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"Circular Economy and Global Value Chains:
The Case of The Construction Sand Sector"

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Acknowledgements

When I discovered the global sand crisis and the lack of awareness, I knew that I want to write my master's thesis about that topic. Please keep in mind, that the sand sector is in its early steps of being understood and documented. Hence, I aim to contribute to a better understanding as a basis for future research.

In the following chapters and pages, I therefore hope to raise awareness for the global sand crisis, to critically reflect "solutions" that cannot work as only solutions and to create a starting point for further research.

I want to thank Cornelia Staritz, for supervising my thesis and for taking the time to discuss every aspect of this fairly new topic together. It helped me to shape my scientifical thinking and made global value chain research to one of my key interests in research.

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Abstract

Sand is one of the key resources to human development and relevant for almost all sectors of our daily life. It is mined in gigantic amounts to cover the demand, but sand mining causes numerous social and environmental issues. Institutions such as the United Nations are aiming to raise awareness for this sand crisis and highlight circular economy as one solution to reduce the demand for sand. The main research question is: To what extent can circular economy make the construction sand value chain more sustainable?

Based on 14 expert interviews, an on-site visit of a recycling center, as well as document and data analyses, this thesis assesses the potential of circular economy in construction. The research questions are answered on three levels through analyzing expert interviews, documents, literature and data from UN ComTrade. The first level is the sand sector with its actors and geographical dimensions, as well as social and environmental problems, which are analyzed using document analysis, literature review, trade data by UN ComTrade, as well as expert interviews. The second level of research is circular economy in construction, which is analyzed using literature review, document analysis, secondary source interviews by DGNB, as well as expert interviews. The third level of research is limitations of circular economy in construction which is analyzed using literature review, document analysis, secondary source interviews by DGNB, as well as expert interviews.

The key findings of this thesis are that sand mining causes deforestation, loss of biodiversity, beach and coastal erosions and many other social and environmental problems. Circular activities may reduce the demand for construction sand, mainly through recycling and circular planning, while having several limitations such as a lack of data, cost-intensive technologies and not addressing social inequalities. Upgrading potentials are mainly environmental upgrading through reducing resource consumption and economic upgrading through high-value tasks such as recycling. However, those high-value tasks are mainly taken over by large construction companies in the Global North and do not trigger social or economic upgrading in the Global South.

This study contributes to the research on the sand sector, circular economy in construction and linking circular economy and global value chains.

Keywords: Circular Economy, Construction Sector, Sand, Sand Mining, Concrete Recycling, Sustainable Building, Modular Building, Material Passports, Degrowth

Abstract (German)

Sand ist eine der wichtigsten Ressourcen für die menschliche Entwicklung und für fast alle Bereiche unseres täglichen Lebens von Bedeutung. Er wird in gigantischen Mengen abgebaut, um den Bedarf zu decken, aber der Sandabbau verursacht zahlreiche soziale und ökologische Probleme. Institutionen wie die Vereinten Nationen sind bestrebt, das Bewusstsein für diese Sandkrise zu schärfen und heben die Kreislaufwirtschaft als eine Lösung zur Reduzierung der Sandnachfrage hervor. Die Forschungsfrage lautet: Inwieweit kann die Kreislaufwirtschaft die Wertschöpfungskette von Bausand nachhaltiger gestalten?

Auf der Basis von 14 Experteninterviews, einer Besichtigung eines Recyclingwerks, sowie Dokumenten- und Datenanalysen wird in dieser Arbeit das Potenzial der Kreislaufwirtschaft im Bauwesen analysiert. Die erste Analyseebene ist der Sandsektor mitsamt Akteuren und geografischen Dimensionen sowie sozialen und ökologischen Problemen, die anhand von Dokumentenanalysen, Literaturrecherchen, Handelsdaten von UN ComTrade sowie Experteninterviews analysiert werden. Die zweite Forschungsebene ist die Kreislaufwirtschaft in der Bauwirtschaft, die anhand von einer Literaturrecherche, Dokumentenanalysen, von der DGNB durchgeführten Interviews sowie Experteninterviews analysiert wird. Die dritte Forschungsebene sind die Grenzen der Kreislaufwirtschaft in der Bauwirtschaft, die anhand von Literaturrecherchen, Dokumentenanalysen, Interviews mit Sekundärquellen durch die DGNB sowie Experteninterviews analysiert werden.

Die zentralen Ergebnisse dieser Arbeit sind, dass der Sandabbau zur Abholzung von Wäldern, zum Verlust der biologischen Vielfalt und zu vielen anderen sozialen und ökologischen Problemen führt. Zirkuläre Aktivitäten können die Nachfrage nach Bausand verringern, allerdings gibt es einige Einschränkungen, wie z. B. fehlende Daten und kostenintensive Technologien. Bei den Upgrading Potentialen handelt es sich hauptsächlich um ökologisches Upgrading durch die Reduktion des Ressourcenverbrauchs und um wirtschaftliches Upgrading durch höherwertige Aufgaben wie das Recycling. Da diese Aufgaben jedoch hauptsächlich von großen Bauunternehmen im globalen Norden übernommen werden, lösen diese kein soziales oder wirtschaftliches Upgrading im globalen Süden aus.

Diese Studie leistet einen Beitrag zur Forschung im Sandsektor, zur Kreislaufwirtschaft im Bauwesen und zur Verknüpfung von Kreislaufwirtschaft und globalen Wertschöpfungsketten.

Schlagwörter: Kreislaufwirtschaft, Circular Economy, Bauwirtschaft, Sand, Sandabbau, Betonrecycling, Nachhaltiges Bauen, Modulares Bauen, Gebäudepässe, Degrowth

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1. Introduction

Sand is the fundamental resource for almost all sectors that are critical to human development. Buildings, infrastructure, electronic devices, glass, as well as innovative renewable energy technologies such as photovoltaic panels are made of sand (UNEP 2022). Experts refer to sand as the "currency of development" (Pereira 2020: 102) as sand is particularly high in demand in regions where development is considered a central aspect of national politics (Pereira 2020: 63). Despite its importance for modern human development, the extraction and usage of sand causes numerous social and environmental damages (UNEP 2022). Sand mining leads to environmental degradation, biodiversity loss, water pollution (Sakhtivel 2021: 28), land loss due to increased erosion rates and more (Lorenzo/Gomez 2019: 8) while poor global governance is allowing corruption and illegal organizations such as the sand mafia to rise and control large parts of mining activities, especially in the Global South (Lorenzo/Gomez 2019: 9). In addition to its strategic role in economic growth and human development, sand is essential for fisheries, livelihoods and biodiversity, and acts as a barrier against coastal erosions (Peduzzi et al. 2022).

The global demand for sand ranges between 40 and 50 billion tons per year making it the most extracted commodity in the world (Peduzzi et al. 2022). Yet, the whole extent of sand mining is not fully documented, due to the high level of illegal activities and low transparency within the sector (Da/Billon 2022: 2). Nevertheless, it is scientific consensus, that due to the enormous social and environmental damages through sand mining and the imminent sand shortage the consumption of sand must be reduced (Peduzzi et al. 2022).

The official sustainability report published by the United Nations Environment Program suggests circular economy as one of ten recommendations to reduce the demand for primary resources such as sand, reduce waste and reduce emissions in general (Peduzzi et al. 2022: 17). Therefore, I want to examine the chances and limitations of circular economy in the construction sand value chain.

While circular economy is becoming a fast growing economic and political agenda for international sustainable development (Ghiesellini et al. 2018; UNEP 2019; Peduzzi et al. 2022; Beiser 2018; Pereira 2020), there are still substantial knowledge and data gaps in terms of explicit applications of circular economy in global value chains as well as its limitations (Osobajo et al. 2020: 1). The concept of a circular economy model promises an endless economic cycle in which resources are reused again after they have been processed and consumed. This process aims to maintain the lifecycle for as long as possible. This should also enable the decoupling of global economic growth from the consumption of non-renewable resources (Suarez-Eiroa et al. 2019: 954). This master's thesis is intended to investigate to what extent the concept of the circular economy in the construction sector can contribute to making the construction sand value chain more sustainable.

The construction industry is responsible for more than 40% of all global emissions and a third of global waste and is the main consumer of many of the world's most extracted materials, including sand (Pereira 2020: 13ff.). A circular model could ensure that raw materials can be recycled and reused after consumption. This could reduce emissions and waste as well as the consumption of primary resources in general (Suarez-Eirao et al. 2019: 956). Above all, due to the economic, ecological, and social dimensions of sand mining, the importance of a circular economy concept in the construction sector is particularly relevant for international development studies (Suarez-Eirao et al. 2019: 955), while having several limitations that will be examined in this thesis. Because of its huge impacts on the environment and consuming more natural resources than any other industry, the construction sector can play a key role in achieving sustainable societies in the transition to a circular economy (Osobajo et al. 2020: 4).

The main research question for this master thesis therefore is:

To what extent can circular economy activities make the construction sand value chain more sustainable?

The research question will be answered with the following sub-questions:

1. Who are the key actors and locations in the construction sand value chain and what are the power relations?
2. What are the ecological and social problems of sand mining?
3. How does the construction sector understand circular economy and how is it currently implemented in the construction sand value chain?
4. What are the limitations of circular economy in the construction sand value chain?

The theoretical framework to address these questions consists of a global value chain approach and the theory of circular economy, as well as the circular supply chain concept, which will further be used to align theory and practice.

To gather empirical data, expert interviews are conducted, as well as a literature review, a document analysis, and an analysis of global trade data. This data is used to conceptualize the global sand sector, analyze social and ecological problems of sand mining and present circular activities implemented into the construction sand value chain. The research questions are answered on three research levels: First, the sand sector is analyzed through gathering literature and analyzing data and documents, as well as through empirical data. Second, circular activities in construction are analyzed and evaluated by literature and document analysis, as well as secondary interviews and expert interviews conducted in this research. Third, limitations of circular economy are analyzed using document and literature analyses, as well as secondary interviews and expert interviews.

The key findings of this thesis are that the excessive demand for construction sand due to the construction boom all over the world leads to intense numerous social and ecological damages, such as loss of biodiversity, coastal and beach erosions, deforestation, and environmental destruction, as well as unsecure and illegal work, poor mining conditions and corruption. Circular activities can help to reduce the demand for construction sand, mainly through activities, such as recycling, modular building, circular planning, processing demolition waste on site, as well as using soil excavation as building materials and more while having several limitations such as a lack of data, quality, and price issues as well as the need for high-tech and cost-intensive machines and infrastructure. Upgrading potentials remain mainly in the field of environmental upgrading through resource consumption, whereas economic upgrading and social upgrading potentials are missing, since the higher-value activities, such as recycling or processing demolition waste on site are mainly taken over by large construction companies from the Global North.

The thesis starts with chapter 2, which introduces the concepts of global value chains, circular economy, and circular supply chain. Chapter 3 provides an overview of the methods that were used to conduct this study. Chapter 4 explains the global sand business with its actors, geographical dimensions, governance as well as the social and ecological issues of sand mining. Chapter 5 provides an overview of how the construction industry understands circular economy, what circular activities are currently implemented into the construction sector and the limitations of circular economy in construction. Moreover, chapter 5 aligns theory with practice by providing a linkage of the two concepts of circular economy and global value chain and by mapping of the empirical findings of this study to the concept of circular supply chain. Chapter 6 concludes the thesis.

2. Theoretical Background

This chapter provides an overview of the theoretical background of the thesis. First, the theoretical concept of Global Value Chains is introduced, and second Circular Economy. Moreover, the concept of circular supply chains is presented as a first theoretical approach to link circular economy and global value chains.

2.1.Global Value Chains

Starting in the 1990's, interdisciplinary research fields have developed to analyze global economy in production networks and supply chains. Goods are the starting point of those analyses that continue to focus on the production of goods, analyzing different phases of production, like research and design, procurement of resources and supplies, as well as sales and marketing. The end of the chain is consumption and waste. The central question of this research field is who are the actors within this chain and what values are generated by which actor (Fischer/Reiner/Staritz: 2021b: 33).

Value chain research in general aims to analyze global industries and networks, with each approach having a different focus and perspective. Analyzing global value chains is a central part of development studies, since value chains play a key role in global networks, power asymmetries and inequalities. There are four different approaches on value chain research, which are presented later in this chapter. Global value chain analysis is also very relevant in studies on neocolonialism, where several scientists describe the tremendous power of multinational corporations as the latest stage of imperialism (Nkrumah 2016 [1965]; Frank 2016 [1966]; Ziai 2020).

The global value chain research has different approaches that were developed over the last decades. This research focuses on the Global Value Chain approach, but it is still important to outline the other approaches for a better understanding. I will use two main books to define global value chains: Gereffi on "Global Value Chains and Development: Redefining the Contours of 21st Century Capitalism" (2018) as well as Fischer, Reiner and Staritz "Global value chains and unequal development: Labor, Capital, Human and Nature" (2021a, b).

To understand the different perspectives on global value chain research one must outline the developments and dynamics that have led to today's economic framework which allows unequal development and unequal value appropriation.

The decades after World War II were dominated by modernization theorists such as Rostow, who were convinced that all economies go through five stages of economic development (Rostow 2016 [1960]) without regard to their initial standing in terms of industrialization or dependent economic ties. Modernization theories received a lot of critique, mainly for its Eurocentric perspective and the neglect of colonial histories (Gereffi 2018: 2). Those critiques were developed further and turned into the contrary development theory of the post-World War II era, dependency theories. Dependency theorists are highlighting historic exploitative structures in the context of colonialism that continue to have an impact today. This becomes apparent when looking at the increasing linkages and networks between core countries and its peripheries in a capitalist system. The asymmetric ties between centers and their peripheries are rather the reason for many of the problems of the Global South than being the solution. This can be observed in many examples from Latin America and Africa, where dependent economic structures have only led to underdevelopment instead of progress (Gereffi 2018: 3).

In the 1970’s and 1980’s dependency theories were further developed and were started to be linked into economic phenomena like value chains. The first approach of global value chain research is Commodity Chains (CC). Starting in the 1980’s Wallerstein and Hopkins introduced commodity chains as a network of production processes to manufacture one commodity. Their concept is focusing on geographical inequalities along the commodity chain, such as the uneven competition and the resulting limited ability to acquire value that was created along the supply chain. Therefore, according to Wallerstein and Hopkins, those commodity chains reproduce unequal development through a world system that is structured in centers, peripheries, and semi-peripheries (Hopkins/Wallerstein 1986: 159). Wallerstein’s world system theory provides a framework for global development based on commodity chains which began to spread in 16th century. With Europe in the center of this capitalistic framework, parts of the commodity chains were outsourced due to lower production costs, turning those areas into peripheries, that were disadvantaged in the value appropriation compared to the centers of the world system (Wallerstein 2008 [1988]: 171). The central question for this CC framework is therefore how CC reproduce and structure a hierarchical world system and focuses on center-periphery-relations (Fischer/Reiner/Staritz 2021b: 34).

In this period several development strategies have been implemented in specific areas of the Global South. One main strategy was import-substituting industrialization as a model of growth. This was implemented in Latin America, with Brazil and Mexico as strategic countries, Eastern Europe and other areas to support global trade. Further it was intended to help countries in the

Global South to enter the global market (Gereffi 2018: 11). In contrast to that, East Asian countries focused on an export-oriented industrialization, which led to emerging economies in South Korea and Taiwan (Gereffi 2018: 12ff.). This opens the question, why some of the countries were able to benefit from the development strategies while other countries did not and remained underdeveloped. One key message of studies that focused on this question is, that those comparisons might be oversimplified and much more complex to answer, due to historical patterns and geopolitical engagement of the countries (Gereffi 2018: 13).

Because of these complex questions about the impact of economic strategies and global trade, the CC framework was further developed (Gereffi 2018: 13) by Gereffi in the 1990's into the second approach Global Commodity Chains (GCC). Gereffi et al. (1994) defined GCC as a network of corporations, states and households that are connected through a commodity (Gereffi et al. 1994: 2). To elaborate the analysis of a commodity chain further, the authors developed four dimensions of a GCC: The input-output structure shows that value-adding activities are distributed across different areas of the chain and are connected in the manufacturing process of the commodity. The geographical dimension highlights the distribution of production networks. Another dimension is the structure of governance, which describes the power relations that control financial and human resources along the commodity chain. The fourth dimension is the institutional network of local, national and international regulations that frame and control the commodity chain (Fischer/Reiner/Staritz 2021b: 34). One central aspect of analyzing GCCs is the role of lead firms. According to Gereffi (2018) there are two different ways, lead firms can control their commodity chains: As far as companies navigate in producer-driven commodity chains, they are exercising their power through knowledge and technology in production. While central production steps remain within the lead firm, labor-intensive production steps are getting outsourced to suppliers. This applies in particular in capital intensive commodity chains, like the automotive or aviation sector (Gereffi 2018: 44ff.). However, lead firms in buyer-driven commodity chains control a global decentralized network of suppliers, typically located in the Global South (Gereffi 2018: 46), turning those lead firms into hollow corporations or "manufacturers without manufacturing" (Fischer/Reiner/Staritz 2021b: 35). Those lead firms are specialized in Sales, Marketing and Design, while not having any production factories. Hence, Gereffi refers to them as merchandisers instead of manufacturers, with their central task being the management of production and trade networks and assuring the integration into the commodity chain (Gereffi 2018: 47). Another important aspect of GCC research is economic upgrading, which symbolizes the adaptation of more complex activities that extract more value from the chain (Gibbon et al. 2008: 331).

The third and most important approach for this study is Global Value Chains (GVC). Global value chain research has developed to analyze global industries since this perspective was a central limitation of previous development research. From its inception it aimed to focus on power relations and inequalities, created by global commodity chains. According to Gereffi et al. (2005) there are five ways in which companies are set up and govern activities in their global value chain (Figure 1): First, market linkages, where activities are driven by price, second, modular linkages, where requirements are codified and passed on to competent suppliers that act according to the lead firm's standard. Third, relational linkages, where information and competencies are exchanged between the lead firm and suppliers, governed by reputation and trust. Fourth, captive linkages, where the dominant buyer gives a detailed instruction for their production to the less competent suppliers, thus the activities are governed by power of the buyer, and lastly fifth, hierarchy linkages, where activities within the same firm are governed by the management hierarchy (Gereffi et al. 2005: 83ff.). Ponte and Sturgeon (2014) add three variables, that moderate the five ways of governance of Gereffi et al. (2005) above. According to the authors the three variables are the complexity of information provided by the supplier to the buyer, the codification of this information, and the capabilities of the suppliers (Ponte/Sturgeon 2014: 203).

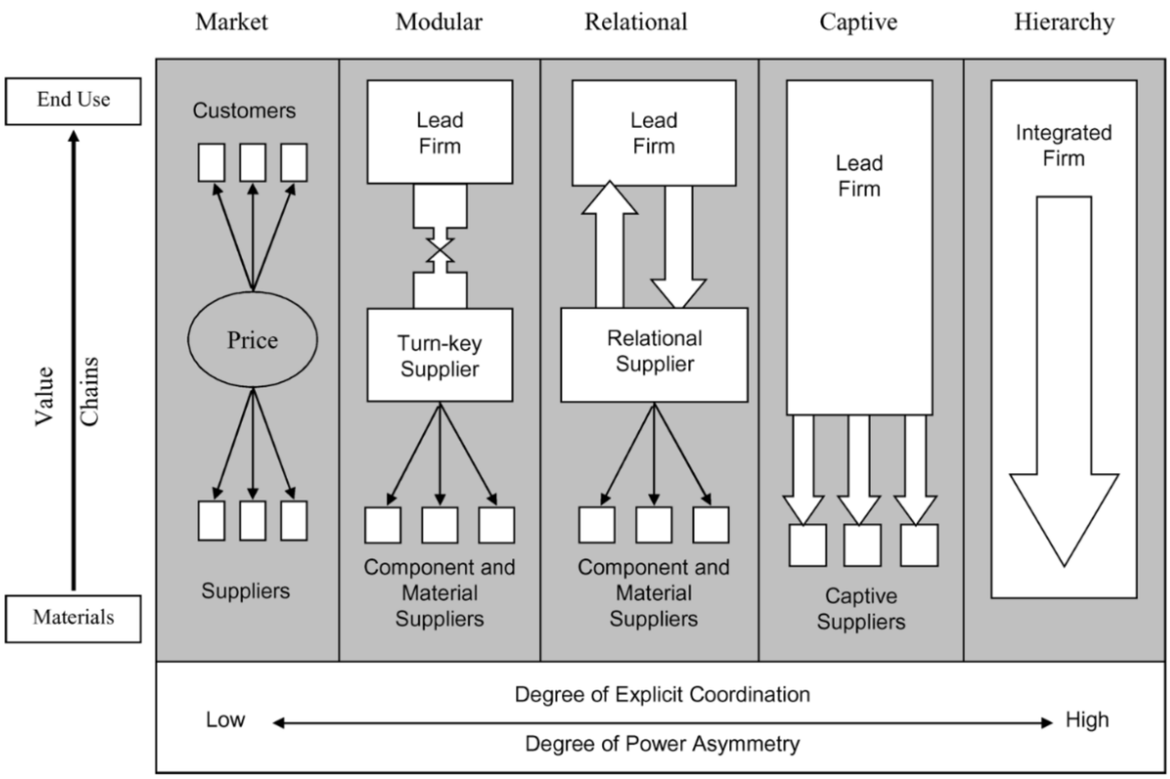

Figure 1. Five global value chain governance types (Gereffi et al. 2005: 89)

The fourth approach on analyzing value chains is Global Production Network (GPN). This approach tries to focus more on the institutional and social context of linkages within an international network. Hence, the whole chain of actors that contribute to shaping a global production are analyzed, such as governments on national levels, multinational organizations, international trade organizations as well as non-governmental organizations (Gereffi 2018: 230). An important step in the analysis are power relations between actors that are spread across multiple countries. NGOs have also engaged in research on lack of employment rights and poor working conditions in value chains which has been further used for campaigns and advocacy with international organizations and their suppliers (Gereffi 2018: 230).

