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Design for Deconstruction and Disassembly: Barriers, Opportunities, and Practices in Developing Economies of Central Asia

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Abstract

Construction waste management is becoming an emerging issue in light of the massive increase in construction activities in the developing economies as part of their rapid economic growth. The gradual tightening of building regulations towards energy consumption creates the need to decrease the building materials and components during construction, and one of the proposed ways to achieve it is to reuse. The building components can be initially designed for disassembly (DfD) to improve and optimize the process, thus proposing significant benefits to the circular economy in all three sustainability pillars (economic, social, and environmental). Nevertheless, current practices in developing countries of Central Asia show that lifecycle analysis of buildings' end-of-life influence is not a well-practiced activity. This paper investigates the barriers, opportunities, and current practices of deconstruction and disassembly in one of the fast-developing Central Asian countries based on the literature review and stakeholder opinions. Conducting relevant PESTEL analysis, this research also proposes practical strategies, methods, and recommendations for the construction industry to develop circular economy projects and improve disassembly and deconstruction analytics.

Keywords: Kazakhstan; Buildings; Construction; Sustainability; Circular Economy; PESTEL;

1. Introduction

More than 80% of the construction waste ends up in landfills, while reusing and recycling activities are minimal in developing countries [1,2]. Currently, most buildings are constructed according to the linear economy model, which does not consider the end-of-life of buildings. Thus, all the value put into the production of the building materials is lost at its end-of-use. In contrast, circular economy (CE) aims to conserve this value by creating a loop of reusing, repairing, refurbishing, remanufacturing, and repurposing. One of CE principles is Design for Disassembly (DfD) promises a good solution for the construction industry, as it aims to design robust and adaptive buildings which are easy to repair and recycle after their lifetime [3]. Examples of linear economy principles in construction include using liquid sealing methods (e.g., pouring fresh concrete on-site, liquid silicones, and foams) and using different materials layers with different life cycles. In contrast, DfD uses construction methods that are easy to maintain; for example, prefabricated elements are assembled using "dry" methods (e.g., bolting) and employs building elements that are accessible for maintenance (e.g., all the pipes and cables are visible and accessible for maintenance and repair) [4].

This paper aims to investigate the barriers, opportunities, and current practices of deconstruction and disassembly in

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one of the fast-developing countries in Central Asia, based on the literature review and stakeholder opinions. The following research objectives are pursued in this study: (1) Develop a throughout understanding of deconstruction, disassembly, and their roles in the circular economy; (2) Investigate the barriers, opportunities, and most common practices of DfD in the context of developing economies through literature review and stakeholders analysis; (3) Develop strategies, methods, and recommendations for the construction industry toward their sustainable projects.

2. Literature Review

1.1. Design for Disassembly concept

DfD is the concept that considers the final demolition stage during initial design and planning [1]. Thus, it aims to save the value that has been inputted into the building material or structural element even after the building's end-of-use. It is the hardest to disassemble the structure at the following points: in the adjacent layers, between the structure and the building's skin, building services, and finishing facilities [2]. If the buildings are initially designed for disassembly, it will significantly improve the environmental effect due to the possibility recover almost 95% savings of the embodied energy of the construction materials and up to 50% of the total building's life cycle energy [2]. Moreover, it would improve the waste management issues.

