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Sustainable construction supplies in modern cities

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Abstract

The implementation of construction projects largely determines the development of modern cities. However, such projects impact both urban freight transport and residents. To reduce this impact, increasingly more attention has been paid to the issues of sustainable development. Sustainable urban freight transport has become a priority for European cities. It also contributes to construction supplies. This article presents the results of analyzing construction supplies and the assessment of their compliance with the principles of sustainable development using the example of the city of Szczecin. This allows for the diagnosis of problems in this area, and solutions in the field of sustainable construction are collected. The presented research includes unstructured observation of construction projects in progress, structured interviews with entities implementing construction projects in Szczecin, and additional expert research to identify solutions in the field of sustainable construction supply in cities. This enables the research objective to be achieved and conclusions to be developed.

Introduction

The world has undergone dynamic urbanization. Two hundred years ago, city dwellers constituted only about 3% of the population (Czornik, 2008, p. 9). In 1950, 30% lived in cities and, in 2018, this percentage increased to 55%. In 2020, 60.05% of people lived in urbanized areas in Poland, whereas the average rate in Europe was 75% (The World Bank, 2018). According to UN estimates, by 2050, 68% of the world's total population will live in cities (United Nations, 2018). As the number of residents increases, their needs and requirements evolve. The final effect is the need to provide goods and services that satisfy them and to provide them with a comfortable life and an appropriate level of security in many dimensions (Ghosal & Halder, 2018, pp. 108–109); the city is taking responsibility for this matter. City authorities are obliged to provide residents with opportunities for comfortable living, appropriate infrastructure, mobility, public order and security, and guarantee access to education, health care, labor market, social assistance, and culture. All this is not possible without the implementation of construction projects.

The construction sector plays an important role in socio-economic life. Its intensity is an indicator of the development of both urban environments and the economy in general. However, construction activity is associated with the need to carry out various processes, which may have a negative impact on the surroundings of the construction site during the work implementation stage. One such process is construction supplies. The transport necessary for its implementation may pose a challenge to the entire city transport system. Construction supplies are

characterized by the need to use high-tonnage vehicles, a large number of empty journeys, the need to adapt deliveries to assembly and construction works, which are often not consolidated, and unloading that takes place directly on the road. This specificity also makes the construction industry responsible for a significant part of CO_2 emissions, noise pollution, destruction of road infrastructure, and reduced levels of road traffic safety (UNEP, 2022).

Therefore, the specificity of a sustainable approach to the implementation of construction processes is increasingly discussed in the literature on the subject. However, these considerations are not exhaustive. The results of a bibliometric review indicate that the literature in this field primarily focuses on alternative materials for sustainable construction, sustainable construction management, recycling and waste reduction, and social sustainability in construction management (Udomsap & Hallinger, 2020). Additionally, construction is increasingly being discussed in the context of circular economy (CE) (Hossain et al., 2020). It is emphasized that CE can support the transition from traditional to sustainable construction. However, publications in this area usually concentrate on waste production, energy, materials, and water usage (Sfakianaki, 2015; Afshari & Górecki, 2019; Ghufran et al., 2022). Another direction of consideration regarding sustainable construction is lean construction (Solaimani & Sedighi, 2020). The lean concept focuses on creating value, improving efficiency, reducing costs, and minimizing waste throughout the construction process. Particular emphasis is placed on resource consumption (i.e., minimizing consumption, reusing resources, and utilizing renewable or recyclable resources), protection, and creating a healthy and non-toxic environment (Carvajal-Arango et al., 2019). Another topic addressed in the literature is the use of telematics systems, which allow for rational planning and utilization of resources, as well as more efficient project implementation (Whitlock et al., 2018; Buchanan & Gardner, 2019; Santos et al., 2019; Papadonikolaki, 2020, pp.15–34). As evident from the above, the literature on sustainable construction focuses on various aspects of the construction process, with a detailed emphasis on the materials and resources used, their consumption and recycling, waste management, and the improvement of construction technology. This approach, however, minimally considers logistics, not treating it as an element that integrates all elements of the construction process. Due to the crucial role of supply chain logistics in sustainable construction and the lack of sufficient research presented in the literature, a research gap has been identified.