Gereffi (2018) aims to integrate workers as a productive and social dimension into the challenging environment of GPNs in the Global South and highlights social and economic upgrading as a potential for both, workers and employers. Two perspectives to cover the different dimensions of labor are first, to see labor as a productive factor and second, to see labor as socially embedded. If labor is seen as a productive factor, productivity of labor and labor costs as well as labor markets are in the focus of the analysis. The main assumption of this perspective is, that a corporation needs “to produce at the lowest possible marginal cost to remain competitive” (Gereffi 2018: 231). Seeing labor as socially embedded however, means viewing employees and workers as a social individual beyond their role as a sole factor in production. This means, that individuals are human beings with needs and capabilities. An important aspect are national and international rights, which can have positive or negative impacts on their participation in GPNs. In addition to seeing GPNs as an environment of production, it must also be seen as a social protection network, which has a tremendous impact on the well-being of their workers (Gereffi 2018: 231).

One key perspective of value chain research is the potential for upgrading. Upgrading has been defined as a shift to higher value activities in production within the chain of production steps. This can involve an improved technology, higher knowledge and higher skilled work, as well as increased benefits or profits for individuals. As the GVC approach focuses mainly on labor-intensive manufacturing sectors, GPN approaches have widened their focus to include service and agricultural sectors, as well as tourism and outsourcing production (Gereffi 2018: 232). Due to the diversity of sectors, economic upgrading must be broken down into specific types of upgrading: Process upgrading means efficiency increases in production due to automation or other production changes that lead to higher productivity. Product upgrading involves a shift to a more advanced set of products with enhanced features, which are built through more skilled jobs. Functional upgrading appears when firms change their activities towards higher value-added tasks, which can be achieved either through vertical integration, which means taking over other stages of a production process rather than relying on external suppliers, or through specialization, which means substituting lower value-added tasks with other sets of activities to acquire more value within the supply chain. Chain upgrading occurs when firms are shifting towards new industries or markets through new manufacturing technologies or marketing channels (Gereffi 2018: 232ff.). Those types of economic upgrading have two dimensions, both capital and labor. The capital dimension refers to new technologies or advanced machineries, whereas the labor dimension refers to the development of skills and productivity of workers. Hence, labor is seen solely as a factor of production.

Social upgrading, however, implies improvements in the field of “rights and entitlements of workers as social actors” (Gereffi 2018: 233). According to Gereffi, access to better work, enhancement of working conditions, protection of workers and strengthening of rights improve the quality of workers’ employment. The International Labour Organization has published a Decent Work Agenda, which manifests standards and rights at work, as well as social protection. According to the agenda, work must be carried out “under conditions of freedom, equity, security, and human dignity” (Gereffi 2018: 233). Social upgrading consists of two components: measurable standards which are observable and quantifiable aspects like employment type, wages, working hours and social protection and enabling rights, which are less easily observable and quantified, such as non-discrimination, empowerment, freedom of association and the right to collective bargaining. Enabling rights is mainly related to workers being able to negotiate their working conditions and to speak up about misbehavior or other issues that may hinder the improvement of their well-being (Gereffi 2018: 234).

It is often implied, that economic upgrading automatically leads to social upgrading, through better working conditions and higher wages, however, there are numerous case studies that paint a different picture. One famous example is the Chinese Foxconn Factory, a supplier for global electronics brands, like Apple and Nokia. While the Chinese electronic production has accelerated dramatically, creating millions of jobs, the social working conditions were worsened. Excessive working hours, lack of adequate safety measures, unpaid overtime work and generally poor management practices have led to disastrous health states of workers, peaked in more than a dozen suicides in the first eight months of 2011 alone (Gereffi 2018: 234).

Given the fact, that social upgrading is also hard to measure and hence quantify, the links between economic upgrading and social upgrading are complex. There are implications that social upgrading may result from economic upgrading strategies, but it cannot be implicitly and generally assumed. The impact of economic upgrading on social upgrading can also differ between the different types of work that are performed within value chains and production networks. According to Gereffi, there are small-scale households and home-based work, low-skilled labor-intensive work, medium-skilled mixed production technologies work, high-skilled technology-intensive work and knowledge-intensive work (Gereffi 2018: 235ff.). Especially the first two categories of workers, small-scale households/home-based work and low-skilled labor-intensive work, face difficult social upgrading opportunities, since they are often unskilled and irregular workers, with weak employer attachment and hence lower measurable standards. Moreover, irregular workers are overly represented amongst women and migrants, where challenges such as discrimination or language barriers can further impede social upgrading (Gereffi 2018: 239).

Ponte (2022) further describes that "economic upgrading is a necessary but not sufficient condition for social upgrading" (Ponte 2022: 8) and may come with hidden costs such as poorer working conditions for suppliers (Ponte 2022: 7ff.).

Since initial contributions seem to focus on economic upgrading, there was further research development into social and environmental upgrading. Environmental upgrading is defined as “the process by which economic actors move towards a production system that avoids or reduces environmental damage from their products, processes or managerial systems” (De Marchi et al. 2019: 312) and should lead to production systems and networks in which emissions, biodiversity losses and material exploitation are reduced. That can be achieved either through first, process improvements, created through reorganized production systems or newly integrated technologies, second, product improvements, achieved through the usage of recycled materials or third, organizational improvements, which means enhancing the sustainable operations within an organization through certifications and standards (De Marchi et al. 2019: 312ff.).

Drivers for environmental upgrading can either be external actors, such as customers, national or international policies which the organization need to follow, or internal actors, such as lead firms or suppliers, who try to increase the sustainable awareness across the whole supply chain and hence set standards to follow. This often leads to increased pressure on suppliers as lead firms decide to enhance their sustainability across the value chain. The more power the lead firm holds, the more pressure it can pass on to its suppliers, to fulfill sustainable standards and practices (De Marchi 2019: 319). However, environmental upgrading may be difficult to measure. While process and product improvements can be easily measured, organizational improvements may be only indirectly measurable. It is also important to analyze environmental upgrading in relation to social and economic upgrading, since it cannot be understood in isolation from other upgrading types (De Marchi 2019: 320).

Krishnan et al. (2023) also highlight that standards, demanded and required by lead firms, often come with a knowledge transfer in a top-down manner, that further increases dependencies and power relations (Krishnan et al. 2023: 32). This particularly counts for the mining sector and its activities. The authors showed furthermore that the value which was created through environmental upgrading is mainly acquired by lead firms from the Global North, increasing their reputation in terms of sustainability and opening new sustainable markets for them, while small-scale miners often experience environmental downgrading (Krishnan et al. 2023: 46).

Ponte (2022) promotes three ways of upgrading: First, improving products or processes, second, changing or adding functions to the core business to improve economic, social or environmental conditions, and third, transferring capabilities and opportunities between chains and using resources, activities, services in other sectors too. A case study of the South African wine value chain has shown that sustainability and environmental upgrading has often been opportunistically used by lead firms to promote their marketing and reputational enhancement, rather than improving the situation of the farmers and wine producers. The hidden costs of environmental and economic upgrading have been carried mainly by the grape farmers and wine producers at the end of the wine value chain (Ponte 2022: 14ff.). The same results were found in a case study of the East African coffee value chain. Since sustainability features have become a central and public demand of consumers, buyers and markets lead firm continue to outsource those costs to the farmers and small-scale miners of their used resources. According to Ponte, most of the recent research on East African coffee value chain show, that sustainability certifications focused on environmental upgrading and improvements have not translated in raises of farmer’s income or an improvement of their livelihoods (Ponte 2022: 18).

There are some indications, that this situation improves, if the farmers are included into the process of environmental improving and upgrading. But in general, sustainable certifications which are pushing for economic and environmental upgrading usually end up in putting more pressure on farmers through increasing the intensification of production on their existing land which again ends in damaging the local biodiversity (Ponte 2022: 19).

Sustainability continues to play an important role in GVC studies. According to Hofstetter et al. (2021), large manufacturers and lead firms from the Global North have a central responsibility in supporting sustainability issues within GVCs. The authors also build the bridge between GVC and circular economy by stating that circular economy has the potential and ability to shift power relations between actors within GVCs and to influence the governance of whole industries (Hofstetter et al. 2021: 23).

2.2.Circular Economy

According to sustainability experts, circular economy is a comparatively new paradigm to overcome the dissent between economic and environmental issues (Pomponi/Moncaster 2017: 710). There was an increased awareness about sustainable economic practices from an academic perspective during the 1970’s and 1980’s, thinking about a more responsible consumption of resources (Pomponi/Moncaster 2017: 713).

Evolving in the 1970’s based on the idea of reducing the consumption of resources for industrial production, circular economy was introduced as a new economic paradigm to consume natural resources in a more sustainable way. However, the multidisciplinary nature of circular economy and its continuous development makes it almost impossible to define the concept of circular economy in a simple way (Tushar et al. 2022: 2ff.). Moreover, it is still progressing and evolving, while being criticized by social and environmental NGOs and activists in particular.

In 1989, Frosch and Gallopoulos published their article “Strategies for Manufacturing”, calling for a new economic paradigm to move away from linear economic processes towards an integrated ecosystem that enables the circularity of resources across all sectors mainly to avoid waste and pollution (Frosch/Gallopoulos 1989: 146). Their concept of using one industry’s waste as raw materials for another industry was further interpreted into the assumption, that the planning phase of products plays a key role in enabling circular processes of resources (Pomponi/Moncaster 2017: 713). A similar string of research evolved with the cradle-to-cradle concept of Braungart et al. (2007), where the authors developed a design framework based on circular resource loops. Those concepts were later adapted by the Ellen MacArthur Foundation who turned the ideas of circular economy into the mainstream concept we see in today’s research later in 2013. One year later, the concept of circular economy gained further popularity, when the European Union published its report “Towards a Circular Economy: A Zero Waste Program for Europe” in 2014.

In general, circular economy concepts promise to keep resources and products in a closed loop in order to safe resources and to maintain economic growth with regard to planetary boundaries. Among others, I have used a meta-research by Suarez-Eirao et al. (2019) to define circular economy in a general manner, since many wide-ranging studies and definitions were analyzed and combined into one comprehensive definition. The authors define circular economy as a regenerative production and consumption system that aims to keep the extraction of resources, the amount of waste produced and emissions within the planetary boundaries and to preserve the value of a resource for as long as possible (Suarez-Eirao et al. 2019: 958).

Circular economy has often been promoted as a solution for sustainable development and economic growth to tackle environmental challenges and to conserve natural resources (UNEP 2019; UNEP 2022; Pereira 2020; Beiser 2018). Since the circular model is that popular in economic research, as well as being mentioned in the work of influential institutions such as the United Nations frequently as a solution to the sand crisis, this research aims to examine the concrete linkages between the circular economy and the global value chain of construction sand.

In terms of circular economy, the Journal of Cleaner Production is the most cited journal in this thesis, followed by Sustainability and Resources, Conservation & Recycling.

As already outlined, because of its inter- and multidisciplinary nature, there is not one correct definition of circular economy (Norouzi et al. 2021: 2). Therefore, the definition of circular economy will be further discussed by using the following table, which provides definitions from a broad literature:

Table 1. Definitions of circular economy (sorted by year of publication).

Definition of Circular Economy	**References**
"The circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption. It enables key policy objectives such as generating economic growth, creating jobs, and reducing environmental impacts, including carbon emissions"	Ellen MacArthur Foundation (2013)
"Circular Economy systems keep the added value in products for as long as possible and eliminates waste. They keep resources within the economy when a product has reached the end of its life, so that they can be productively used again and again and hence create further value"	European Commission (2014)
"Model of production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution)"	Sauvé et al. (2016)
"We define the Circular Economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling"	Geissdoerfer et al. (2017)
"The Circular Economy is an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and	Murray et al. (2017)

managed, as both process and output, to maximize ecosystem functioning and human well-being”	
“A circular economy describes an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operational at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations”	Kirchherr et al. (2017)
“Circular Economy is a sustainable development initiative with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system. Circular economy promotes high value material cycles alongside more traditional recycling and develops systems approaches to the cooperation of producers, consumers and other societal actors in sustainable development work”	Korhonen et al. (2018)
“Circular economy is a regenerative production- consumption system that aims to maintain extraction rates of resources and generation rates of wastes and emissions under suitable values for planetary boundaries, through closing the system, reducing its size and maintaining the resource's value as long as possible within the system, mainly leaning on design and education, and with capacity to be implemented at any scale.”	Suárez-Eiroa et al. (2019)

Suarez-Eirao et al. (2019) define the paradigm of the circular economy based on three strategies: Material inputs and waste outputs should be minimized, the value of raw materials should be maintained as long as possible and products that have reached the end of their life cycle should be returned to be integrated into the existing cycle (Suarez-Eirao et al. 2019: 953).

The most widely used circular model in economics was presented by the Ellen Macarthur Foundation in its publication “Towards A Circular Economy” (2013). Benachio et al. (2020) analyze a broad range of circular economy studies in the construction sector and claim that the most cited definition of circular economy was the one by the Ellen Macarthur Foundation (Benachio et al. 2020: 4). Their definition highlights key activities within the circular economy concept: reuse, remanufacture, reduce and recycling. According to the Ellen Macarthur Foundation, products and materials at the end of their lifecycle should either be reused by another consumer (reuse) or parts of the product that are still working should be further processed in another product (remanufacture). Another option is to process materials to a state in which they can be used as secondary materials and can re-enter the production cycle (recycling) (Ellen Mac Arthur Foundation 2013: 25). Ghisellini et al. (2018) and others (Hopkinson et al. 2019; Stahel 2016; Ghisellini/Ulgiati 2019) claim that to reach a sustainable future the construction industry must also focus on reducing and reusing resources, since it has a strong focus on recycling activities (Ghisellini et al. 2018).

Furthermore, circular economy activities aim to decouple economic growth from the extraction of finite resources. To achieve this, the extraction rate of resources “has to be lower than the regeneration rate of those resources” (Suarez-Eirao et al. 2019: 956), as it is described in the Planetary Boundary Framework by Rockström et al. (2009). Therefore, the consumption of non-renewable resources should be eliminated, or non-renewable resources should be consumed as slow as possible (Suarez-Eirao et al. 2019: 956).

It is worth noting, that the concept of circular economy ignores the social dimension of sustainability, which is a core perspective of a truly sustainable development. Hence, circular economy cannot provide a holistically sustainable economy but should rather be seen as one of many approaches to achieve sustainable development (Al-Sinan/Bubshait 2022: 4).

The following table summarizes the scientific paper that present circular economy as one of the main solutions to the sand crisis to identify the research perspective on circular economy:

Table 2. Articles that present circular economy as one of the main solutions to solve the sand crisis.

Authors	Journal	Focus
Pereira (2020)	Sand Stories (Book)	Solving the global sand crisis and analyzing the sand sector
Gronwald et al. (2021)	Bundesanstalt für Geowissenschaften und Rohstoffe	Analysis of sand value chain and practical implications
Peduzzi et al. (2022)	UNEP Report	Solving the global sand crisis
Da/Billon (2022)	The Extractives Industry & Society	Sand mining and unregulated supply chains
Morley et al. (2022)	Resources	Analyzing sand flows
Holm et al. (2023)	Forum on Responsible Mineral Supply Chains	Explore responsible sourcing of sand and aggregates

As the construction industry consumes huge amounts of natural resources, varying between 30% and 40% of all natural resources consumed worldwide and is the main producer of global waste, circular economy activities in construction have been researched and conceptualized since decades (Benachio et al. 2020: 2). This underlines the importance and relevance of sustainable solutions for the construction sector.

A meta-research by Suarez-Eirao et al (2019) has analyzed the link between circular economy and sustainable development. The authors conclude that circular economy can be a tool to ensure sustainable development, but the exact context represents a research gap (Suarez-Eirao 2019: 953). While mainstream research looks at circular economy primarily from economic and environmental angles, there is some research (Murray et al. 2017; Kirchherr et al. 2017), that also includes the social dimension of circular economy.

Circular economy brings sustainable benefits to every sector, as it would theoretically mean a more sustainable consumption of resources. However, in terms of positive impacts, the construction sector outweighs any other sector by far, when it comes to implementing circular solutions (Pereira 2020: 159).

Besides political suggestions like the “Communication from The Commission to The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions” (2014) from the European Commission, there are little to no legally binding regulations regarding circular economy.

The EU Taxonomy Law acknowledges the importance of moving towards a circular economy and includes it as one of the environmental objectives within its framework. This demonstrates the recognition of the benefits associated with reducing waste, improving resource efficiency, and minimizing the ecological impact of economic activities. Within the taxonomy framework, the circular economy objective strives to ensure that economic activities adhere to sustainable patterns of production and consumption. This involves optimizing the use resource, minimizing the generation of waste, and promoting the reuse, recycling, and recovery of materials (Bär/Schrems 2021).

To align with the circular economy objective as defined by the EU Taxonomy Regulation, economic activities must meet specific criteria and thresholds. These criteria evaluate factors such as the utilization of recycled materials, the reduction of waste generation, the design of products for long-lasting use and repairability, and the endorsement of circular business models but have no legally binding requirements or sanctions in case of non-fulfillment.

By incorporating the circular economy objective into the taxonomy framework, the EU Taxonomy Law encourages businesses and investors to adopt practices that contribute to a more sustainable and resource-efficient economy. It serves as a clear signal for economic activities prioritizing circularity, enabling informed investment decisions and facilitating the transition to a circular economy across diverse sectors, but still lacks specific legal requirements with legal enforcements and compensations (Troidl 2023).

Corvellec et al. (2021), criticize that the concept of circular economy is so complex and diffuse that it is almost impossible to measure its specific impact. Since the concept currently includes everything, from recycling materials and renting and replacing products, to sharing economy applications and technologies it is very difficult to define circular activities in connection to its measurable impacts and solutions to tackle sustainability issues. Some experts claim that circular activities only delay negative environmental and social impacts of linear business models instead of eliminating them. One central critique is that circular economy tends to focus on reducing resource consumption rather than addressing social inequalities and sustainable development. To sum up, the authors criticize the circular economy concept for its promise, that every actor will benefit from its implementation, focusing on efficiency increases and synergies of a win-win solution for all, instead of addressing the need of compromises and limitations of growth. According to the authors, consumption is not unproblematic, just because materials get recycled (Corvellec et al. 2021: 422ff.).

A report of the European Commission explains that circular economy can invent new labor opportunities, especially in the repair and recycle part of circular business models (European Commission 2019). Since the social aspects of circular economy are complex to measure, they are often left out in the mainstream research from a business perspective. However, Old et al. (2022) analyze the social areas, circular economy could improve and come up with four key areas: Labor practices and decent work, human rights, society and product responsibility. The first area, labor practices and decent work address aspects such as employment type, occupational health and safety, training and education, diversity and equal opportunity or the fair distribution of income. Human rights aspects are child labor, freedom of association and collection bargaining or forced or compulsory labor. The third area, society, impacts social aspects such as social inclusion, participation and local democracy, anti-corruption, compliance, cultural traditions or local communities. The fourth area, product responsibility address social aspects such as customer health and safety, customer privacy and anti-competitive behavior (Old et al. 2022: 6).