Nevertheless, apart from the environmental incentives to adopt DfD, there are also other motives for the industry, which include economical (e.g., savings on resources extraction and waste handling) and social (e.g., increase of global population requires current buildings to be adaptable for further extension) [3]. Following DfD principles means: reducing the number of materials and components used; choosing materials that are possible for reusing and recycling; using visible and reachable building elements connections; using simple (yet strong) and connections that are easy to deconstruct, e.g., dry connections, dissolvable chemical or reversible welding connections; and practicing utilization of building modules that are robust, substitutable and convenient for transportation [2,4]. Based on the American construction market review, one of the main opportunities to help develop DfD in the industrial market is reducing the time required for building demolition and labor involved in demolition works [5]. DfD could bring some economic incentives. At the same time, the main barriers are uncertainty about the quality of the reused material; low demand due to users' negative perception; financial profitability of demolition practices rather than disassembly; earthquake risks when using bolting connections; high risks of reinforced concrete corrosion (which makes it hard to reuse) [5]. Overall, globally the practice in the construction industry shows the universal approach to DfD (i.e., methodology, specification documents) [6]. Besides the method, another barrier for DfD propagation in the construction industry could be the absence of clear incentives that would encourage the implementation of DfD and CE practices [7]. In addition, the time advantage of demolition contrasted to the longer time needed for disassembly is also found to be a current barrier for DfD [8].

1.2. The main barriers, opportunities, and practices of DfD in Central Asia

Central Asia consists of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Among those with the largest territory and taking a politically leading role, Kazakhstan faces immense growth in the construction industry. Nevertheless, lacking proper waste management is a conventional problem for Kazakhstan and typical for the Central Asian region [9]. Designing residences with easy deconstruction methods (e.g., yurt houses) was quite natural and well-practiced in the population residing in the Central Asian region for many centuries. The nomadic lifestyle forced the residing shelters – "yurts" – to be mobile and easy to deconstruct when needed [10]. Nevertheless, the contemporary settled lifestyle has changed those practices.

Currently, construction activities in Kazakhstan rapidly increase with economic growth. For example, the increase of residential construction is one of the "Kazakhstan-2030" strategies [9]. In 2021, it is planned to commission 17 mln m^2 (in 2019, it was 11 mln [11]) of housing that would be affordable and economical, which shows the main trend on financial constraints rather than focus on circular economy principles [12]. In addition, notwithstanding the decrease of overall business and economic activities during the COVID-19 pandemic in 2020, the construction industry has increased by 11%, and the amount of residential buildings in 2020 has risen by more than 15% [13]. The demand for housing is great in Kazakhstan, while the provision of sq.m. per person is lower than the norms stipulated in the UN standard – 21.9 m^2 contrasted to advised 30 m^2.

Nevertheless, proper regulations and strategies towards circular construction and proper practices on waste demolition are only developing [9]. For example, the factory on production of modular buildings has been recently opened at the end of 2020 [11]. The first experimental blocks have been recently checked and approved for their quality in the first quarter of 2021 [14].

Recent research on current construction and demolition waste (C&DW) shows that 3R strategies are applicable and currently in the stage of development in the Central Asian context [9]. For example, in *Reducing* CD&W, prefabricated building elements and modern building methods are already applicable. In contrast, such practices as efficient logistics of building materials, standardization of hazardous materials management plans, and quantification of necessary treatment for C&DW are not valid yet. In *Reusing* C&DW, there are practices in maximization of high-quality recycled aggregate. However, reducing in-situ building elements and materials cutting or utilizing the same materials for identical purposes still lacks application. Talking about the third R – *Recycling* C&DW, it is still innovative for Central Asia, as the waste is usually buried in the landfills (sometimes even illegal) or sometimes burned (e.g., wood and plastic waste). Although some promising practices, e.g., recycled material for B2B refund, and many more opportunities are yet to be practiced [9]. These include open opportunities for the recycling of such building materials as timber and metals.

Although developing rapidly, Central Asian countries' construction industry is still facing gaps in circular economy principles.