Thus, this article aims to represent the results of analyzing construction supplies and the assessment of their compliance with the principles of sustainable development using the example of the city of Szczecin. An attempt is made to analyze the problems occurring in this area, and a list of solutions in the field of sustainable construction is prepared to solve them. The first section analyzes the implementation of construction supplies in cities. The second section introduces the topic of sustainable construction and supply. The third section presents the results of our research on the implementation of construction supplies in Szczecin. Finally, conclusions are presented.

Implementation of construction supplies in cities

Supply in construction is associated with planning demand, supplies, transport and storage of materials, elements, machines, and scheduling; therefore, it constitutes an important part of the entire process of construction project implementation. Without proper organization of these processes, it is difficult to imagine effective and efficient construction. Transport for construction supplies accounts for up to 30% of all freight transport in cities. Waste generated by construction accounts for 35% of all waste generated (UNEP, 2022). Additionally, the industry is a large consumer of electricity (i.e., 30%) and is responsible for approximately 37% of CO_2 emissions (Murtagh & Badi, 2020, pp. 63–66.; UNEP, 2022). Moreover, research indicates that construction projects may be a source of increasing danger on roads (Osypchuk & Sosik, 2021). Such results mean that construction supplies have a particular impact on the entire surroundings of construction sites, i.e., on city residents, the natural environment, and existing infrastructure. Thus, one of the most important tasks of the main contractor is the selection of an appropriate form of procurement during the planning of a construction project. There are four basic ways of organizing supply: centralized, dispersed, implemented by logistics bodies, and mixed (Sobotka, 2010, pp. 109–113). Each type of supply is suitable for different construction conditions, but centralized supply and supply carried out by logistics bodies are considered the most sustainable. This is indicated by both the literature on the subject and our expert research. They allow for a consolidation of supplies, optimization, quality control, and

the possibility of reducing delivery costs (Sobotka, 2010, pp. 109–113; Li, Zhang & Sun, 2012).

However, the appropriate selection of the type of supply does not mean the absence of difficulties relating to supply. Basically, they can be divided into internal and external problems. The former includes those that influence the implementation of the project, and the latter includes those that influence its surroundings. Internal problems include errors in planning, delivery delays, frequency of deliveries, lack of unloading space, lack of unloading equipment, damage and theft of cargo, excessive inventories, problems in communication with subcontractors, and limited warehouse space. External problems include transport congestion, noise emissions, safety, and air pollution (Bardi et al., 2018; Morel et al., 2020). Additionally, it should be pointed out that existing internal problems contribute to the intensification of external problems, thus making construction supplies a significant burden for cities. Therefore, both the literature and economic practice more often discuss the need to adapt construction to the principles of sustainable development.

Sustainable construction and construction supplies

To reduce the impact of construction supplies on the functioning of modern cities, inhabitants, and the natural environment, various solutions have been introduced to create sustainable and "green" supply chains in construction. The management of these supply chains focuses on environmental impact, energy consumption, materials used, and waste generated. Basically, it can be divided into the following parts (Murtagh & Badi, 2020):

- *Green design,* i.e., design that reduces the environmental impact of the final product or service through the materials used, their production, or resources used.
- *Green manufacturing*, i.e., one that reduces the impact on the natural environment by reducing the consumption of energy, water, and resources. It includes design, production process, and packaging.
- *Waste management* involves reducing the amount of resources used and reusing them wherever possible.
- *Green operation*, i.e., one that reduces the impact on the natural environment, especially through greater energy and water efficiency.
- *End-of-life management* enables the reuse of materials, including reverse logistics.
- *Green transportation*, i.e., one that reduces the impact on the natural environment by using approaches and technologies that reduce the number of trips, fuel consumption, and the amount and weight of transported goods.

This division clearly indicates that, in order to achieve optimal results and synergies, a sustainable approach to construction should be used throughout the entire construction cycle. Appropriate design of facilities and implementation planning directly translate into construction supplies and, thus, the impact on the surroundings of the construction site. However, this does not make it possible to completely reduce it or solve the existing problems. For this purpose, good practices are additionally implemented, which can be broadly divided into organizational and technical/technological solutions, i.e., the so-called soft and hard solutions. Additionally, these may be solutions introduced by project contractors, material suppliers, or city authorities.