In conclusion, circular economy is a concept that aims to keep resources in a closed loop for as long as possible, and also emphasizes cooperation across different sectors. However, the concept is mainly introduced from an economic perspective and lacks a social focus. It claims to aim for environmental sustainability, while still focusing on economic growth and profit as well as efficiency that will lead to more resource consumption. Circular economy remains a controversial concept, that is criticized by many researchers while also acknowledging that there is a lack of alternatives for sustainable resource consumption (I. 2: 3).

2.3.Circular Supply Chain

Since transforming business models towards a circular economy implies a change of the whole value chain, the two concepts of Circular Economy and Global Value Chains are deeply interconnected (Lahti et al. 2018: 4). There is already a long list of researchers and studies focusing on circular supply chain management as a linkage between global value chains and circular economy (Montag et al. 2021; Shaharudin et al. 2021; De Angelis et al. 2018; Chhimwal et al. 2021; Orji/Ojadi 2023; Batista et al. 2018; Batista et al. 2019; Saroha et al. 2020; Farooque et al. 2019).

One string of circular economy research focuses on the business logic of circular supply chains, while the second string of research is more interested in development opportunities through creating circular supply chains. The following chapter describes one of the business approaches to link circular economy and global value chains: Circular supply chains.

Starting in 2010, the research has mainly focused on making supply chains more sustainable by creating material flows back to productive systems to reduce waste. Designing supply chains and production activities in a way, that enable the creation of closed loops through recycling, reusing, remanufacturing and repairing materials (Batista et al. 2018: 448). This can be seen as a first linkage to connect circular economy with global value chains, however, there is little to no literature on social aspects or power relations that will be changed through the implementation of circular supply chains. Most research focuses on the economic and ecological dimension of circular economy, which means, reducing waste and material consumption due to scarcities or demolition costs.

The linear economic model must be replaced by a more sustainable version in the future due to its inefficient use of resources and the exponentially increasing production waste. While a closed-loop supply chain tries to reuse resources, mainly in the form of packaging and products that have reached the end of the product life cycle, within the framework of the original supply chain (hence closed loop), the goal of the circular supply chain is to create a new, circular economic paradigm through cooperation within and outside of their own industry and to switch to a production method with zero waste, thus no remaining waste at all (Farooque et al. 2019: 9ff).

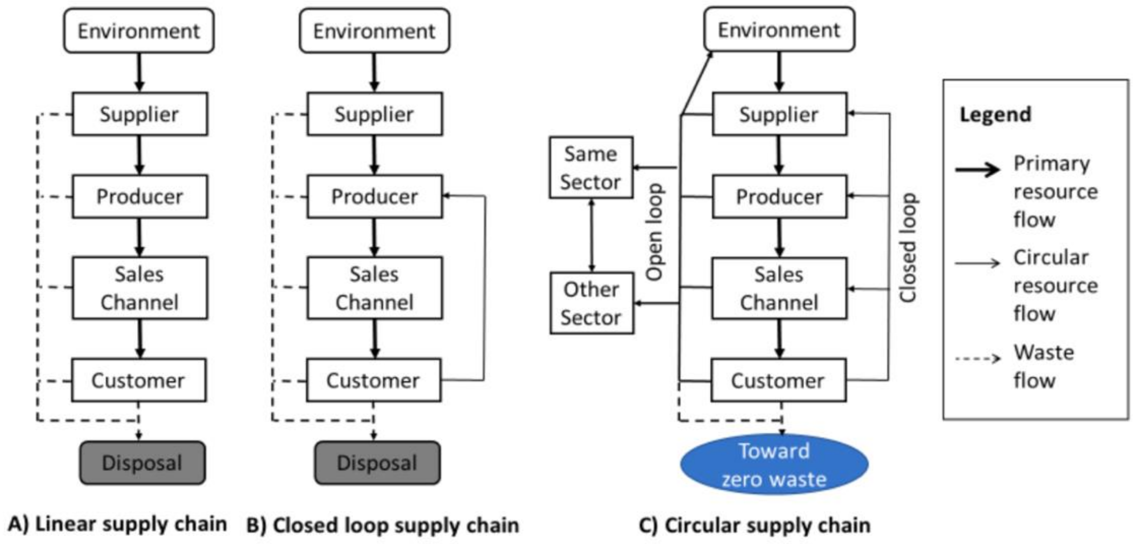

Figure 2. Linear supply chain, closed loop supply chain and circular supply chain (Farooque et al., 2019: 10)

Farooque et al. (2019) describe a circular supply chain as the integration of circular thinking into classic supply chain management, "by recovering value from waste by collaborating with other organizations within the industrial sector" (Farooque et al. 2019: 10). The integration does not only take place within the supply chain, but also includes the natural ecosystems that are affected by the supply chain. Central is the zero-waste vision, which is to be established through innovative business models along the entire supply chain (Farooque et al. 2019: 8ff.).

Farooque et al. (2019) classify circular supply chain as a growing field of research, which, however, is of very high importance, as it has critical potential for essential changes in the economy in order to come closer to sustainable production methods. In addition, the authors see a large research gap in the circular supply chain research field that must be filled in the future in order to be able to analyze and implement the full potential of the economic paradigm (Farooque et al. 2019: 41ff).

Circular supply chain management is described as the integration of circular thinking into classic supply chain management. A circular approach leads to a reduction in the need for raw materials and primary resources in the supply chain. In order to transform a classic supply chain into a circular mindset, the structure and conception of a supply chain must be changed from a linear model to a circular concept. The authors see the three main opportunities in the reduction of energy requirements, lower emissions and increasing productivity within the supply chain (Amiri et al. 2022: 3ff).

Schroeder et al. (2018) mention that circular supply chains offer a huge opportunity in terms of production, consumption and resource management, but since lower income countries appear to act more circular than they high-income counterparts in the Global North, the question remains if circular economy can also act as a development opportunity to tackle power structures and dependencies between the Global South and the Global North (Schroeder et al. 2018: 77). Since most of the value and power are already appropriated by high-income countries in the Global North, scientists agree that it is likely that those countries will continue to capture the relevant resources they need to persevere their power. One of the many open questions of circular economy and circular supply chains therefore is, if they can reduce inequalities and lead to a fairer distribution of resources and value creation and appropriation (Schroeder et al. 2018: 77ff.).

A literature review by Lindgreen, Salomone and Reyes (2020) describes that the social dimension of sustainability remains severely underrepresented in the implementation of circular economy concepts. Less than a third of all researched articles on the topic of circular supply chains address social components of sustainability at all (Lindgreen et al. 2020: 13ff.). Hence, power relations, working conditions or other socioeconomic parameters and perspectives are not in the focus of the circular supply chain research. This can also be taken as an indicator, that major changes in power dynamics and asymmetries will not take place through circular supply chain models as defined today.

Figure 3 presents a theoretical approach to link the concepts of circular economy and circular supply chain presented by Farooque et al. (2019) in figure 2 and global value chain of Da and Billon (2022). A key objective of this thesis is the linkage between the two concepts of circular economy and global value chain, hence this concept shown in figure 3 is working as a baseline to connect the concepts and provide a new framework for future research.

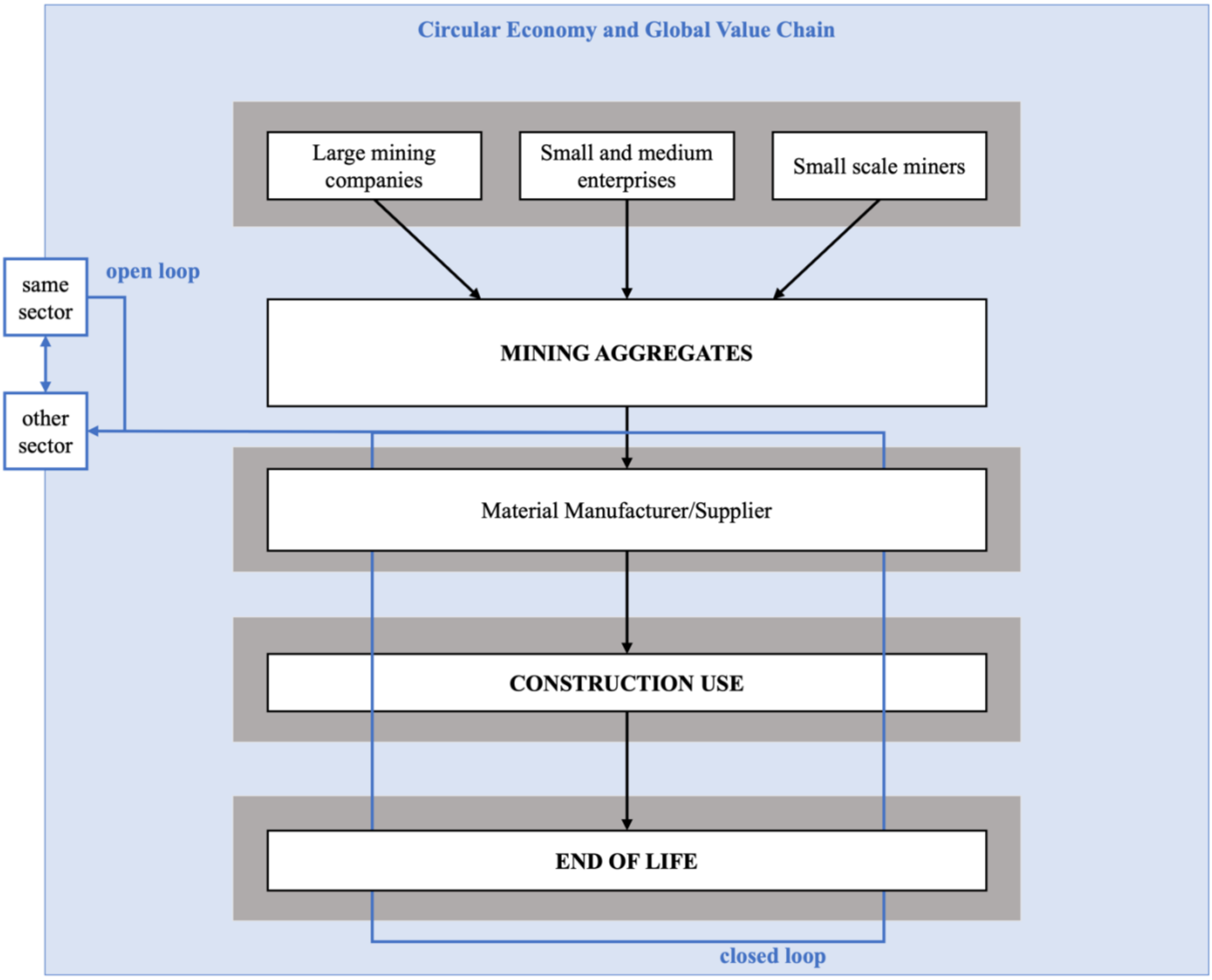

Figure 3. Theoretical concept to link circular economy and global value chain. Adapted from Farooque et al. (2019) and Da/Billon (2022) (A.M.)

This concept is later used to analyze the empirical results of this thesis and to answer the main research question (*To what extent can circular economy make the construction sand value chain more sustainable?).* After presenting the circular activities implemented in construction in chapter 5.3 (Circular Activities in Construction), those activities are then mapped into the concept to show the linkages between the circular economy and the global value chain of construction sand in chapter 5.5 (Linking Circular Economy and Global Value Chain) and to elaborate the developmental perspective on circular supply chains.

2.4.Synopsis

To draw a synopsis of the theory I took into consideration for this thesis, I will summarize the context of the theories I am using.

The theory of Global Value Chains is used to get an understanding of how global value chains work and how they can be analyzed. The main part of this thesis is the analysis of circular economy with its definitions and limitations, as well as the linkage between circular economy and global value chains. The theoretical understanding of global value chains is the baseline for the later introduced circular supply chain. The concept of circular economy is used to understand circular activities, that industries like the construction sector implement to extend product and material lifecycles.

I am using the theory of global value chains and its concepts of social and environmental upgrading, power relations and governance since this perspective is missing in circular economy and circular supply chain concepts. Diving into the actors, geographical locations, governance structures, as well as input-output structures allows a deeper understanding of value chains and their power relations, which sustainable initiatives aim to change. The global value chain perspective therefore needs to be part of analyzing the construction sand value chain and the potential of circular economy in construction in order to recognize those power relations and governance structures. Therefore, I am using this perspective to add onto the circular economy research and circular supply chain approach.

One important theoretical part is social and environmental upgrading, introduced by Ponte (2022). Circular economy could lead to the creation of new income streams in the recycling business and the usage of so called "waste". It is still to evaluate, how low-income countries can get access to those resources and generate income streams from it (Albaladejo/Mirazo 2023). Although economic upgrading often overlaps with social and environmental upgrading, this is barely the case in the construction sand value chain, as most of the circular activities are carried out by large construction companies from the Global North who will continue to capture most of the value created along the value chain.

This thesis shows that there are several upgrading opportunities along the construction sand value chain through circular activities in construction (chapter 5.3). The construction industry mainly aims at reducing primary resources such as construction sand through circular activities which can be clearly seen as environmental upgrading. However, the lack of initiatives aiming at improving mining conditions shows that social upgrading is currently not in the focus of circular economy in construction. This will be further outlined in chapter 5.6 (Synopsis of the Results) and chapter 6 (Conclusion).

3. Methodology

This research project was conducted using qualitative research methods, to be specific semi-structured interviews alongside with literature and document analyses. Moreover, a field trip was conducted to gain knowledge about concrete recycling and to observe the process and machine chains of recycling aggregates that will later be used as secondary aggregates to replace construction sand.

To structure the empirical results of the thesis, I am answering the research questions on three levels: First, explaining the sand sector with its actors, governance, inputs and outputs as well as social and ecological problems within the global value chain. Second, examining circular economy activities within the construction sector and focus on the activities that are currently implemented. And third, analyzing the limitations of circular economy activities in the construction sand value chain.

Based on the book "Handbook of Global Value Chains" by Ponte et al. (2019) the value chain of construction sand is conceptualized. This is done through Global Value Chain Mapping: Identifying key companies, products, activities, stakeholders and geographic locations that are involved in the production and processing of a good or service from conception to production and to the final consumer. This is essential to understand where, how and by whom economic, social and environmental value is created (Ponte et al. 2019: 30).

After mapping the global value chain of sand, semi structured interviews were conducted. Amongst the interview partners were experts from the construction sector, e.g. "Wirtschaftskammer Österreich", "Concular", "Baukarrussell", "Fraunhofer Institut", "TU Berlin", "PORR" and "Österreichischer Verband für Baustoffrecycling" and also initiatives on sand, that are working in the field of sustainable sand mining, e.g. "Stockholm Resilience Center", "Global Sand Observatory" and "Sand Stories". In addition to the expert interviews, I also took a tour to the recycling factory in Himberg, Vienna to understand the recycling technologies and processes.

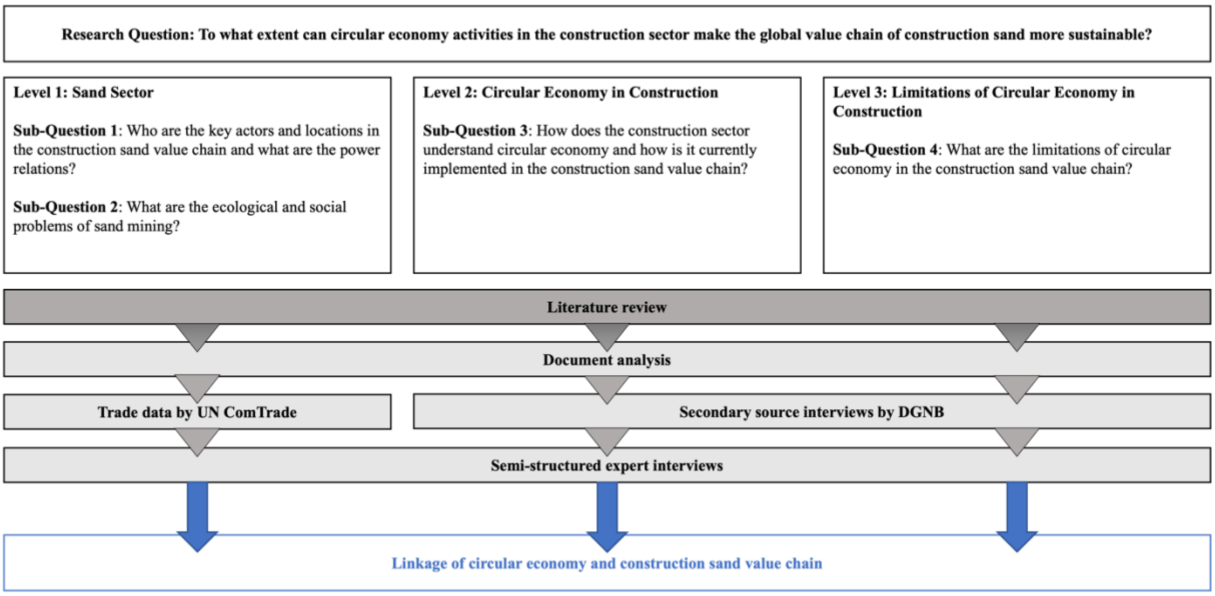

Figure 4. Research questions and methods used (A.M.)

Figure 4 sums up the (sub)questions and used methods to answer the main research question of this study (*To what extent can circular economy activities in the construction sector make the global value chain of construction sand more sustainable?*). The answers to question 1 (*Who are the key actors and locations in the construction sand value chain and what are the power relations?)* and question 2 (*What are the ecological and social problems of sand mining?)* allow an understanding of the sand sector, which displays the first level of research. Those two questions are answered through a document and literature analysis of relevant studies that have already been conducted on the sand sector (Jouffray et al. 2023; Beiser 2019; Perreira 2020; UNEP 2019; Da/Billon 2022; Gavriletea 2017; Tasantab 2021; Morley et al. 2022; Peduzzi et al. 2022; Sakhtivel 2021; Lamb et al. 2019, Filho et al. 2021), as well as qualitative interviews with experts on the sand sector. In addition to that, UN Comtrade data bases as well as Statista.com data enable a view on global sand data to draw a picture of global value chains of construction sand. Due to the lack of valid data in the construction sector, the scientific research that has been done in this field is extremely important to answer the first and second sub-questions of this thesis. Of particular importance is the newly published report on ocean sand by Jouffray et al. (2023), since it is a pioneering summary of actors, activities, governance and environmental issues of the ocean sand sector. Moreover, the expert interviews provide valuable insights to power relations, social and ecological problems, as well as the main actors in the construction sand value chain.

The second level of research implies circular economy activities in the construction sector. For this, the third question (*How does the construction sector understand circular economy and how is it currently implemented in the construction sand value chain?)* is answered through an extensive literature analysis (Benachio et al. 2020; Al-Sinan/Bubshait 2022; DGNB 2023; Jones/Comfort 2018; Wijewickrama et al. 2021; Ma et al. 2020; Huang et al. 2018; Lockrey et al. 2016; Osobajo et al. 2020), as well as expert interviews that try to provide an overview of how relevant actors of the construction sector percept circular economy at the moment. The answer of the third question is particularly useful to understand circular economy in the context of construction sand, which represents the second level of analysis of this study.

The third level of research covers the limitations of circular economy in the construction sand value chain. To collect this information, semi structured expert interviews were conducted alongside an extensive literature review and document analysis to answer question 4 (*What are the limitations of circular economy in the construction sand value chain?)*.

The empirical results from research questions 3 and 4 are used to map the circular activities into the value chain of construction sand. The answers to the first, second and third level of research allow and enable a linkage between the two concepts of circular economy and global value chain in the context of construction sand, which highlights the main findings of this study. This linkage between the two concepts is made by referring back to the theoretical concept of circular supply chains, which was presented in chapter 2.3 (Circular Supply Chain). The circular construction activities are mapped into the concept and therefore explain to what extent the circular activities can make the global value chain of construction sand more sustainable.

3.1.Data

Geographical dimensions are analyzed using quantitative data analysis of global trade data. The United Nations Comtrade database provides detailed annual and monthly global trade statistics by commodity, product or others. The commodity code for sand, gravel and other commodities that are used for concrete production is 2517. Due to the low governance and transparency in the global sand trade, the databases for sand are poor. This will be described in more detail in the limitations of my methodologies at the end of the chapter 3 (Methodology). To recognize the key actors in the construction sand value chain, as well as social and ecological problems of sand mining, I analyze other research and studies, that tried to map the value chain of sand (Jouffray et al. 2023; Beiser 2018; Perreira 2020; UNEP 2019; Da/Billon 2022; Gavriletea 2017; Tasantab 2021; Morley et al. 2022; Peduzzi et al. 2022; Sakhtivel 2021; Lamb et al. 2019; Filho et al. 2021).