2. Methodology

This research is based on literature review and stakeholder interviews regarding current DfD practices, barriers, and opportunities in the Central Asian construction market. PESTEL framework is utilized in this research for analysis of the factors that form current DfD practices. PESTEL stands for Political (impact of government), Economic (degree of profitability), Social (attitude of the public), Technological (technological innovations), Environmental (the level of sustainability), and Legal (rules and regulations) factors [15]. In total, 17 companies were interviewed regarding the implementation of DfD principles in their construction work processes. The ethics of interviewing process was approved by the Arctic University of Norway (UiT) regulations. The stakeholders for the interview were chosen from the Kazakhstani construction market from different profiles, e.g., design/architectural, contractors, management, and materials manufacturing companies. The following measures were identified through stakeholder engagement activities (e.g., interviews, surveys, and face-to-face meetings) and discussed in detail: 1) DfD concept propagation, 2) Adoption of DfD building methods and 3) Preference to refurbishment/adaptation of the existing structure instead of its demolition.20% of the respondents represent designer views, 45% - client views, while 55% of the respondents are involved into actual construction as contractors (some of the companies execute both client and construction views). 60% of the interviewees show the opinion of the large companies (including the top construction companies in Kazakhstan, which have offices in all the cities), 20% - of the medium-size companies, while 20% are from small-size companies.

3. Analysis and Results

3.1. Interview results

3.1.1. Design for Disassembly concept propagation in Kazakhstan

The stakeholders' interview has shown that the Design for Disassembly concept is not popular in the Kazakhstani construction sector. Only one out of seventeen construction companies mentioned that they deliberately attempt to adopt the DfD principle for the circular economy and economic benefits in their construction process. However, around 40% of the respondents shared that they unintentionally consider DfD for some structure parts–facades, interior walls, networks, or frames. Those stakeholders that adopt modular technology also automatically follow DfD principles. In their interview, one of the stakeholders shared that they had accomplished dismantling dormitory blocks of modules, then transported them to another country region and erected a new temporary hospital for treating COVID-19 patients. Some stakeholders adopt DfD concepts only for temporary buildings needed only during construction, while designing for disassembly of permanent structures is not that common.

Compared to the design and architectural companies, contracting companies have much less interest in developing the DfD concept in Kazakhstani buildings. This lower interest is linked to their lesser involvement in the design and more involvement in building works. They tend to follow those technical plans and local construction regulations already developed by the design engineers. Thus, any obligation or responsibility for the development of DfD is left for the Clients' choices and interests. Nevertheless, contractors are also open for DfD if it provides an easier way of working. Thus, one company has mentioned that they prefer when the building services (e.g., piping systems) are not hidden with the interior finishing for further maintenance.

3.1.2. Adoption of DFD building methods

Choice of dry building methods over wet building methods: Adopting wet building methods (e.g., in-situ concrete pouring, glue sealing) significantly increases the complexity of demolition of the structural elements and decreases the initial value of the building material. Therefore, it was necessary to analyze if the stakeholders were interested in dry construction methods.

In general, two out of seventeen stakeholders use dry methods on site. Wet methods are still used to save time during project construction; still, more than half of the stakeholders attempt to perform mechanical connections where possible. However, this choice is dictated for economic reasons as usually dry methods are faster and more convenient. For example, wet methods usually require additional bothers during low temperatures, such as heating, heat insulation. Thus, cold climatic conditions make dry methods more favorable. The economic feasibility of the dry methods depends on the project complexity, as the opinion regarding its effect on costs differed among the stakeholders. For example, some companies consider replacing wet construction methods with dry, driven by economic reasons (time and cost-saving) rather than circularity and sustainability.

Nevertheless, another contractor shared that they had experience in one of their projects to avoid wet methods – the concrete screed was replaced with foam concrete sheeting, which reduced time and labor works but increased the total cost by 15%. Some companies prefer prefabricated structures are also over in-situ casting, e.g., construction from blocks or the use of precast concrete columns, piles, walls, floor slabs, beams, crossbars, facade panels. Column fastening with bolted connections instead of welding is favorable because of the circularity issues and is motivated by time and cost savings. In addition, dry methods are consistently employed for façades and drywall installations. Sometimes wet methods are preferable over dry because of structural advantage – for example, concrete or masonry works.