City authorities can implement solutions and technologies in the field of road traffic organization. These solutions are not targeted specifically at the construction industry but at general city logistics. However, they can also contribute to a more sustainable construction supply through the need for adaptation. Such soft solutions include multi-use lanes, low-emission zones, zero-emission zones, and entry bans for selected groups of vehicles at certain hours. The hard solutions implemented by the city include green wave, traffic monitoring, technologies enabling the collection and dissemination of information about the current road situation, accidents, road works, and expected travel times (Jaśkowski, Sobotka & Czarnigowska, 2018; Karatsoli, Karakikes & Nathanail, 2018).

Soft solutions implemented by material suppliers include night deliveries, consolidation of deliveries, and the involvement of construction consolidation centers (CCC) (Allen et al., 2012; Lundesjo, 2015). Hard solutions focus primarily on telematics and include delivery bicycles, alternatively powered vehicles, unmanned vehicles, autonomous delivery robots, unmanned aerial vehicles (UAVs), wireless communication systems, automatic toll collection systems, fleet and freight management systems, driver support systems, automatic vehicle access control systems, and mapping and visualization programs (Browne, Allen & Leonardi, 2011; Barth, Wu & Boriboonsomsin, 2015; Miler et al., 2020). The above-mentioned solutions contribute to more rational delivery planning, increased road safety, and shortened travel times, which in turn translates into

a reduction in the impact of transport for construction supplies on cities.

Solutions implemented by direct contractors of construction projects are solutions directly relating to the planning and implementation of works. Soft solutions in this area include rational scheduling, collective orders, and construction logistics planning (CLP) (Brown, 2015). Hard solutions included building information modeling (BIM), 3D printing in construction, RFID/GPS/barcodes, and ERP systems (Whitlock et al., 2018; Buchanan & Gardner, 2019; Papadonikolaki, 2020, pp. 15–34). The solutions mentioned above vary in terms of the necessary resources and implementation difficulties, but they can significantly reduce the negative impact of construction supplies in cities. Comprehensive implementation of good practices by all participants in the construction process allows for additional synergy effects. This is evidenced by research conducted in this direction as part of projects, e.g., SUCCESS (VPF, 2017), and the results of the operation of CCC (Allen et al., 2012).

Analysis of the implementation of construction supplies in Szczecin

Szczecin, the capital city of the West Pomeranian voivodeship in Poland, is the largest city in the voivodeship and the third biggest city in Poland in terms of area and the seventh in terms of population (source: Central Statistical Office). In this city, construction activities are continuously developing. The average annual number of construction projects in progress at any given time is 40. However, it is important to consider that the average project implementation time in the construction industry is 2.5 years. In 2019–2022, survey research was conducted on 24 construction sites carried out by 12 companies acting as both the main contractors and subcontractors. All the projects were for structures with a size of at least 1000 m^2. Table 1 presents basic data on the location and research subjects. The research facilities were selected due to their location and the level of advancement of construction works. Construction works carried out in city centers take place in conditions of dense development and heavy transport traffic, which means that their supply may deepen existing problems and must be carried out taking into account this specificity. All examined construction facilities were at the stage of erecting walls and specialized construction works; this relates to the number of deliveries carried out at these stages.

Table 1. Basic data about research subjects

Place of research	Szczecin, Poland
Average annual number of construction projects in progress	40
Average project implementation time	2.5 years
Number of surveyed projects	24 construction sites
Number of surveyed companies	12 companies acting as both main contractors and subcontractors
Size of projects	from 1000 m^2

To properly construct a questionnaire used for structured interviews, experts (i.e., 14 from 5 European countries) were asked about the parameters necessary to assess the compliance of construction supplies with the principles of sustainable development. Such parameters include the type of construction supplies, the number of deliveries made daily, and the use of sustainable solutions. Through interviews with experts, good practices in construction supply logistics that contribute most to the compliance of construction supplies with the principles of sustainable development were identified. These include construction consolidation centers (CCC), construction logistics plans (CLP), night deliveries, permanent unloading areas, alternative storage areas, multi-modal transport networks, sustainability ratings, telematic solutions (e.g., BIM, ERP, 3D models, RFID, and alternative fuel vehicles), and multi-actor multi-criteria analyses. Additionally, it was considered important to ask in the interviews about barriers relating to the implementation of the above-mentioned solutions. The projects carried out in Szczecin were examined in terms of these parameters. The key findings are presented in the following.