3.2.Documents

The following table shows the documents and reports used to answer the research questions mentioned above. Besides using other studies and papers in a comprehensive literature review, the listed documents below were analyzed in a more detailed manner, using the deductive categories described in figure 5 to answer the research questions of this thesis. The focus areas of the documents are circular economy and its limitations, as well as the sand sector and its actors, social and ecological problems and power relations.

Table 3. Documents and reports analyzed in this thesis.

Report	Organization	Authors
Towards A Circular Economy (2013)	Ellen Mac Arthur Foundation	-
Towards a circular economy: A zero waste programme for Europe (2014)	European Commission	-
Sand and sustainability: finding new solutions for environmental governance of global sand resources (2019)	UNEP-Grid Geneva	Peduzzi et al.
Mapping Global Sand. Extraction, Research and Policy Options (2022)	-	Katz-Levigne, Pandey & Suykens
Sand and sustainability: 10 strategic recommendations to avert a crisis (2022)	United Nations Environment Programme, UNEP-Grid Geneva	Peduzzi et al.
Ocean Sand: Putting Sand on the Ocean Sustainability Agenda (2023)	Ocean Risk and Resilience Action Alliance (ORRAA)	Jouffray et al.

3.3.Interviews

A total of 14 experts were interviewed for the sample of this research. The experts interviewed can be seen as a diverse sample covering knowledge in both, circular economy, and the construction sand value chain. While there are several limitations that will be elaborated later in this chapter, the sample will be valid to answer the main research question (*To what extent can circular economy make the construction sand value chain more sustainable?)*

All experts agreed on sharing their name and organization in this thesis.

There are three types of expertise considered for this study: (1) Sand sector experts and sand mining researchers from relevant organizations such as Stockholm Resilience Centre, Sand Stories, Global Sand Observatory (I. 1; I. 2; I. 6; I. 10), (2) recycling and sustainable construction experts (I.3; I. 4; I. 5; I. 7; I. 8) and (3) circular economy actors in construction (I. 9; I. 11; I. 12; I. 13; I. 14).

Table 4 shows the expert, the organization they are working for and their area of expertise.

Table 4. Sand sector experts and circular economy in construction experts.

#	Name	Organization	Type of Actor
1	Jean Baptiste Jouffray	Stockholm Resilience Centre, scientific organization in corporation with the University of Stockholm focusing on research on natural resources and extraction	NGO
2	Kiran Pereira	Sand Stories, organization focusing on spreading awareness about the global sand business	NGO
3	Tomas Kasper	Austrian Building Materials Recycling Organization (Director), PORR AG (Head of Recycling Department), one of the largest construction companies in Austria and Europe and a very important actor in recycling building materials	Industry
4	Thomas Romm	Baukarussell (Founder), working on sustainable building models for over 20 years and successfully implemented most of the	Industry

		prestigious sustainable construction projects in Vienna, that were used as examples in this study	
5	Volker Thome	Fraunhofer Institut (Head of Department “Inorganic Materials and Recycling”), focusing on circular economy activities in construction and leads projects in the field of construction sand and research on new technologies in the field of concrete recycling	Research
6	Pascal Peduzzi	UNEP-GRID/Global Sand Observatory (Director), official organization of the United Nations to tackle the global sand crisis. Peduzzi was one of the first researchers to raise awareness for the sand topic in his publication “Sand, rarer than one thinks” (2014)	NGO
7	Kathrin Kippert	TU Berlin, focusing on research in the field of circular economy and works in European projects on sustainable usage of raw materials	Research
8	Antonio Rimoldi	Federation of the European Precast Concrete Sector, focusing on the optimization of concrete production	Industry
9	Luise von Zimmermann	Concular, German startup who tries to use all building materials that are deconstructed in new buildings	Industry
10	Andreas Pfeiler	Wirtschaftskammer Österreich (Director), Austrian authority, which coordinates the interests of Austrian business actors and communities	Industry
11	Martin Pauli	Arup, global design and consulting company which offers a wide range of service in construction	Industry
12	Tina Kristensen	Troldtekt, Danish developer and manufacturer of acoustic solutions for ceilings and walls, working closely with architects	Industry

13	Alexander Geißels	Saint-Gobain Isover, manufacturer of building components	Industry
14	Teodor Tudorica	Craftwand, manufacturer of wooden building components and pioneer in producing modular building components	Industry

Interviews 11, 12, 13 and 14 were conducted by the "German Council of Sustainable Building" (DGNB) and were provided by the organization since it contains important information about how the construction industry defines circular economy, which is a central empirical research question of this study. The DGNB interviews (I. 11; I. 12; I. 13; I. 14) need to be critically reflected since they were conducted by DGNB and are hence not under the control of scientifical research guidelines. DGNB is Europe's largest network for sustainable building. It is a non-governmental organization that consists of over 2000 construction actors and focuses on education and network in the field of sustainable construction. Committees of the NGO among other things work on certification methods, enabling and sharing knowledge exchange amongst actors and drive sustainability topics within the construction sector (DGNB 2023).

Three out of 14 interviews (I. 3; I. 4; I. 9) were conducted in person, seven interviews were conducted online (I. 1; I. 2; I. 5; I. 6; I. 7; I. 8), and four interviews (I. 11; I. 12; I. 13; I. 14) were provided and conducted by DGNB, as mentioned above. Interviews 1-10 were conducted in January, February and March of 2023 and the DGNB interviews were conducted in 2019. All interviews were guided by a set of questions in the manner of a semi-structured interview.

The interview questions were set out in a way that first, general questions about the sand sector were asked, to cover the first level of analysis. After that, introductory questions about circular economy were asked followed by questions about limitations of circular economy in construction to answer the second and third level of analysis. The interviews conducted by DGNB consist of three questions, asking about a definition of circular economy in construction, their organization's specific role in the circular progress in the construction industry and chances and limitations of circular economy in construction.

The interview questions are attached in Annex A. The interviews were evaluated with the method of a structured content analysis according to Kuckartz, which is a general text analysis of written data. The main categories are derived from the previous research and the designed guideline. These main categories are highlighted in the collected data, from which the subcategories are derived inductively. These subcategories serve to further divide and categorize the main categories. The subcategories are analyzed and classified based on all interviews. After this text work, connections and interpretations of the text material are then elaborated (Kuckartz 2018). The categories and subcategories of this thesis can be seen in Figure 5.

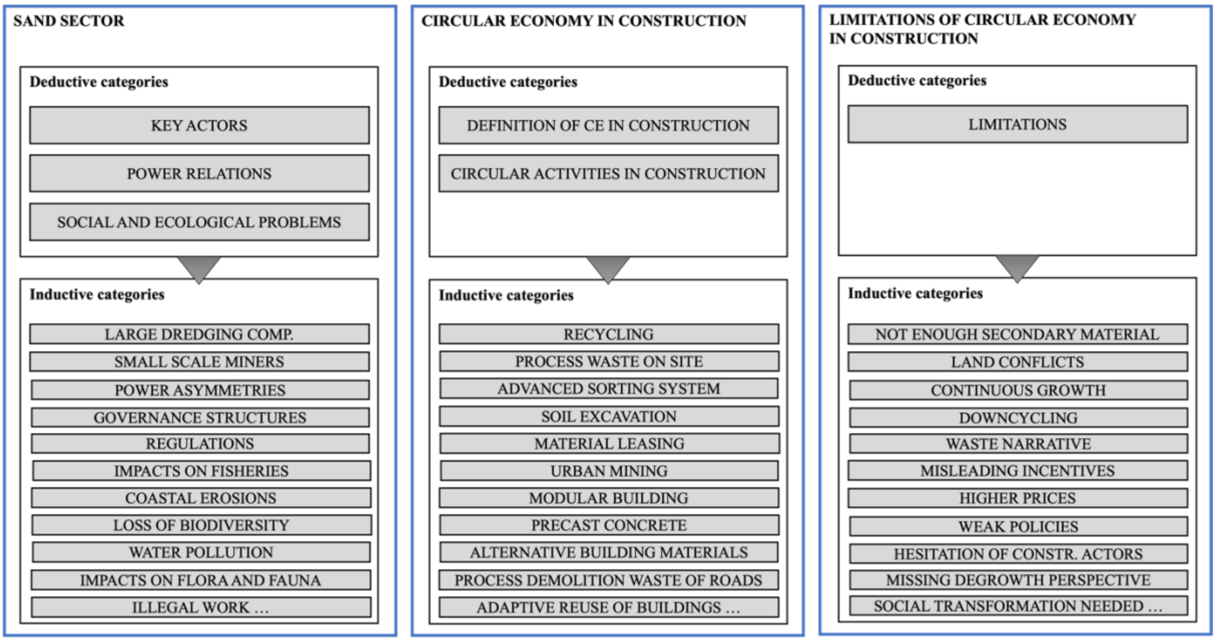

Figure 5. Coding categories of the material (A.M.)

One central aim of this study is to link the two concepts of circular economy and global value chains. After analyzing documents, interviews and data I reflect the empirical results in regard to the concept of circular supply chain. This is done by mapping the circular activities that have been reported by experts into the concept of circular supply chain. This mapping shows what the chances and limitations of circular economy in the construction sand value chain are and how the two concepts are linked and connected.

3.4.Limitations of Methods

I am aware that those methods have several limitations.

First, sand databases are poor and inadequate. This applies onto the whole construction sand value chain, which makes it difficult to grasp the sector and its actors. Nevertheless, I am trying to collect all relevant data points through the UN Comtrade database and the expert interviews. The UN Comtrade databases cover the most important countries in global construction sand trade, but the exact numbers and trade volumes are very likely to be much higher, since there is almost no data transparency or regulations that comply companies to announce their exact numbers publicly. However, there is sufficient access to the UN databases, which is why this data was used for the thesis.

Second, I was able to include 14 interviews, being aware that they do not represent all actors of the construction sand value chain. However, the information provided by NGO, industry and research actors are very valuable and cover a broad perspective on the social and ecological issues of sand mining, as well as circular solutions that are implemented in construction. Kiran Pereira, Pascal Peduzzi and Jean-Baptiste Jouffray are internationally famous and respected researchers in the field of sand mining and the sand value chain in general, being regular cited scientists in scientific papers and attending international panels on the topic. Therefore, winning them as interview experts was extremely valuable for this thesis. Some of the organizations and actors who did not respond to my interview requests were Extractive Industry Transparency Initiative (EITI), Österreichische Forschungsstiftung für Internationale Entwicklung (ÖFSE), Coastal Care and Circular Republic.

Third, it is important to mention that the empirical results focus mainly on the German and Austrian construction sector since most of the experts are working in German or Austrian institutions (I. 3; I. 4; I. 5; I. 7; I. 9; I. 10; I. 12). Nevertheless, I tried to include a global perspective with asking experts from international organizations (I. 1; I. 2; I. 6; I. 8; I. 11; I. 13; I. 14). Still, the results cannot be generalized and cannot speak for all construction industries across all countries and continents.

Fourth, given space limitations, I will not be able to examine the whole supply chain of sand in the same depth. There may be other empirical results or circular activities in construction when focusing also on the transportation phase of the construction sand value chain and including other actor types.

Fifth, I did not conclude any field research and did not visit sand mines in the countries mentioned in this thesis. The data and information used in this thesis are based on expert interviews, literature review and document analyses.

Furthermore, growing up in a neoliberal society I am aware that I am not immune to neoliberal narratives about growth and efficiency. Furthermore, I am part of a social group in the Global North, that benefits from existing economic structures and processes. Hence, I will never be able to fully understand what it means to suffer from global inequalities and dependent dynamics within a global value chain. Nevertheless, I aim to being aware of those blind spots and actively trying to put another lens and perspective onto my research findings and practices.

4. The Global Sand Business

Sand is the second most used resource in the world after water and is the central material from which modern societies are built. Cities and their infrastructure, such as the concrete of the buildings, the glass of the windows, the asphalt of the streets, and the electronic chips that are built into smartphones and laptops, are made of sand. Sand is one of the most important raw materials in today's daily life (Pereira 2020: 3) and, at 50 billion tons per year, is the most extracted resource in the world. The daily consumption of sand per person is approx. 18 kg per capita, each person consumes an average of 6500 kg of sand per year (Hernandez et al. 2021: 1ff.). Katz-Levigne et al. (2022) define four central research areas along the sand supply chain: land reclamation, livelihoods and mining activities, ecological problems and political conflicts, and sand-related corruption (Katz-Levigne et al. 2022: 17). Hence, this chapter intends to provide an overview of the global sand business.

Since there are sand reservoirs all over the world, there is not one key source, like it is the case for other natural resources. Hence, thousands of mines in all countries of the world sum up to a colossal impact that cannot be ignored (Beiser 2019: 11). The largest sand-consuming industries are the construction industry, the glass industry and the semiconductor industry, but the construction industry uses more sand than all the other industries combined (Pereira 2020: 3).

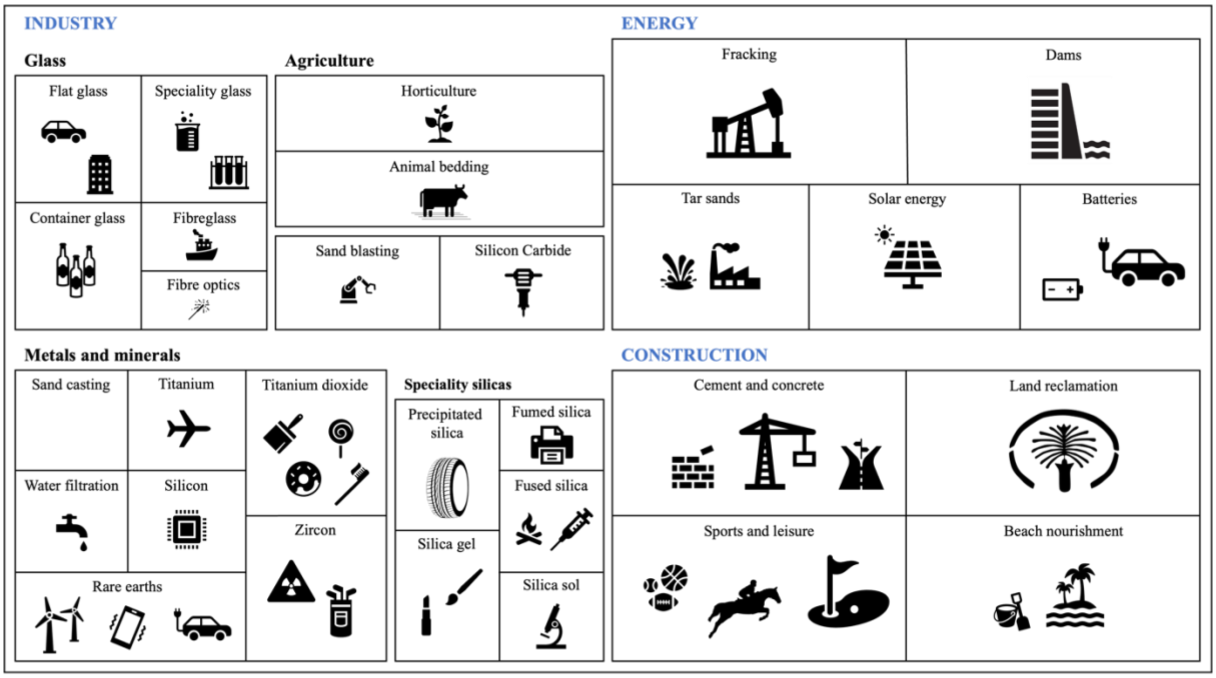

Figure 6. Applications of Sand. Adapted from Pereira (2020) (A.M.)

Figure 6 displays all applications of sand in today's industries. It is striking, that due to its versatility, sand is used in every area of people's everyday lives. From pharmaceutical products, to food, to infrastructure and electronics, sand has been used and processed in extreme numbers (Pereira 2020: 6).

There is a common consensus in research that the excessive extraction of sand is one of the central ecological problems and for years already, the United Nations have been warning of a sand shortage if consumption continues to increase (Peduzzi et al. 2022: 2ff.). Megacities like Dubai and Singapore illustrate how land reclamation and the excessive construction boom as a development goal contribute to excessive sand consumption. Since sand has never been mined at this rate before in the past it cannot be renewed naturally as quickly as it is consumed (Beiser 2019: 182). Hence, sand cannot be seen as a renewable resource in human-life-scale (I. 2: 2).

Due to the limited scope of this thesis, I will continue to focus on the applications of construction sand in cement and concrete production, land reclamation and beach nourishments as shown in figure 5. As each of these applications would be detailed enough for a separate study, the following chapters can only provide an overview of the construction sand value chain.

4.1.The Global Value Chain of Construction Sand

Across all sectors and applications, sand consumption is intensely complex and difficult to grasp. The following chapter therefore aims to provide a detailed mapping of the construction sand value chain with its input-output structure, its key actors and governance, as well as the social and environmental problems which are caused by the excessive sand mining.

As a basis for this GVC mapping as introduced by Gereffi (Gereffi/Fernandez-Stark 2011; Gereffi et al. 2005; Ponte et al. 2019), I will use the construction value chain of Da and Billon (2022) as a starting point for my analysis.

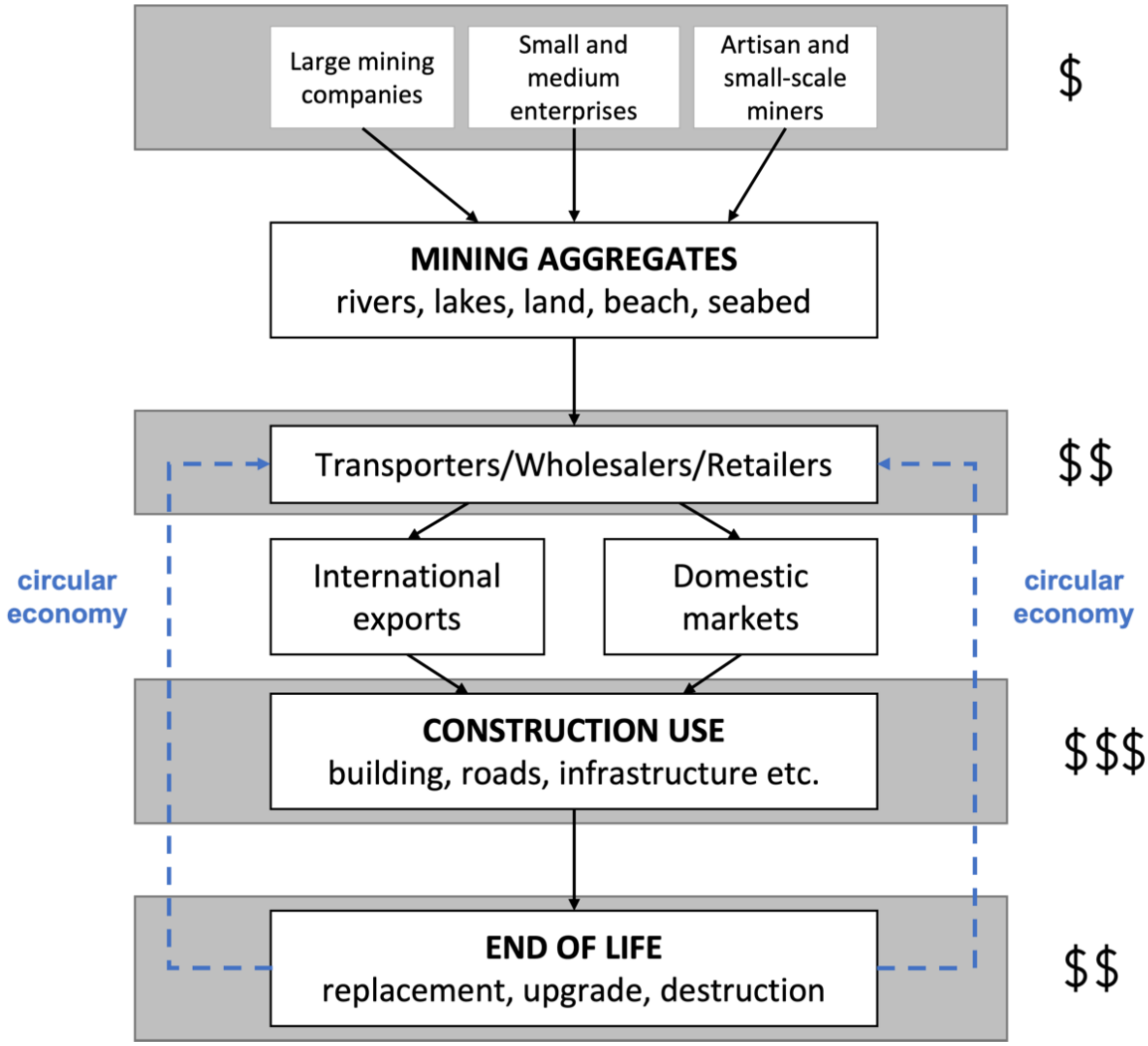

Figure 7. Sand Mining and Construction Sand Value Chain (Da/Billon 2022: 3)

Figure 7 shows the construction sand value chain with all key stages and the according value distribution. The blue circle shows the potential interaction of circular economy activities within the supply chain: The first stage of the construction sand value chain is the resource extraction phase, where the resources are extracted. The white areas cover the relevant actors, that dominate this phase, being large dredging companies, small and medium enterprises and artisan and small-scale miners. According to multiple experts, the two main actor group in the resource extraction phase in the construction sand value chain remain large dredging companies and small-scale miners (I. 1; I. 2; I. 6). The second stage is the transportation phase. The extracted minerals get transported, mainly by the same dredging companies, since construction sand is mainly mined locally and does not get transported widely, while countries with local sand scarcity depend on international sand trade (I. 2: 2). The third stage is the construction phase, where the sand is being processed to building materials, like cement, concrete or other filling material. The fourth stage of the construction sand value chain is the end-of-life phase.

