability by providing the project stakeholders with the influencing WCFs on both WG and WP and mapping them into clear and inclusive knowledge. Which would pave the path toward lower waste approaches and technological solutions. In the meantime, it should be highlighted that the construction industry includes a wide range of buildings and infrastructure types which involve various practices and technologies. Therefore, it is suggested to consider WCFs according to the discussed project types and sizes. Furthermore, it has been shown that this study is novel hence further studies are recommended to either confirm or extend the related findings.

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