In the surveyed construction facilities, the most popular type of supply turned out to be mixed supply (Table 2). Centralized procurement was used in only 29% of the facilities. Procurement provided by logistic organizational units did not occur at all. This proves the low awareness of construction companies about the benefits of choosing a more sustainable

Table 2. Procurement type

Procurement type	Number of construction sites
Centralized	7
Dispersed	8
Mixed	9
Procurement provided by logistic organizational units	0

type of procurement. The next question asked about the average number of deliveries per day. Detailed results are presented in Figure 1.

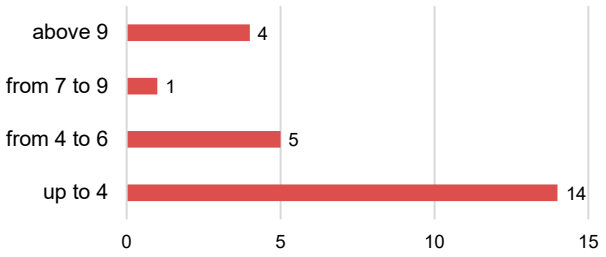

Figure 1. Average number of deliveries per day

The research showed that in most of the surveyed construction projects, the average number of deliveries per day was 4. This proves rational planning and possible consolidation of deliveries. As part of the research, correlations between the type of procurement and the number of deliveries were noticed. In the case of choosing centralized procurement, in 71% of the projects, the number of deliveries was fewer than 4 per day. When selecting dispersed procurement, in 63% of the projects, the number of deliveries ranged from 4 to 6 per day. However, for mixed procurement, a clear correlation could not be determined. Choosing centralized procurement provides greater opportunities for consolidating deliveries, which naturally contributes to reducing the number of deliveries and, in turn, leads to a reduction in the negative impact on the natural environment and city residents.

The next question analyzed the surveyed projects in terms of the use of sustainable development solutions in the implementation of procurement. Research has shown that companies implement this type of solution to a very small extent. Among the entire list of good practices, only permanent unloading areas (10 objects), consolidation of deliveries (10 objects), and specific hours of deliveries (e.g., night deliveries) (8 objects) were used. It was noted that none of the solutions required financial outlays. This state of affairs indicates that enterprises have little awareness of the impact of procurement on the construction site surroundings. Additionally, a significant knowledge gap was identified regarding the solutions that can be implemented and the benefits associated with them. To identify the reasons for such limited implementation of good practices, companies were additionally asked about this. Detailed responses are presented in Figure 2.

The above was a multiple-choice question. The answers clearly indicate the numerous reasons for such limited implementation of good practices. Most enterprises indicate high implementation costs (10 out of 12), functional problems (8 out of 12), and a lack of legal requirements regarding the implementation of sustainable development principles (8 out of 12) as most important for them.

Conclusions

Construction plays a key role in the development of modern cities. However, during implementation, it may constitute a significant burden on the areas adjacent to the construction site. To a large extent, it is caused by the supply processes necessary to implement the project. Deliveries for construction procurement play a crucial role in city logistics. They have a negative impact on both the natural environment and the quality of life for residents. Therefore, adapting construction supplies to the principles of sustainable development is becoming increasingly important. This topic is also discussed more often in the literature on the subject, but the conducted research shows that, in practical terms, actions taken in this direction are very limited.