After the demolition of old buildings, building materials get either recycled or deposited by deconstruction or recycling companies (I. 3: 5).

Construction activities began to decrease in 2021, when the material prices skyrocketed, and supply shortages became unavoidable due to the Covid-19-Pandemic. The construction activity began to rise again in the second quarter of 2022, after the economy started to recover after the pandemic, when the Russian invasion into Ukraine induced severe supply shortages again and caused energy prices to explode (Rubinsohn et al. 2023: 2ff.). The RICS Construction Activity Index is formulated by merging current and 12-month projections from four categories: residential workloads, non-residential workloads, infrastructure workloads, and profit margins. The weighting of these categories is uniform in the index computation. To accommodate variations on a global and regional scale, the categories are assigned weights utilizing the World Bank's GDP (Gross Domestic Product) PPP (Purchasing Power Parity) data series. This data series relies on consistent prices from 2017. This approach ensures that the index accurately represents the relative significance of construction activity in diverse nations and regions. To determine the weights for the current responses, the GDP data from the preceding year is employed. For instance, if the index pertains to the year 2020, the responses from that year are weighted using the GDP data from 2019. In cases where there is an inadequate number of responses to establish a national-level sample, the responses are amalgamated to address any gaps in regional coverage. This inclusive strategy facilitates a comprehensive portrayal of construction activity across various regions (Rubinsohn et al. 2023).

4.1.1. Input-Output Structure

Since neither extraction volumes, nor production volumes of sand need to be documented, the exact input numbers of sand are not clear. Even industrial countries and economies only have reliable data on sand consumption for more recent years (Pereira 2020: 14). Therefore, this chapter aims to provide an overview of the applications of construction sand.

There are different types of sand, which can be classified into three categories. The first distinction is made according to the source from which the sand is extracted. It can be distinguished between terrestrial and marine sand mining. Terrestrial sand mining is done through open pits and quarries, as well as through river deposits, whereas marine sand mining is accomplished through offshore deposits in the ocean (Gavriletea 2017: 2). Another distinction is based on the chemical composition of the sand, such as mineral sand, quartz sand or gypsum sand. The grain size is another option to differentiate. While fine sand is 0.06-0.2

millimeters in size, medium sand is 0.2 - 0.6 millimeters in size. One speaks of coarse-graded sand from a size of 0.6 millimeters and everything over 2 millimeters is referred to as gravel (Al-Sinan/Bubshait 2022: 5). The distinction between the source of the sand is critical to its use: desert sand is too round due to wind erosion and does not have sufficient adhesion for the cement and concrete required by the construction industry. Sand from rivers, lakes and seas is firmer and more adhesive because of water erosion, and thus contains the important adhesion. Soil sand consists mainly of quartz and other minerals and is usually mined together with gravel. Sea sand basically has a similar structure to soil sand, but it must be cleaned of sea salt in a time and cost intensive manner, which adds to the costs. Therefore, especially small-scale mining companies try to avoid this additional cost-intensive step and extract sand from soil, rivers and lakes (Beiser 2019: 8ff). Sea sand is mainly used for landfill, such as in Singapore's land reclamation (Torres et al. 2021: 643) or in the construction of artificial palm islands in Dubai (Beiser 2019: 9). The glass industry requires sand with a particularly high quartz content (>95%) (Beiser 2019: 9).

The main product made from sand is concrete. Concrete consists of two-thirds sand and gravel and one-third cement. Cement is a fine powder that is ground from limestone and clay and other minerals, sometimes also sand (Beiser 2019: 30). Large amounts of sand are therefore required for producing both fundamental building materials, cement and concrete (Gronwald et al. 2021: 15 ff). After the sand has been extracted, washed and sorted, it is transported further and brought to a storage location or directly to a concrete or cement manufacturer, who processes the sand together with cement to make concrete (Gronwald et al. 2021: 27).

According to the Global Cement and Concrete Association the volume of concrete consumption was 14 billion cubic meters in 2020, whereas the volume of cement consumption was 4,2 billion tons in 2020 (GCCA 2023).

The technology of sand mining has not changed significantly in the last few decades and thus remains at a rather simple technological standard. The sand from river and lake beds is transported ashore or to floating platforms using suction pumps or dredged from ships using shovels. On land, sand is mainly excavated from open pits. Sometimes it is necessary to break up rocks using explosives and crushing machines to get to the sand. Irrespective of the source, the sand must first be roughly cleaned and sorted into the various grades on conveyor belts (Beiser 2019: 10 ff).

4.1.2. Geographical Dimension

Due to the poor data quality, there are various data sources that can be used to map the global construction sand trade flows. Moreover, some data sources distinguish between different sand types, while other sources cover all sand types at once. This must be considered when analyzing the following data.

This chapter aims to display central locations that are playing a key role in the global sand trade. To cover as much of the available data as possible, UN Comtrade data was used, as well as other publications (Morley et al. 2022; Filho et al. 2021; Hernandez et al. 2021; Jouffray et al. 2023; Katz-Levigne et al. 2022; Lamb et al. 2019; Pereira 2020; Torres et al. 2021) that have analyzed global construction sand trade data.

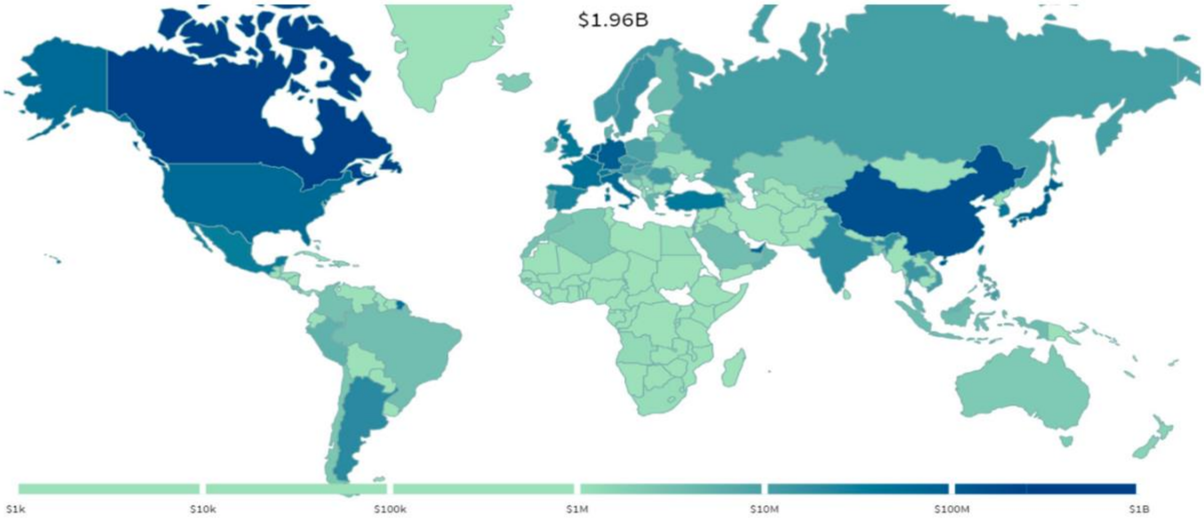

Figure 8. World's sand importers in 2019 (Filho et al. 2021: 2)

Figure 8 shows the world’s sand importers in 2019 and highlights that almost every country relies on sand imports, even if it is one of the largest sand producing countries like the US, China or Germany. This implies on the one hand, that sand data is poor and does not distinguish between different industries where sand is used and on the other hand, that the sand supply is unevenly distributed across and within countries (Filho et al. 2021: 2).

Morley et al. (2022) highlighted USA, Germany, Australia and the Netherlands as the top four exporters of sand, while Singapore, the Netherlands, Belgium and Japan were the top four importers of sand, since they are implementing huge land reclamation projects and are dependent on sand imports. According to the authors Singapore holds a 11% market share of all sand imports globally (Morley et al. 2022: 3).

Figure 9 and 10 show UN Comtrade data about sand exporting countries by quantity (Figure 11) and by trade value (Figure 12) in 2021. While Malaysia, the Netherlands, the United States of America, Belgium and France were the top sand exporting countries by quantity, the United States of America, the Netherlands, Germany, Belgium and Malaysia were the top sand exporting countries by trade value in 2021. Other sources such as Filho et al. (2021) and Gavriletea (2017) also report China and India as main producing countries of sand, but there are implications that those countries produce sand mainly for the national and local construction industries. Malaysia supplies large infrastructural projects of megacities like Singapore and Dubai, where huge amounts of sand are used for land reclamation projects, while the Netherlands, Belgium and France are home to large dredging companies that will be outlined in chapter 4.1.3 (Actors and Governance Structure).

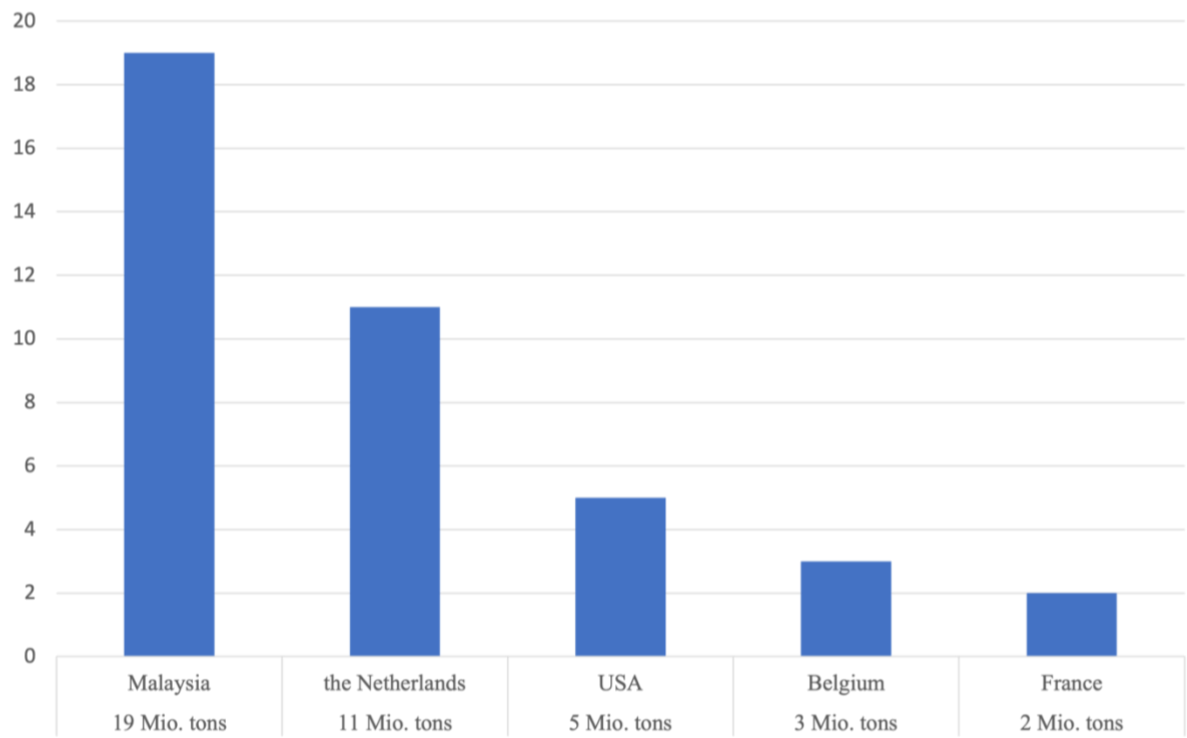

Figure 9. Top export countries of sand by quantity 2021. UN Comtrade Data (A.M.)

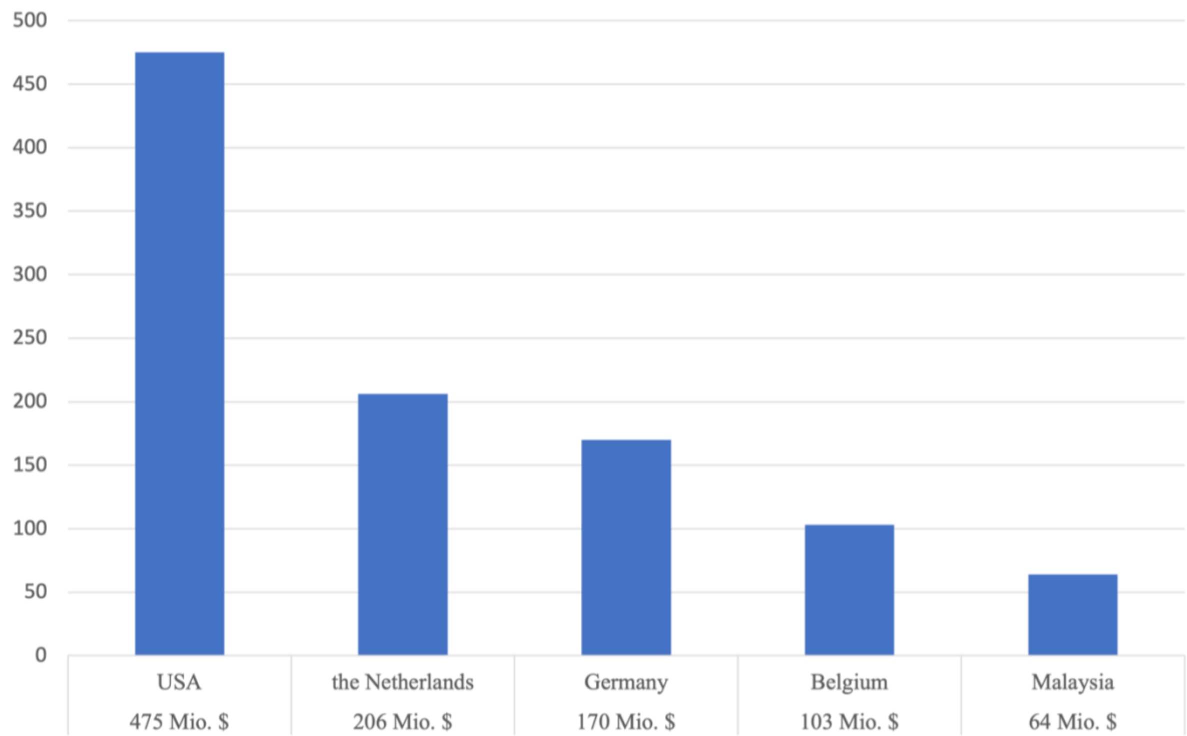

Figure 10. Top export countries by trade value 2021. UN Comtrade Data (A.M.)

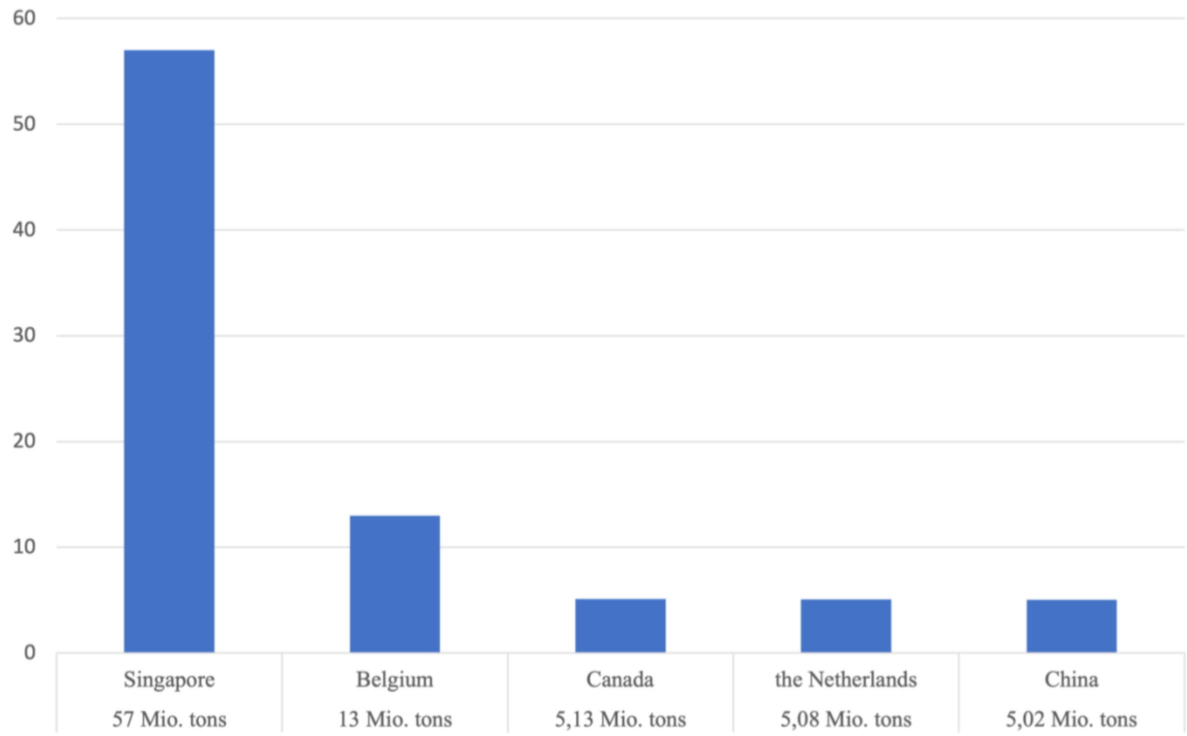

Figure 11. Top import countries of sand by quantity 2021 (UN Comtrade Data)

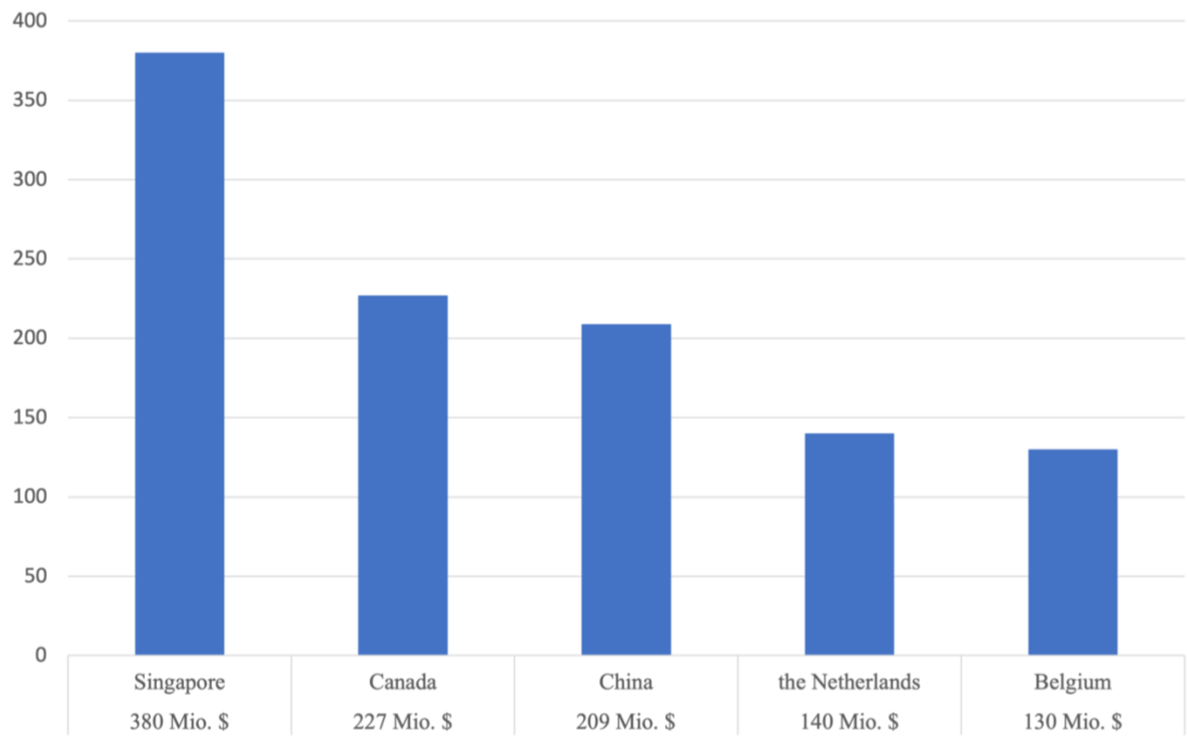

Figure 12. Top import countries by trade value 2021 (UN Comtrade Data)

Figures 11 and 12 show the top importing countries of sand by quantity and trade volume in 2021. The top import countries by quantity and by trade value are Singapore, Belgium, Canada, the Netherlands and China, while only the sequence of countries is different. Nevertheless, Singapore is by far the number one importing country of sand, due to its large infrastructural and land reclamation projects. Singapore's mission to increase the land size through land reclamation by 30% in 2030 compared to 1965 allows a glimpse into the sand consumption that was already covered and will continue to be covered through imports from Singapore's neighbors in the Global South in the upcoming years (Lamb et al. 2019: 1517). Singapore's prime minister Lee Kuan Yew once declared land reclamation and the related sand imports from countries like Myanmar, Cambodia, Malaysia as a necessity for economic growth. Besides being an important sector for work for locals, Singapore's construction industry is the largest sector for migrant workers (Lamb et al. 2019: 1517ff.).