Overall, contractors do not have full power to replace dry building methods over wet – all connections and joint types are specified in project documentation, and contractors cannot deviate from project specifications. Thus, again, it is more a responsibility of a Client to develop project specifications that would adopt circular economy and design for disassembly principles. Economic feasibility is the main reason why wet methods of construction are still in use on construction sites. Nevertheless, depending on the project, cost efficiency is also sometimes a driver for dry methods development.

Consideration of different lifecycles of the construction materials: Consideration of the building materials lifetime periods is also essential in the context of DfD, as the difference in their periods of wearing out or failing would create a burden for further maintenance and demolition of other adjacent materials, too. Consideration of different materials' life cycles used for layering is always considered at the design stage by engineers, especially exterior façade wall panels materials chosen to have a similar life cycle. In economic considerations, the companies aim to use the most long-lasting materials with proper quality certificates (e.g., those that can be used over 50 years). Contractors in their interviews have shared that different lifetime periods of layering materials were not considered in their practice, as it is designers' job to estimate life cycles and develop good drawings and project specifications for contractors' work. In addition, the issue of some building layers failing is not a common problem. Moreover, companies enforce a guarantee period for the whole life cycle period of the finishing materials as per their datasheet for most materials.

Using structures able to disassemble: No stakeholder entirely designs their construction process structures that can be disassembled. The main barrier is the lack of proper technology development, which leads to the limited production capacity of such structures that can be disassembled later. Nevertheless, it was observed that design for disassembly is quite common for temporary structures in industrial construction, such as toilet pods, temporary workforce housing, and field offices.

3.1.3. Preference to refurbishment/adaptation of the existing structure instead of its demolition

Designing the building for its further adaptation for another practical use is not common among the construction parties. Only the existing heritage buildings with cultural importance get restored, as regulations require it. Nevertheless, from the experience of stakeholders, it is not economically viable to renovate old buildings (usually through structure stiffening); therefore, they try to avoid it. Whereas, in the construction of roads and bridges, refurbishment is preferred due to economic profitability. According to the results of the interviews, lack of shared responsibility impedes design for further adaptability. After completing the building design, Architectural companies do not take responsibility for the project's completion of the building's end-of-use.

3.2. Discussion of the DfD development prospects

The statistics for previously discussed measures are summarized in Table 1, which shows the percentage of interviewed stakeholders that use DfD concepts, their adoption of DfD building methods, or preferences to refurbish the buildings instead of their demolition.

Table 1. Statistics on DFD development prospects among the interviewed stakeholders

Level of use			**Description**	
No use	**Moderate**	**Full**		
53%	41%	6%	Stakeholders using DfD concepts	
35%	53%	12%	Stakeholders that adopt DfD methods	Choice of dry building methods over wet building methods
53%	35%	12%		Consideration of different lifecycles of the construction materials
29%	71%	0%		Using structures able to disassembly
35%	65%	0%	Stakeholders prefer to refurbishment /adaptation of the existing structure instead of its demolition	

As the DfD concept is quite innovative for the Central Asian region, it can meet many barriers and opportunities while finding its place in the local construction sector. Starting with the challenges, one of the greatest is the financial barrier, as DfD principles require good investment at the starting stage. All the stakeholders have mentioned that the project budget amount plays an important role, and they still choose conventional building methods if it is cheaper than innovative methods. Therefore, unless the involved parties would not see quantifiable economic profit (either in terms of materials cost, time, or labor savings), DfD is hardly likely to conquer the local market. The technology limitation could also produce a challenge for DfD development in Kazakhstan. Another barrier is the deficiency in collaboration between all the construction participants, i.e., each party is working solely on certain stages (e.g., design, erection, or demolition). This situation puts unavoidable stress on the client and design/architectural companies expected to provide all the technical directions for the contractors. It also decreases the responsibility from the contractors, which, by results of the interview, appear to have much less interest in CE or DfD, thus, can take such decisions at the construction site that can contrast DfD. In addition, there is a lack of interest in building's refurbishment, and, as a consequence, it undergoes demolition. This barrier could be solved by implementing DfD into construction regulations, which would align with the aims of all the construction parties.