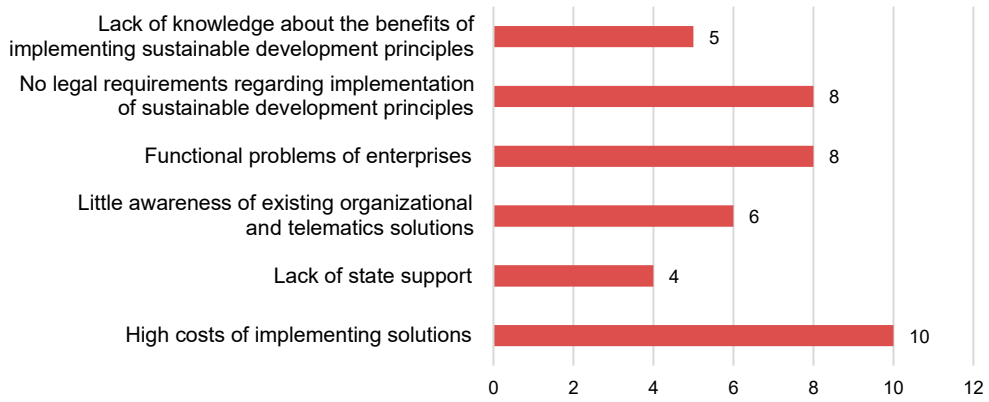

Figure 2. Reasons for limited implementation of good practices

This article presented an analysis of construction supply implemented in selected projects in Szczecin. The most frequently chosen type of procurement was identified, the number of daily deliveries was determined, and the use of sustainable solutions was assessed. These parameters allowed for determining the extent to which the implemented construction supply aligns with the principles of sustainable development. The literature review and expert studies have demonstrated that centralized procurement is considered a more sustainable approach. By centralizing the procurement process, it becomes possible to consolidate deliveries, thereby reducing the overall transport volume. This consolidation leads to a significant reduction in negative environmental impacts associated with transportation. However, this is not the most commonly chosen type of construction procurement in Szczecin. This relates to difficulties in organizing deliveries for all subcontractors involved in the construction process. Such a procurement type requires precise planning and coordination. Additionally, studies have shown that procurement provided by logistic organizational units did not occur at all. Companies are not aware of the benefits of using this type of procurement, and, in times of economic difficulties, they fear the costs associated with it. In light of the above, construction supply in Szczecin cannot be considered fully sustainable in terms of the chosen procurement type.

The number of deliveries made daily on the examined construction sites, in the majority of cases (14 out of the total), was less than 4. The research showed that choosing centralized procurement allows for reducing the average number of deliveries per day. This is achieved by consolidating deliveries, creating optimal schedules, and rational planning. The choice of centralized procurement, together with the implementation of good practices in the field of sustainable development, will allow for a significant reduction in the negative impact of construction supplies on the functioning of modern cities by reducing the volume of transport and its better organization. The obtained results allow us to conclude that companies are taking steps towards reducing the number of daily deliveries. However, the construction supply in Szczecin cannot be characterized as completely in line with the principles of sustainable development in this context. Additionally, it should be emphasized that the results obtained in this research cannot be considered universal. This is due to the individual characteristics of each examined construction and local conditions. Depending on the construction site's location, investment values, and local legal regulations, the possibilities of choosing supply forms, implementing good practices, and the benefits derived from their implementation may vary. However, it seems justified to state that the results may be extrapolated to objects with similar characteristics.

The conducted research has shown significant knowledge gaps regarding the implementation of solutions that contribute to a more sustainable construction procurement among companies. Most of these sustainable solutions were not used at all. Companies indicated economic barriers as the most challenging to overcome when implementing good practices. The research completed in Szczecin demonstrated that the companies involved in construction projects in the city showed little interest in sustainability aspects. The indicated reasons for this were a lack of knowledge about sustainable urban freight transport solutions and the costs connected with their implementation. It seems reasonable in this context not only to promote the implementation of good practices but also to involve authorities in creating initiatives that support tender construction companies adopting sustainable procurement solutions (e.g., logistics quality as a part of economically most advantageous tenders).

The results obtained in the conducted research allowed for an assessment of the construction supply in Szczecin. It can be used to support local authorities in shaping guidelines for the implementation of construction projects in the city. Additionally, the obtained results can serve as a basis for further research on the impact of construction supply on urban logistics, residents, and the natural environment.

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