An analysis by Lamb et al. (2019) highlights the problem of data gaps within the international sand trade, shown in figure 13. While Singapore reported nearly 28 million tons of sand being imported from Myanmar between 2007 and 2016, Myanmar only reported 2.2 million tons of sand being exported to Singapore. The same trade gap exists between Singapore and Cambodia. Singapore reports 80.33 million tons of sand imports from Cambodia, but Cambodia only records 2.77 million tons of sand exports to Singapore. This suggests a high amount of illegally transported sand (Lamb et al. 2019: 1518). There are various ways of dealing with the data gaps. The UNEP report on the sand crisis takes the world data on concrete and cement production, which is much more reliable, and multiplies this data by a factor of 10, since that is roughly the percentage of sand used in cement and concrete production. The lack of reliable data is therefore a central problem in the analysis of the international sand trade (Katz-Lavigne et al. 2022: 8ff; Bisht 2021: 8) and must be critically reflected.

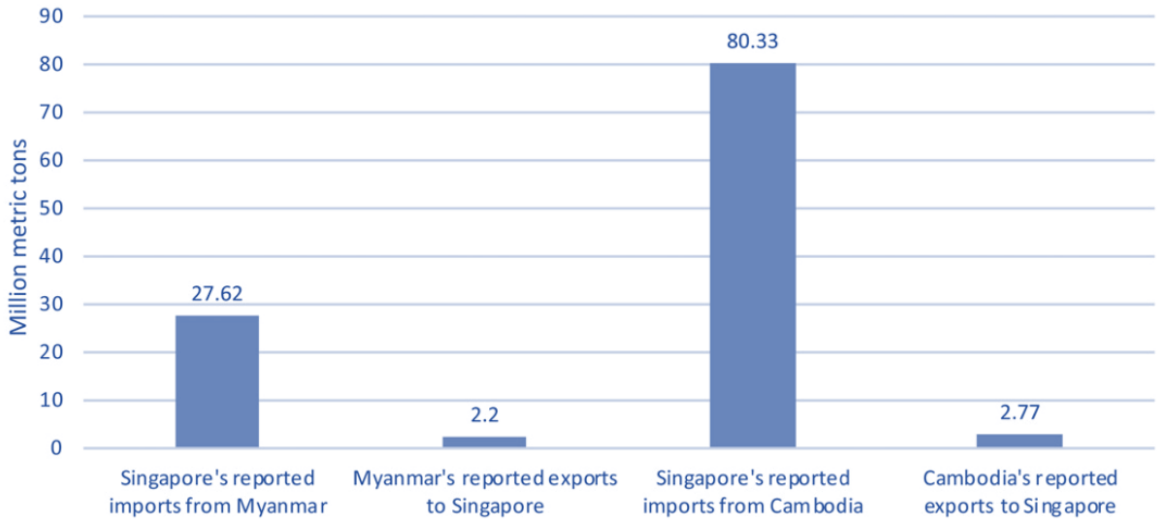

Figure 13. Sand trade gaps (Lamb et al. 2019: 1518)

Considering that some countries, such as Germany, Belgium and the Netherlands are mentioned as top importers and top exporters is also a sign of poor data quality, as the databases do not distinguish between different types of sand and these countries have high production rates in different sand industries, such as construction, semiconductors, glass industry et cetera (Gavriletea 2017: 7).

It should also be noted that construction sand is mostly traded regionally. This explains why China is the largest construction market in the world but is not mentioned as a top export country. China obtains its construction sand supply mainly from regional lakes like the Poyang Lake, which covers 10% of the Chinese construction sand demand, supplying over 400 million tons of sand per year (Katz-Lavigne et al. 2022: 10).

4.1.3. Actors and Governance Structure

As already mentioned above, it is extremely difficult to display the construction sand value chain in a transparent manner due to the insufficient databases on global sand trade. However, it is possible to grasp the largest actors in the different sourcing types of sand: Terrestrial and marine or offshore mining, as well as looking at the largest construction companies, that are using the most amounts of mined sand (I. 1: 2).

Generally, the construction sand value chain is characterized by a highly concentrated market, where only a handful of actors control a large share of the market. Moreover, it is important to note that the value chain of sand is highly interactive with several sectors, hence the list of actors may differ, depending on the research perspective (I. 1: 2).

Since marine mining requires cost intensive high technology and specialized equipment, as well as special environmental permits, this type of sand mining is mainly carried out by large dredging companies in wealthy countries in the Global North, whereas terrestrial sand mining is often carried out by small-scale miners in the Global South (Gavriletea 2017: 2; I. 1: 2ff.).

For small-scale miners especially in the Global South, it is difficult to estimate the exact numbers and volumes. With little to no regulation in the sand mining sector, there are estimates of thousands of small-scale miners selling their sand to the local construction companies. Acknowledging this diversity and lack of transparency is a key message for this chapter, which needs to be considered throughout the whole thesis (I. 1: 3). Figure 14 shows small scale mining in Bangladesh, where hundreds of small-scale miners are shoveling sand with little to no technical equipment (Coastalcare.org 2023). Figure 15 displays beach mining in Sierra Leone, where sand is mined manually by small-scale miners and trucks are filled with sand to be sold to local construction companies (The New Humanitarian 2013).

Figure 14. Small scale sand mining in Bangladesh (Hayder/Coastalcare.org)

Figure 15. Beach mining in Sierra Leone (Trenchard/The New Humanitarian)

Marine sand dredging is by far the largest extraction activity in terms of volume. It is mainly used to dredge gravel and sand for land reclamation and construction. In comparison to other parts of the construction sand value chain it is comparably easy to recognize the big actors in the field. Figure 17 shows the largest dredging companies in the world by revenue in 2022. 95% of the global dredging fleet is owned and governed by the "Big Four" of dredging: Jan de Nul (BE), Van Oord (NL), Boskalis (NL) and Deme (BE), therefore those four companies can be seen as the main actors in marine dredging (Jouffray et al. 2023: 12ff.). Figure 16 shows Chinese dredging vessels on the coast of Sri Lanka, where they are mining for marine sand to use later in construction for land reclamation (Lu 2022).

Figure 16. Chinese dredging vessels in Sri Lanka (Xinhua/Foreign Policy)

According to Da and Billon (2022) countries in the Global North have mainly turned away from lake and river mining due to higher regulations and environmental protection and rely more on marine and terrestrial sand mining and imports (Da/Billon 2022: 6). Countries in the Global South, however, still aim to cover the excessive demand for development and construction projects and are slow to define relevant policies and regulations for sand mining (Da/Billon 2022: 5).

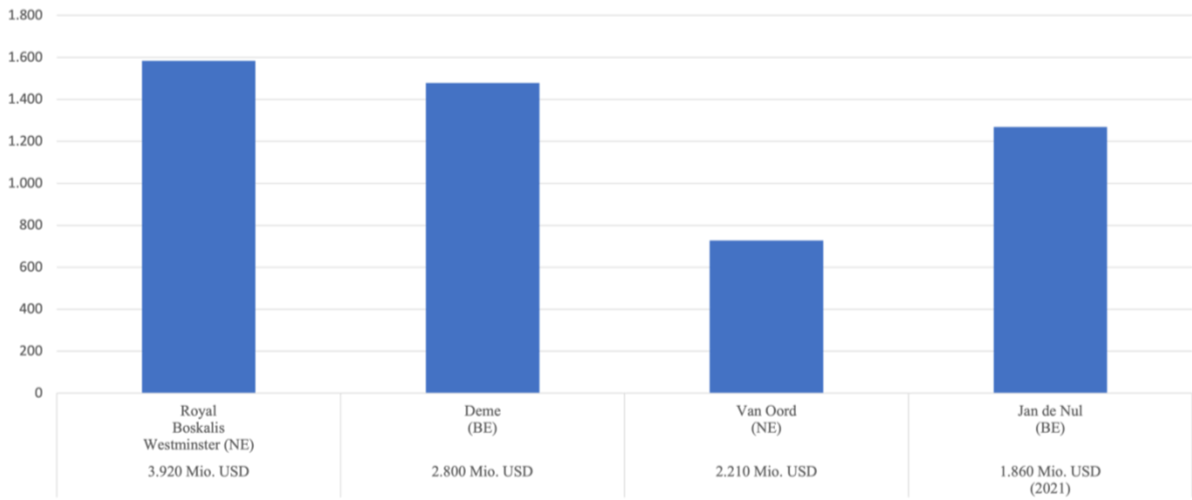

Figure 17. Largest Dredging Companies by Revenue in 2021 (Jouffray et al. 2023: 12)

Since the global concrete production market is much more fragmented than the cement market and cement and concrete are highly interconnected in terms of sand consumption, only the largest cement production companies can be named. The global cement market is dominated by a few companies, the French/Swiss company LafargeHolcim, the German company

HeidelbergCement, the Mexican company Cemex and the Italian company Italcementi, which is owned half by HeidelbergCement (Lehne/Preston 2018: 5).

According to Statista.com the largest cement production companies by revenue are the China National Building Material Company, LafargeHolcim, Anhui Conch Cement, Heidelberg Cement and Cemex. Those cement production actors can be seen in figure 18.

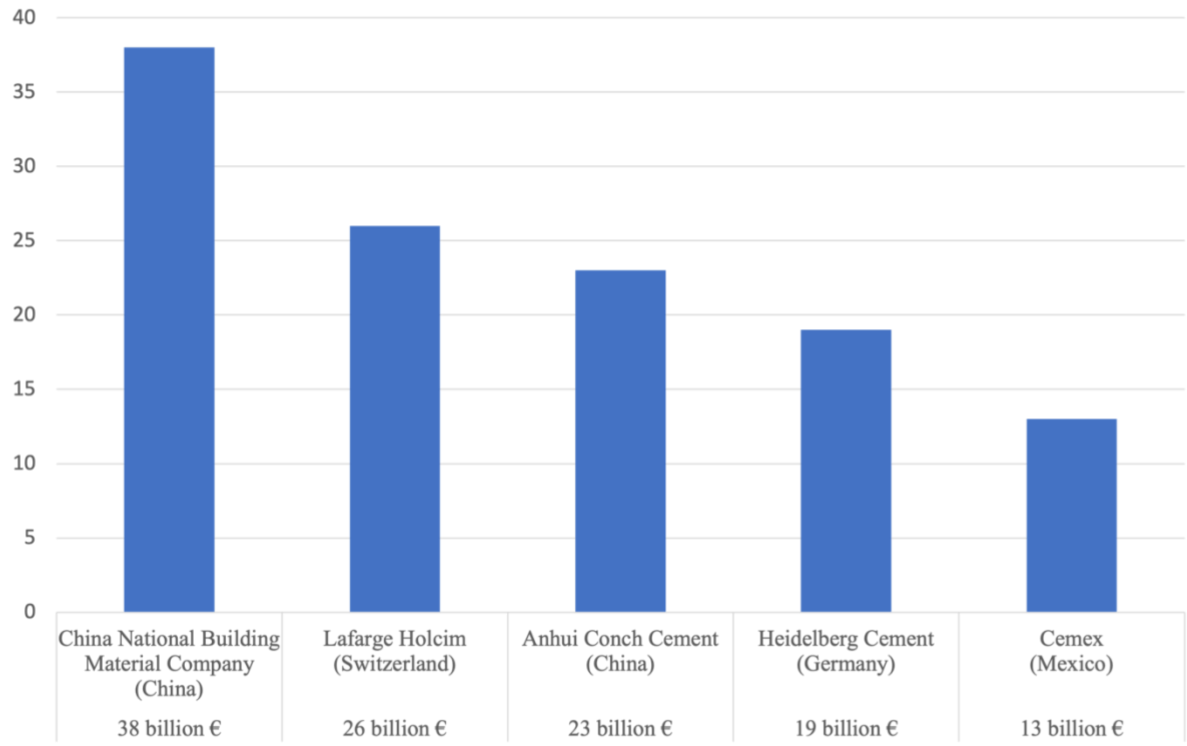

Figure 18. Largest Cement Production Companies by Revenue in 2021 (Statista.com)

The largest construction companies are displayed in Figure 19. The four companies with the highest revenue in 2021 are all Chinese and had a higher combined revenue than all of the other companies in the top 100 list combined. This shows the dimension of the Chinese construction market and the consequential construction sand demand in China (Statista 2023). The dimension of China's sand consumption can be demonstrated through numbers, with China using more sand between 2011 and 2013 than the US in the whole 20th century (Gavriletea 2017: 2).

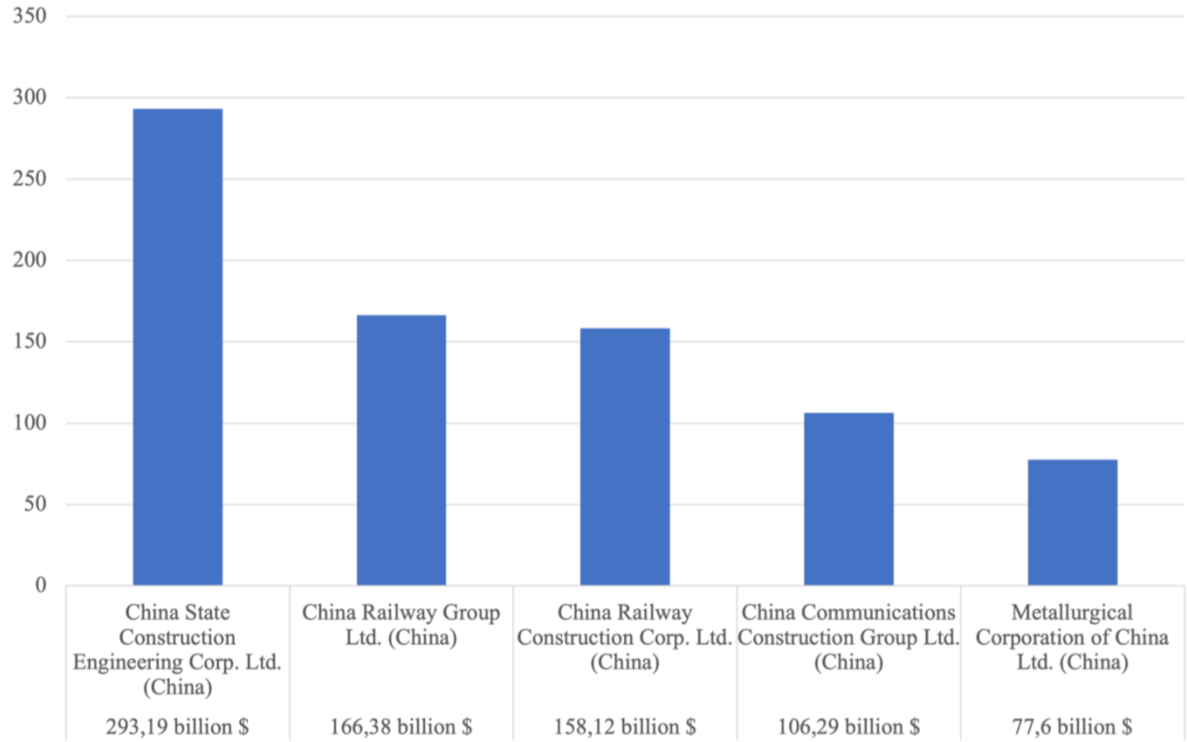

Figure 19. Largest Construction Companies 2021 (Statista.com)

While mentioning and acknowledging the large actors in the construction sand value chain, governance structures must also be considered when describing the dynamics within the construction sand value chain.

According to the five linkages of lead firms governing their supplier's activities by Gereffi et al. (2005) as explained in chapter 2.1 (Global Value Chains) one can distinguished between two ways of governance in the construction sand supply chain. One is the supply of small-scale miners in the Global South, that are reacting to this huge demand of the construction industry and have increased their construction sand mining activities drastically in the last years. Because of its low entry barriers, construction sand mining can be done without high technology. The mining of sand has increased exponentially, mainly due to the increased global demand in the construction sector. Sand mines are considered an attractive source of income in countries of the Global South, leading to small family businesses that mine sand right away, as it is possible without sophisticated technology and skilled workers (Torres et al. 2021: 643).

Small-scale miners of construction sand find themselves in captive governance structures, since the buyer has complete dominance about their mining activities and if the buyer is not satisfied with the quality of the sand, he will simply not buy their sand and shift to another supplier (I. 1: 7).

The other governance structure can be found in construction sand value chains, where the supplier are large European dredging companies that share the power within the value chain with large construction companies. Their linkages can be described as relational since the dredging companies use high technology machines to dredge marine sand from the sea ground and therefore exchange high complexity activities with their buyers. That’s why their business and power relations tend to be more symmetrical since the activities are governed through capability and trust (I. 1: 7).

According to industry experts, the central power has the builder who initiates the construction of a project through a construction company. In most projects, the builder is also the owner of the future building. Clients from construction companies are active in both sectors, private and public. In the beginning of a construction project, the owner selects an architect and a planner and decides the function of the buildings, and the materials that are being used for construction. The building framework conditions are therefore decided by the builder and cannot be influenced by any of the other actors. The construction knowhow, however, has the construction company who itself relies on the material supplier, that has the knowhow of material mining (I. 3: 2). Commonly, large construction companies also have the knowledge of material mining and take over this step of the value chain, as described previously in this chapter. Concluding, the builder and owner of a construction projects defines, if primary or secondary resources are used.

Another industry expert claims that power correlates with money and capital along the construction value chain:

> “Power (in construction) always runs along the money, the bestseller and what that one must achieve in order to be allowed to build. And that's not just how Austria works, that's how Europe works, and a large part of the world, too.” (I. 4: 6)

To sum up, the major actors in the construction sand value chain are dredging companies (Figure 17), cement production companies (Figure 18) and construction companies (Figure 19). In the mining stage of the construction sand value chain there are thousands of small-scale miners, some of them working in illegal mines controlled by criminal organizations.

4.1.4. Regulations of Sand Mining

To this date, there is no global agreement to regulate the mining of ocean sand. This is particularly problematic because of the large amounts of sand that get extracted by industrial dredging ships every day. Mostly, sand mining is regulated at a national level through local communities or authorities (Jouffray et al. 2023: 22ff.).

In many countries, sand extraction is not covered by mineral, water, coast or land use policies, since the mineral is seen as a low-value development mineral and therefore gets little legal attention compared to high-value export minerals. As sand extraction is concerning several policy areas, as resource policy, coastal management, infrastructure, land use planning, biodiversity policy as well as fisheries management, it is intensely complex to govern mining activities, especially since the mineral was seen as a cheap endless natural resource without environmental harm for ages (Peduzzi et al. 2022: 23).