Concerning the opportunities, the recent opening of the factory producing modular structures and its governmental support [14] promises significant development of modular construction on the local construction market. Considering that the financial side could become the most critical challenge for DfD spread, it could also be an opportunity. Several stakeholders mentioned that they sometimes follow DfD principles for savings in terms of working capacity or time.

Table 1 presents the political, economic, social, technological, environmental, and legal factors that affect the DfD development in the Kazakhstani construction sector. These factors are extracted from the analysis based on the interviews with the stakeholders and literature review.

Thus, political stability and policies supporting residential construction favor construction development and prospective circular practices, including DfD. Nevertheless, the economic factor is not promising much – the financial expenses for implementation of DfD building methods and lack of market and demand for reused materials do not provide many prospects to DfD at the current moment. From the social point of view, the current construction sector is not much interested in circular economy practices, so some stipulating measures from the government would be helpful to improve the motivation for DfD implementation. Technological factors show some development towards DfD, e.g., modular factories; nevertheless, they are not developed extensively to cover extensive construction practices. The current state of environmental factors (illegal dump filling with C&DW and high embodied energy needed for construction materials production) dictate the development of DfD practices. However, the lack of legal policies relevant to DfD practices also complicates its growth in the Kazakhstani construction sector.

Table 2. Result of PESTEL analysis for current DfD practices in Kazakhstan

Factor	Description
Political	Political stability Residential construction rates are increasing owing to different governmental policies
Economic	Financial expenses for DfD building methods (prefabricated materials over in-situ concrete pouring; bolting over welding or sealing) Low demand for reusing building materials No market for selling previously used construction materials
Social	Lack of industrial interest and motivation in implementation Circular Economy in the local construction sector Adherence of views towards conventional construction methods In the context of following DfD principles, lack of teamwork between different construction parties (client, design/architects, contractors, material manufacturers & suppliers)
Technological	Low level of technological advancement that is required for DfD BIM technology is not adopted in all the construction companies Modular technology or prefabricated structures technology is also not extensively established Lack of recycling plants for construction waste Promising development of modular construction
Environmental	Existing practices of construction and demolition waste ending on landfills (including illegal dumpings) High embodied energy is required for the production of construction materials
Legal	Absence of relevant policies, regulations, and construction codes for: • design for disassembly concepts (e.g., guidelines for design methods and construction) • quality control of previously used construction materials

5. Conclusion

To conclude, the Design for Disassembly concept is not well developed in the Kazakhstani construction sector, as DfD is not obligatory according to local construction codes and regulations, and there are no specific guidelines for that. Nevertheless, companies involved in construction have already started taking the first steps towards that. Modular construction has recently started its development in Kazakhstan and is planned to scale up further. It is essential to mention that prime motivation for the stakeholders involved in construction is the project's economic feasibility and profitability, which makes cost the main incentive to either follow or abide by DfD principles (as, for example, it is with choice of dry building methods over wet building methods). Furthermore, if building maintenance and renovation would be reflected in the total lifecycle cost (including the contracts), then the construction sector would find it more appealing to adopt DfD practices in order to receive more profit. Therefore, before developing local laws and regulations, it is essential first to develop quantifiable profit for the companies to adopt DfD, as, otherwise, it would put a risk on the local market due to the need for high investments. Although the data collection process has been done territorially in Kazakhstan, the results and conclusion are believed to be scaled up for the whole Central Asian construction sector. As most of the respondents involved in the interviewing process are directly involved in the construction sector, and the "client" and "designer" views are minor, this creates some limitations to this research. The results of the study may be beneficial for many sectors, including manufacturing, as the construction sector has a direct relationship with all other production and service industries and uses the outputs from these industries. Furthermore, using the PESTEL method, which analyzes the topic under-study from a strategic perspective, based on literature and stakeholder analysis to explore trends, barriers, and opportunities for DFD applications in the construction industry also strengthens this contribution..

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