On an international level however, there are some international legal frameworks, like the United Nations Convention on the Law of the Sea (UNCLOS), which are relevant for sand mining. UNCLOS is an international treaty which establishes a comprehensive framework for the governance and use of the world's oceans and their resources. The law entered into force in 1994 and besides giving coastal states the sovereignty to exploit their natural resources, it also obeys coastal states to protect marine environment. UNCLOS defines the territorial waters of coastal states as extending up to 12 nautical miles (22.2 kilometers) from their baselines. Within this zone, coastal states have full sovereignty and control over the airspace, waters, and resources.

Coastal states also have the right to establish an Exclusive Economic Zone (EEZ) extending up to 200 nautical miles (370.4 kilometers) from their baselines. In this zone, they have special rights and jurisdiction over the exploration and exploitation of natural resources, both living and non-living, in the water column and on or under the seabed. Moreover, UNCLOS defines the continental shelf as the seabed and subsoil beyond the EEZ that extends up to 200 nautical miles or beyond if certain geological criteria are met. Coastal states have exclusive rights to explore and exploit the natural resources of the continental shelf. Areas of the ocean beyond the EEZ are considered the high seas. All states enjoy the freedom of navigation, overflight, fishing, and scientific research in this area, subject to certain regulations and the principle of the common heritage of mankind. The treaty establishes the rights and obligations of ships in international waters, including the right of innocent passage through the territorial sea of coastal states and the freedom of navigation on the high seas.

UNCLOS establishes the International Seabed Authority (ISA) as an organization responsible for the regulation and control of activities related to the exploration and exploitation of mineral resources in the international seabed area beyond national jurisdiction. It ensures that these activities are carried out for the benefit of humankind as a whole. UNCLOS is considered a crucial framework for the development of international law governing the oceans. It seeks to balance the rights and interests of coastal states with the freedom and rights of all states in the use and protection of the marine environment and its resources (Peduzzi 2014: 10)

International trade bans of sand play a role in sanctioning specific states, for example North Korea, with the aim to stop the country from sand supply for construction, hence development (Jouffray et al. 2023: 22).

On a European level environmental protection is also governed by European directives, particularly the Habitats Directive (Directive 92/43/EEC) and the Birds Directive (Directive 2009/147/EC). These directives establish protected areas of European significance and may restrict or prohibit sand extraction in certain areas to ensure the preservation of habitats and biodiversity (BMWK 2023).

On country level, in Austria, sand mining is regulated by several environmental laws and regulations. Especially when sand is mined in gravel pits, companies need to comply with water laws and groundwater protections. Depending on the pit size, companies also need permissions in terms of conservations of nature (I. 3: 9).

The extraction of sand in Germany is legally regulated under various federal and state laws and regulations. The specific regulations may vary between different states since the responsibility for mineral extraction in Germany lies with the individual states. The extraction of sand is governed by the Federal Mining Act (Bundesberggesetz), which establishes the framework for the extraction of mineral resources in Germany. It includes provisions on the granting of mining rights, environmental impact assessments, and the restoration of extraction sites. In addition, specific regulations and laws may apply at the state level. For example, some states have their own mining laws or state nature conservation laws that regulate sand extraction. These laws may impose specific requirements for the protection of nature and landscapes, as well as for the restoration and rehabilitation of areas after extraction.

To sum up, sand mining regulations and legislations are mostly characterized by non-binding guidelines that lack true enforcement and sanctions, regardless the international, European or country level. Regulations are needed on a local, national, and international level to have a leverage on social and environmental issues (Koehnken 2018: 5ff.).

4.2.Social, Economic, and Environmental Problems of Sand Mining

One key aim of this thesis is to provide an overview of social and environmental problems of sand mining to answer research question 2 (*What are the social and ecological problems of sand mining*?). The impact depends not only on the location but also on the method of extraction as well as the regulatory context. That being said, regulations can lower the negative impact of sand mining on humans and nature, but still most of the environmental problems cannot be avoided while sand gets extracted (Jouffray et al. 2023: 17).

> "What's interesting when it comes to impact, you have different impacts along the value chain from extraction to consumption. And with consumption the big elephant in the room is the cement and construction industry. With extraction you have the social and environmental impacts." (I. 1: 4)

The following table summarizes the social, economic, and ecological problems of sand mining on a glimpse:

Table 5. Social, economic, and ecological problems of sand mining

Area	**Problem**	**References**
Social	Illegal labor	Morley et al. 2022; Lamb et al. 2019; Filho et al. 2021
	Bad working conditions	Sakhtivel 2021; Da/Billon 2022; Zadeh et al. 2022; Lamb et al. 2019; Filho et al. 2021
	Insufficient health standards	Sakhtivel 2021; Lamb et al. 2019; Filho et al. 2021; Morley et al. 2022
	Insecure employment	Katz-Levigne et al. 2022; Lamb et al. 2019; Filho et al. 2021
	Unsecured workplace	Katz-Levigne et al. 2022; Da/Billon 2022; Zadeh et al. 2022; Filho et al. 2021; Morley et al. 2022
	Child labor	Gronwald et al. 2021; Filho et al. 2021

	Threats through sand mafia	Gronwald et al. 2021; Morley et al. 2022; Da/Billon 2022; Zadeh et al. 2022; Filho et al. 2021
	Land conflicts	Radhuber 2021; Filho et al. 2021
	Reduced fish stocks for fisheries	Filho et al. 2021; Tasantab 2021; Pereira 2020; Lamb et al. 2019; Morley et al. 2022; Adedeji et al. 2014
	Pit lands cannot be used for agriculture	Filho et al. 2021; Tasantab 2021; Pereira 2020; Lamb et al. 2019
	Lack of natural barriers in case of storms and floods	Pereira 2020; Pereira/Ratnayake 2023; Tasantab 2021; Filho et al. 2021
Economic	Illegal trade	Filho et al. 2021; Morley et al. 2022
	Losses through tax debts	Filho et al. 2021
	Illegal work	Filho et al. 2021; Morley et al. 2022
	Corruption	Gavriletea 2017
	Lack of revenue in the tourism industry	Filho et al. 2021
	Political tension between nations	Morley et al. 2022
Environmental	Environmental destruction	Tasantab 2021; Lamb et al. 2019; Filho et al. 2021; Gavriletea 2017; Morley et al. 2022
	Loss of biodiversity	Tasantab 2021; Lamb et al. 2019; Filho et al. 2021; Gavriletea 2017; Morley et al. 2022

	Deforestation	Tasantab 2021; Lamb et al. 2019; Filho et al. 2021; Gavriletea 2017; Morley et al. 2022; Adedeji et al. 2014
	Pollution of groundwater	Tasantab 2021; Lamb et al. 2019; Filho et al. 2021; Gavriletea 2017; Morley et al. 2022
	Soil and organism destruction	Tasantab 2021; Lamb et al. 2019; Filho et al. 2021; Gavriletea 2017; Morley et al. 2022
	Invasive species	Da/Billon 2022; Filho et al. 2021; Gavriletea 2017
	Reduction of shellfish	Da/Billon 2022; Filho et al. 2021
	Increased water turbidity	Da/Billon 2022; Filho et al. 2021; Gavriletea 2017
	Shifting river and lake beds	Filho et al. 2021; Lamb et al. 2019; Gavriletea 2017
	Landslides	Filho et al. 2021; Gavriletea 2017; Morley et al. 2022; Adedeji et al. 2014
	Beach erosions	Filho et al. 2021; Gavriletea 2017; Morley et al. 2022; Adedeji et al. 2014
	Change in water direction, depth and strength	Filho et al. 2021; Gavriletea 2017; Adedeji et al. 2014
	More floodings and hazards	Filho et al. 2021; Gavriletea 2017

On a social level, sand mining has induced diverse and complex issues. In many countries of the Global South, the mining of sand led to the creation of new jobs, to high investments in the areas of sand mines and the export of sand promoted economic growth in the regions (Filho et al. 2021: 2). Hence, besides sand playing a huge role in building up human development like infrastructure and construction, working in sand mines is also a central aspect of economic development within regions of developing countries (Gronwald et al. 2021: 17). However, the extreme consumption of sand has severe consequences for the environment and the people living in the areas where the sand is mined, both on a global and local level. These negative impacts of sand mining occur disproportionately often in countries of the Global South, since work in the sand mines is less technological, less monitored and equipped with fewer safety systems (Filho et al. 2021: 3).

Moreover, the steadily increasing demand for sand due to the economic growth especially within the construction sector causes illegal mines to increase, that have even lower working conditions and standards for their workers and nature (Sakhtivel 2021: 28). The environmental damage as well as insufficient health standards for mine workers are the major problems in the sand supply chain (Sakhtivel 2021: 28). The last decades show that these commodity extraction mines are a place for ecological and social exploitation, while often creating benefits for companies in the Global North (Radhuber 2021: 255). The Environmental Justice Atlas of 2018 reported 557 conflicts because of resource extraction in South America alone (Radhuber 2021: 245). The working conditions in the sand mines are widely problematic. Employment in sand mines is very insecure and exploitative, unregulated and often illegal. In addition, the miners usually work under high security risks, without occupational safety and in areas that are completely unsecured. Many workers have already drowned because they fell into the river and lake beds or drowned because of exhaustion after diving for sand (Katz-Levigne et al. 2022: 21ff). In the sand sector, the worst forms of child labor are appearing and are part of normal everyday work, while there are also reports of violent incidents. Journalists and police officers in particular are threatened, attacked and even killed when they try to take action against illegal sand mines (Gronwald et al. 2021: 19ff).

Due to the lack of governance and monitoring of sand extraction, those illegal sand mines enable the control of illegal organizations such as the sand mafia to rise. In Morocco, research shows that over 50% of sand trade flows are controlled and governed by the sand mafia (Morley et al. 2022: 3). It is significantly problematic, since there are reports of rising violence against journalists and whistleblowers, that try to improve working conditions and the enablement of political interventions (Da/Billon 2022: 4; Zadeh et al. 2022: 2). There are also some indications that in countries with poor regulations and a high demand for sand other, low-quality materials were used instead of sand, such as marine sand not washed from salt. This lowers the stability of the concrete made of sand and hence affects the static of buildings. Building defects following earthquakes in Morocco, Nigeria, Thailand, Italy, South Africa and Taiti have been linked to poor sand quality (Langweil 2022).

With all due attention to addressing social problems caused by sand mafias, it is important to also acknowledge sand mining as a legal source of income for many people in the Global South, that are operating in legal and licensed mines, earning their income without any illegal activities or crimes (Peduzzi et al. 2022: 14). However, since the sand mafia is increasingly taking over legal and licensed mines, political actions need to happen (Morley et al. 2022: 3).

Going further the value chain of construction sand, the ongoing growth of construction buildings and soil sealing is environmentally harming since it creates land conflicts with agricultural and societal activities (I. 4: 10).

The main economic issues caused by sand mining mainly affect illegally traded sand. This costs the states losses through tax debts, illegal work and a lack of revenue in the tourism industry. The main reasons for illegally traded sand are financial profit, the growing demand for sand, the lack of verification systems in the sand sector, as well as low penalties and, above all, poverty. In addition, there is insufficient education in the regional populations of sand mines in the Global South about the negative effects of sand mining (Filho et al. 2021: 8). The following stages of the construction sand value chain after the mining phase also show economic and social issues. The construction sector has a large issue of illegal work, especially in the construction and building phase (I. 4: 7).

In terms of environmental problems, sand mines have led to environmental destruction, loss of biodiversity and water pollution in the affected countries. They also affect coastal biodiversity, sea levels, pollute groundwater and destroy soil and the organisms living in it through explosions to extract sand (Tasantab 2021: 2). In addition, the sand mines have a serious impact on the flora and fauna of the areas. Many family businesses in countries of the Global South are dependent on fishing, especially in coastal areas and on rivers and lakes, which, however, suffers greatly from the sand mines. Fish stocks are being reduced by the destruction of their habitats and are additionally threatened by invasive species. There are multiple studies that show a significant reduction of shellfish and fish populations in mining areas, due to the increased turbidity caused by sediments of sand mining. The turbidity reduces the light under water, which makes it impossible for water creatures and to chase other micro-organisms to ensure their lives (Da/Billon 2022: 4). The Chinese Lake Hongze has lost 99.5% of all its biomass due to sand mining, which severely disrupts the local ecosystem (Morley et al. 2022: 3).

Sand extraction disturbs the vegetation on the banks of rivers and lakes, which causes additional damage to various organisms. The beds of rivers and lakes are shifting due to sand mining, which causes landslides. Especially in coastal areas, however, the masses of sand on the beach ensure safety during storms and floods, which are then no longer present due to the landslides and hence leave the population unprotected. In terms of groundwater, sand mining causes changes in the direction of water flows, water depths and currents strengths, which affects, among other things, the water quality and groundwater for the surrounding population (Filho et al. 2021: 9ff). In Mumbai alone, over 80,000 fishermen have turned away from fishing and turned to working in sand mines (Pereira 2020: 83).

Soil extraction and sand mining from open pits also causes several environmental damages. Science shows, that former pits are retaining rainwater, posing health hazards and cause floodings since the soil is not able to absorb the water after excessive mining activities (Tasantab 2021: 3). Furthermore, after serving as open pits for sand mining, the land mostly remains unsuitable for agriculture and crop cultivation which also affects the food supply of locals (Tasantab 2021: 4).

An important function of sand is in the form of beaches as a natural protective barrier during high tides and flooding. Researchers have confirmed that Sri Lanka, for example, was so severely affected by the damage caused by the 2004 tsunami because of the excessive sand mining that had been carried out for decades, since the country had previously suffered massively from sand mining and beaches were missing as a natural protective barrier (Pereira/Ratnayake 2013: 10).

According to Lamb et al (2019), there are three main groups that have been neglected in previous research on sand production and trade. On the one hand, there are those people who are directly affected by sand mining because they cultivate riverbanks or sandbanks on their subsistence or semi-subsistence farms. The second group represents those people who are indirectly affected by sand mining. These can be small fisheries that lose coastal areas due to increased sand mining, are less able to fish and are therefore affected by poverty. The third group mentioned by the authors are the miners in the sand mines. As already mentioned, the working conditions are tough, and the employment relationships are mostly insecure (Lamb et al. 2019: 1513ff).

To sum up, the social, economic, and ecological damages to humans and nature are severe and are not just happening in the Global South. The loss of biodiversity, the loss of fertile soil for agriculture, the loss of barriers against floods and storms and the economic damage through illegal trade and corruption are some of the most severe impacts of the excessive demand for sand that societies are currently consuming.

5. Circular Economy in Construction

After presenting circular economy from a theoretical perspective in chapter 2.2 (Circular Economy), this chapter aims at explaining circular economy in construction from a theoretical perspective, as well as displays the empirical results reported by interview experts on how they define circular economy in construction and what circular activities are already implemented in construction.

5.1.How Literature Defines Circular Economy in Construction

There is a broad literature on defining circular economy in the construction sector. The following table shows an overview of definitions of circular economy in construction:

Table 6. Definition of circular economy in the construction industry context (Osobajo et al. 2020: 9).

Authors	**CE in construction**
Fernandez (2007)	It entails activities that both supports economic growth and facilitates the closing of material loops and the overall promotion of resource efficiency
Yuan et al. (2011)	Is the flow of raw material to product, then not to waste in the environment but to regenerated product
Dean et al. (2014)	It is aimed at improving the efficiency of materials and energy use
Smol et al. (2015)	It is keeping the added value in products to eliminate waste
Wang et al. (2015)	Is the transformation of resources to products to regenerated resources mode

Esa et al. (2017)	It is an approach for waste minimization throughout the overall construction cycle
Nasir et al. (2017)	It pushes for a closed-loop supply chain design, enabling any products at the end of their life cycle to re-enter the supply chain as a production input
Ghisellini et al. (2018)	Is a new model of economic development that promotes the maximum reuse/ recycling of materials, goods and components in order to decrease waste
Akanbi et al. (2018); Huang et al. (2018); Minunno et al. (2018)	Is reducing, reuse and recycling of materials
Leising et al. (2018)	Is a system where material loops are closed and slowed and value creation is aimed for at every chain in the system
Mahpour (2018)	A system that is restorative or regenerative by intention and design to replace the end-of-life concept with restoration
Sierra-Pérez et al. (2018)	It optimizes raw material use to minimize environmental impacts

It can be summarized, that the circular economy in construction has a strong economic focus, mentioning efficiency (Dean et al. 2014; Fernandez 2007), economic growth (Fernandez 2007) and economic development (Ghisellini et al. 2018) when defining circular economy in construction. In addition to that, some experts have stated that circular economy in construction is often mixed up with concrete recycling (I. 4: 1), seen as a “necessary evil” (I. 9: 1), but still realizing the need to shift towards a more sustainable consumption due to the enormous amounts of materials being used (I. 3: 4).

In construction the main circular activities aimed at a perspective of buildings as material banks, where resources are temporarily stored and as soon as they reach their end-of-life phase they are re-integrated into the planning and design phase of a new building (Benachio et al. 2020: 4). The four key stages of buildings, that are considered for circular activities are project design, material production, construction, operation and end-of-life. As buildings are usually built with a long term perspective it is important to include circular activities already into the first stage, the project design and planning phase (Benachio et al. 2020: 5ff.). Research shows that most of the scientific articles focus on the end-of-life phase when it comes to circular activities in the construction sector with two-thirds of all articles mentioning only circular activities to avoid waste, e.g. material recycling (Benachio et al. 2020: 6). This shows that research is still trying to understand how circular economy activities can be implemented in the different stages of a building's lifecycle. This lack of knowledge can be explained by particularly complex supply chains and often short-term oriented construction companies, that don't include long term perspectives on the end-of-life stage of buildings into their planning (Benachio et al. 2020: 8).

A particular focus in the implementation of circular activities in construction is given to the reuse of materials. As this research seeks to investigate the potential of circular economy to improve the construction sand supply chain this aspect is specifically important to mention. The reuse of materials could help to avoid the sand crisis, sand shortage and over consumption of non-renewable resources. The concept of reusing materials can be structured into three different levels. The micro-level of reusing materials focusses on specific materials that can be reused in specific components of new buildings. An example for that would be recycled concrete, cement or other building materials such as timber. The meso-level includes applications of reuse in whole buildings, not just focusing on specific materials such as concrete or timber. The macro-level looks at the construction sector as a whole and tries to integrate material reuse from the end-of-life stage into the planning phase. With this approach buildings should be designed and built with a view to preserving resources for as long as possible but already taking into account the circularity of specific materials (Benachio et al. 2020: 9). Saliba et al. (2023) argue that the micro-level of circular economy analysis also includes the social impact of circular economy on people and their work, whereas the meso-level analyses a broader understanding of circular business activities in industries and the macro-level focuses on broad impacts on material consumption across industries and sectors. According to the authors, over 80% of circular economy research addresses the macro-level of analyzing circular economy and only 11% of research addressing the micro-level with all its social impacts on work and livelihoods (Saliba et al. 2023: 20ff.).

In addition to general concepts for the reuse of materials research also highlights the importance of material passports. In order for buildings to be seen as material banks and storages the public needs to know which materials are currently used and which materials are soon to be demolished, which can then be kept in the circular loop and be used in the planning and design phase of new buildings (Benachio et al. 2020: 8ff.).

According to Hofstetter et al. (2021) linear models still dominate industry and research. The newly published report by the German Sustainable Building Council (DGNB) also supports this argument, stating that only 8,6% of the construction industry is circular (DGNB 2023: 8).

Some key aspects of why the construction sector is so tied to the linear economy are the cheap raw materials that are widely available, and the exploitative and cheap labor conditions that deepen the lack of accountability. The construction sector in general lacks a culture of repair and maintenance, as the materials and products are built to being disposed. This is also a reason why recycled material are not competitive in terms of pricing compared to new building materials (UKGBC 2023: 11).

5.2. How Construction Experts Understand Circular Economy

In addition to the definitions provided by literature, this thesis also includes an empirical analysis of the valuable perspectives of construction experts and how they define circular economy in construction.

In the construction sector circular economy activities are defined as practical approaches to keep building materials in a closed cycle for as long as possible in order to reduce the need for primary resources within a construction project (I. 3: 1).

> “(Circular Economy is the) Protection of the environment, protection of resources and the reusability of our products after the building's use phase. So, we are already thinking about what will happen to our products if the building is converted or dismantled at some point.” (I. 13: 1)

The construction industry is aware of their huge impact on environment, whether thinking of their carbon footprint or their immense material consumption (I. 3; I. 4; I. 5; I. 11; I. 12; I. 13; I. 14). The quote above shows that the central part of circular economy in construction is to think about the end-of-life stage already when planning a construction project.

Initially circular approaches came mainly from plastic industries, that had a leading role in developing circular business models to avoid waste and plastic pollution. According to industry experts, the construction industry recognized the potential in using those circular models because of the large amounts of materials that are used in the construction sector (I. 3: 4).

> "Circular economy is the paradigm shift from a linear economy, where resources are taken and thrown away, to a circular economy, where resources stay in a closed loop." (I. 11: 1)

Another industry expert, however, mentions that the definition of circular economy depends on the construction actor you are asking:

> "I think depending on who you ask you will get a different answer. Material manufacturers think more of recycling or downcycling. Planners are more concerned with enabling sustainable procurement of raw materials. From my perspective, however, the construction industry as a whole sees it as a necessary evil, for example due to EU laws." (I. 9: 1)

According to industry experts, the construction industry is intensely money-driven, which causes the industry to focus on the economic and monetary drivers of a project instead of moral or environmental questions. In contrast to that, architects and planners are more often morally driven and tend to think more about resources and materials in general up to a total rejection of demolitions (I. 9: 1ff.).

Another industry expert mentions, that circular economy is still often mixed up with concrete recycling, meaning that the other dimensions of circular economy, e.g. reducing or remanufacturing materials are mainly left out (I. 4: 1) and hence one main problem is "the misunderstanding that it is confused with concrete recycling" (I. 4: 1). Explaining this further, the expert mentions that instead of focusing on the end of the resources lifecycle, the construction industry should start with the planning phase when defining circular economy:

> "We preach a planning and building culture, so to speak, that really looks very closely at what a building site is and how can I make the best possible use of it there? Because only then can we use circular economy for climate protection purposes, so to speak. Otherwise it is an end in itself, (…). If circular economy consumes more energy and has no ecological balance, which has an advantage against primary raw material regeneration, it is nonsense." (I. 4: 2)

> "This means, then, that the circular economy takes place first and foremost at a very high level, at a very high altitude, in the area of urban planning and project development, and can only then be perfected all the way to actual construction. But if this first step is missing, it is already incredibly difficult to take any more steps." (I. 4: 3)

5.3.Circular Activities in Construction

Circular economy has several chances to make the construction sand supply chain more sustainable. Most of those promising activities aim to reduce the amount of primary raw materials, including sand. Since this research tries to evaluate the effects of circular economy activities on the supply chain of construction sand, only relevant circular economy activities in the construction sand supply chain are being mentioned and analyzed, since there would be many more circular ambitions in the construction industry in general.

The central chance of circular economy is that there are no adaptable alternatives in economics that will be adapted in a capitalistic world. If we as a society want to address waste issues and material scarcity as well as environmental and social damages due to mining and dredging activities circular activities and concepts need to be enhanced and encouraged so that resources can be saved (I. 2: 3).

Wijewickrama et al. (2021) define different circular activities along the supply chain in the construction sector. In the first phase of project design the potential reuse of materials should be analyzed and included into the planning of buildings. In the second phase of the construction project, the production of the materials, the following circular activities are mentioned: Manufacturing companies should be motivated to reuse their own materials and to prepare material passports for this, so that there is constant knowledge of the materials currently used and stored in buildings. This is also known as urban mining, where already built buildings are seen as a material storage that can be used after demolition. In general, as many materials as possible should be reused at this stage. The third phase of construction aims to use recycled materials on site and reduce construction waste. In the fourth stage, the usage phase of the building, the cost and use of materials should be analyzed to be able to continue working with the materials used in the future. In the last end-of-life phase, the demolition of the building is designed in such a way that as little construction waste as possible is produced and the demolished materials are already planned for transport to newly planned buildings or for previous processing. Finally, the building passports should be updated and thus create an optimal basis for reuse in urban mining (Wijewickrama et al. 2021: 3).

The following table 7 summarizes the ten circular economy activities in construction, which were reported in the conducted expert interview of this thesis:

Table 7. Circular Economy Activities in Construction.

#	Circular Economy Activity in Construction	Problem addressed in Construction Sand GVC	Highlighted by Actor Type
1	Concrete Recycling	Reduce primary sand resources through substitution	Industry, NGO, Research
2	Process demolition waste on site	Reduce transportation costs and emissions	Industry
3	Advanced sorting system for construction and demolishing waste	Improve recycling quality	Research
4	Processing soil excavation on site	Reduce primary sand resources	Industry
5	Precast Concrete	Reduce primary sand resources	Industry
6	Urban Mining / Material passports	Reduce sand demand, avoid waste and enable circularity of buildings	Industry, NGO, Research
7	Modular building	Avoid waste and enable circularity of buildings	Industry, NGO, Research
8	Alternative building materials	Reduce primary sand resources	NGO, Research
9	Material leasing	Reduce primary sand resources	Industry

10	Adaptive reuse of buildings	Reuse buildings and reduce primary resources	NGO

Empirically, the central circular activity in construction is concrete recycling, which is the first circular activity in the table above. All interviewed experts are aware of concrete recycling being the main activity when it comes to circular economy in construction. Concrete recycling is most obvious initiative since concrete is the main product which is made of sand. The main trigger of concrete recycling is material scarcity, which is receiving more awareness within construction actors.

Concrete recycling can be done in a high technology chain of machines. After a building gets demolished, the material gets sorted and transported to a recycling center. A recycling center consists of a chain of technological machines, that sorts the demolition waste into different aggregates. Figures 20, 21 and 22 show those machines and the sorted aggregates. The machines are working with magnets and sorting technologies, separating the aggregates from other materials like metals, plastics, and toxics. The aggregates run through the whole chain of machines, sorting and crushing the material ever finer until it has the demanded sand-like size. Those aggregates are then being sold to construction companies that are using it mainly as unbound aggregates for asphalt construction or as additional aggregates for concrete and cement production (I. 3: 6ff.). One NGO expert adds, that as of today, not one single country can cover their demand for construction sand through concrete recycling (I. 2: 2).

Figure 20. Recycling center machine chain (A.M.)

Figure 21. Recycling machine (A.M.)

Figure 22. Recycled and sorted secondary aggregates that replace construction sand (A.M.)

Figure 23 shows that 60% of Austrian construction projects comply with reusing and recycling 90% of construction and demolition waste. European countries like Switzerland, Denmark, Germany and Benelux countries have lower quotas, which means not even half the construction projects are reusing and recycling 90% of the construction and demolition waste, except Denmark, who has a quota of 57%. However, the lack of valid data plays also central role in those data overviews, since there is no concrete way of tracking the data and pulling apart, how those quotas are being defined and tracked.

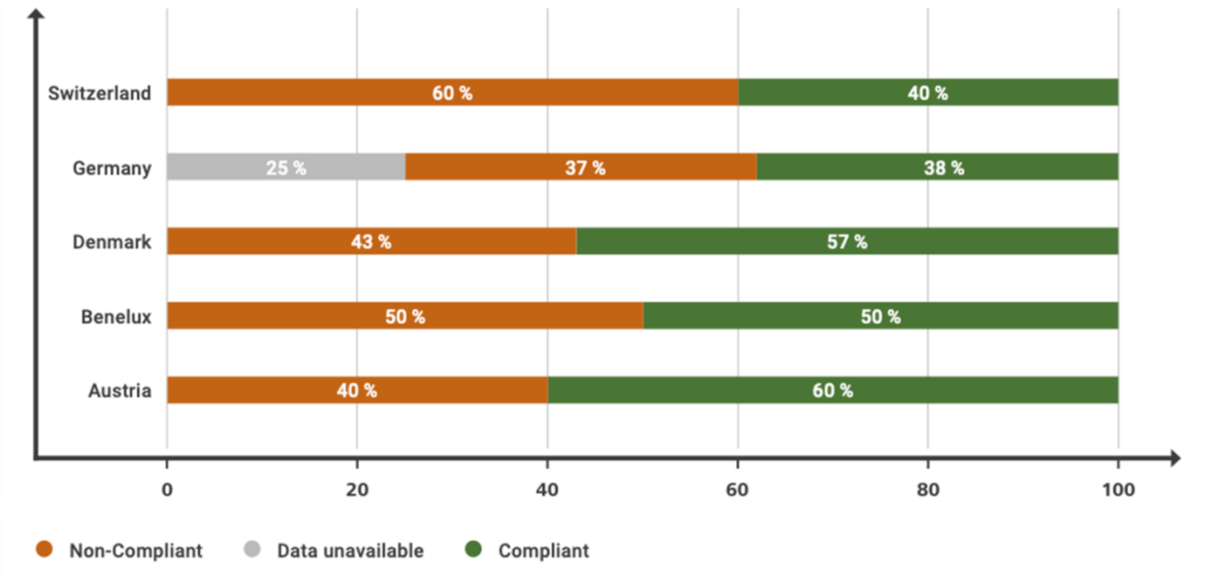

Figure 23. Country comparison: reusing and recycling 90% of construction and demolition waste complying with the EU taxonomy (DGNB 2023: 22)

The DGNB published a country comparison on how the construction projects of a country comply with the EU taxonomy of reusing and recycling 90% of construction and demolition waste. It shows that in an international comparison Austria has quite good quotes, with 60% of construction projects reusing and recycling 90% of the construction waste (DGNB 2023: 22).

The second circular activity that is currently implemented in the construction sector is processing demolition waste on site. This can be done to avoid transportation costs and to ensure that the recycled material is used right away for the new construction project (I. 3: 5). This was already successfully implemented in some projects, e.g., a pilot project in Paris. In this project, demolition waste was recycled on site to secondary aggregates in a local machine und processed to concrete in a local concrete plant (Pereira 2020: 167). Another example is one construction project in Munich, where demolition waste from the old building was recycled on site and used for the new construction building (Sonderabfallwissen 2020). According to NGO experts, this technology is cost- and energy-intensive, which makes it not accessible to every country (I. 2: 3), which will be further outlined in chapter 5.4 (Limitations of Circular Economy in the Construction Sand Value Chain).

The third circular initiative in construction is developing an advanced sorting system to improve the sorting and recycling quality of concrete to save natural sand resources. This activity is mainly done by scientific institutions like the Fraunhofer Institute, that is focusing on new innovations in the field of concrete recycling for a high-quality recycling, which enable a reusage of resources on an equal quality level. Currently, concrete is recycled mainly mechanically through crushing which creates a sand-like aggregate that will later be used as an additive material for concrete production. With the new Fraunhofer Institute technology, the demolition waste gets separated into the original aggregates through underwater high pressure electric explosions: A method, which is called Electrodynamic Fragmentations, which are high power impulse methods. With this technology, concrete is put under water, gets shot with ultra-short spikes in the range of 120 nanoseconds in length, which then run along the surface of the grains, mechanically weakening the concrete. “You get an electric shock and an electric explosion, and the explosion can practically blast the concrete apart at the original grain boundaries” (I. 5: 3). Using electrodynamic fragmentations to sort concrete could change the whole way how concrete gets recycled, because it can transform recycling towards an equal value recycling in a closed and endless loop, according to research experts. This technology enables an advanced sorting and recycling system, which saves natural resources like construction sand through keeping primary resources longer in the cycle. According to one of the research experts, this innovative technology can ensure that natural resources like construction sand can be recycled several times (I. 5: 3).

Another huge opportunity and the fourth initiative of circular economy in construction is the usage of soil excavation on site so that no new primary resources need to be transported to the construction place. Currently, most soil excavation gets deposited because in the beginning of constructing buildings the construction companies do not have enough space to store the soil excavation until usage. Therefore, minerals like sand get deposited, but are being transported to the construction site later as fresh concrete from a supplier. Using the soil excavation right away at the construction site would need a mobile processing infrastructure but could win extra 40 million tons of sand in Austria per year (I. 3: 4ff.).

> “One aspect that is pretty promising is using soil excavations, which are the largest flow of material anyway. In Austria, that's about 40 million tons a year as excavated soil and 30 million tons, i.e. 3/4, are landfilled and only 10 million tons are used for backfilling or something. And I see potential there, if it's only 5 or 10 million, then that's 50% or 100% of the demolition materials, so you could double the amount in recycling, for example. That you look at what of the 30 million tons is just recyclable, there are certainly enough excavations that end up on the landfill for structural reasons (...), if materials have to be landfilled. But I still believe that some of the excavated material could be fed back into the cycle." (I. 3: 4ff.)

According to industry experts, there are already some projects in Austria, where the architects are using soil excavation on site. One famous Viennese project is the Seestadt Aspern project led by architect Thomas Romm, where the soil excavation was processed on site which led to a 50% reduction of needed primary aggregates like construction sand (I. 4: 3; I. 3: 8). Figure 24 shows that project and the “Viennese Model” of circular building.

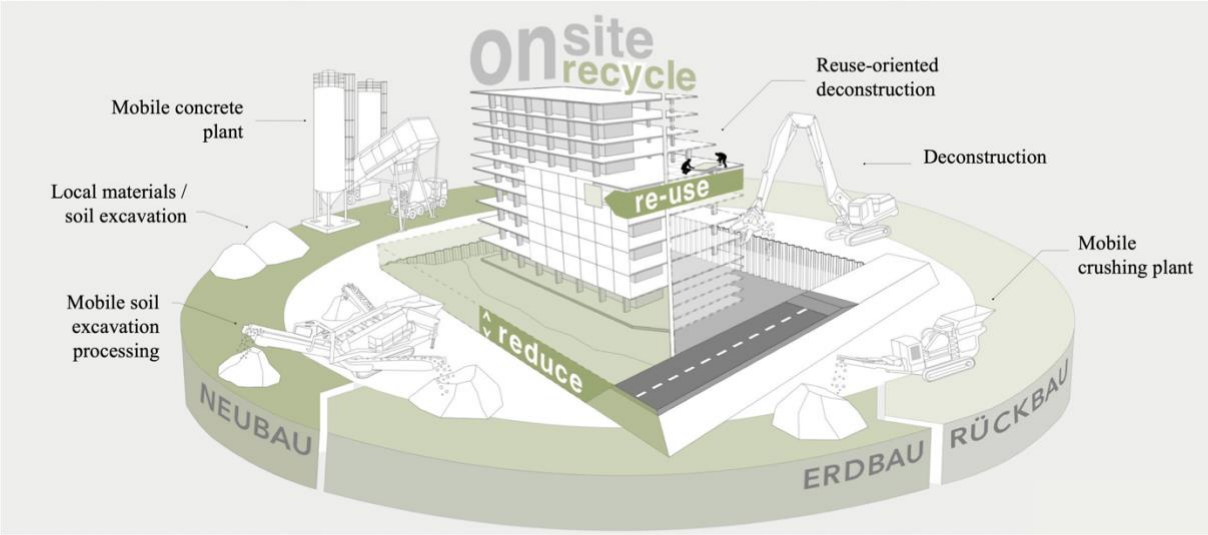

Figure 24. The "Viennese Model" of circular building (Romm/Kasper 2018: 37)

The Viennese Model is a building method, which aims at reducing primary material flows and demolition waste with using circular activities such as concrete recycling, processing of soil excavation and reuse-oriented deconstruction through mobile construction plants, which are processing materials on site (Romm/Kasper 2018: 36ff.).

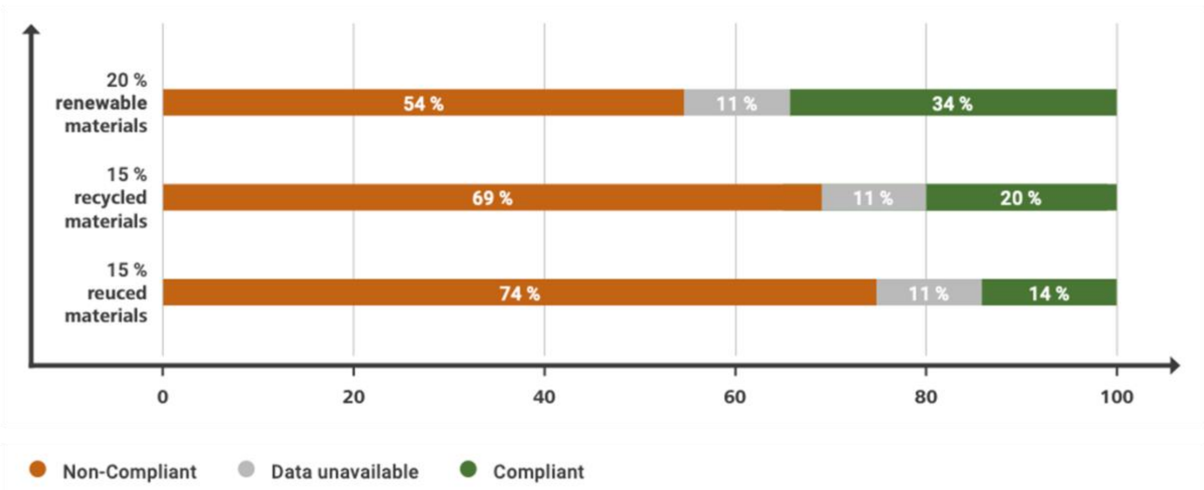

Figure 25. Material requirements within the EU Taxonomy (DGNB 2023: 25).

Figure 25 shows that only a third of the projects fulfilled the quota of 20% renewable materials, while the quotas for recycled materials and reused materials were only fulfilled by less than a third of all reported projects (DGNB 2023: 25).

One of the industry experts reported that precast concrete (activity 5) may lead to a more efficient circular usage of concrete, since it enables concrete production without side effects of construction sites, like material waste or machine inefficiencies (I. 8: 4). However, no other expert reported precast concrete as a circular activity. Another industry expert provides his evaluation of precast concrete:

> “With precast concrete elements, I'm always skeptical about whether it's really worth it. And of course you no longer have individuality in new construction, although that could also be a good point for a social change, that you no longer need something totally individual out of necessity. This also goes in the direction of modular construction, where you also have this. It may well be that prefabricated concrete elements make it possible to build more quickly and to prepare the concrete independently of the weather or to work more precisely without waste. It's about 5%, so of course you can use resources more efficiently." (I. 3: 10)

Hence precast concrete may lead to a more sustainable resource consumption, but since it also enables a faster construction due to less waste and weather-independent production, it may also lead to more resource consumption in the long run.

The sixth circular activity in construction is working with material passports. Following the concept of circular building, buildings must be seen as material banks, that store materials for a specific period before providing materials for new buildings. One important aspect is using material passports to collect regional data on the amount, qualities and different types of building materials that are currently stored in a city. There are mainly startups in the construction sector that focus on creating material passports for buildings, which aim to collect important data about buildings and materials used for later reusage (I. 9; I. 2; I. 3). One German startup is Madaster, which is trying to move cities towards seeing their buildings as material banks to plan and build from in the future. It is most recently collaborating with the German city Heidelberg for a unique project in Europe: Together with the city government, Madaster is aiming to collect all data about all the materials, including minerals, that are currently installed in Heidelberg’s buildings. With this data, the infrastructure for recycling will be installed and secondary materials and minerals can be planned for new buildings (Schmale 2022).

Another chance for planning buildings is circular activity 7 (Modular building), which means creating standardized pieces, that can be split afterwards for reusage or recycling. This would enable an increased circularity capability right from the start of a building lifecycle.

> "So, we look at the conception, the materials, we focus very strongly on timber construction and modular construction on industrialized construction methods that are manufactured as serially and very integrated as possible from design to production to use. And we have a function as an advisory team (…) that makes sure we educate the whole industry and help our customers to make their business projects more circular." (I. 11: 1)

In addition to those activities, that aim to reduce primary resources through recycling and remanufacturing, other activities need to take place. Therefore, alternative building materials must be used. While alternative building materials (Activity 8) are a specific field of sustainable and green building, they still have an important impact on circular economy. Using the circular supply chain concept of Farooque et al. (2019), circular economy does also mean the exchange of materials and interactions with other sector, aiming to reduce the general consumption of natural resources. Alternative building materials are a broad research field. The most used alternative to sand and concrete is timber, since it is seen as a renewable resource. Timber can be used as a biotic construction material for almost all components in a building (Binder/Riegler-Floors 2018: 102).

Zadeh et al. (2022) state, that alternative building materials were mainly researched to reduce greenhouse gas emissions, not to replace sand, which furthermore underlines the low global awareness of the sand crisis. The authors list agricultural waste, recycled rubber, construction and demolition waste, iron, quarry dust, glass powder, silica fume, slag, as well as washed bottom ash as the main alternatives for sand in construction. Most of the materials are byproducts of production of other sectors, such as agricultural waste, silica fume, slag and washed bottom ash, which work as a sand replacement in the production of concrete and cement (Zadeh et al. 2022: 3ff.).

The ninth circular initiative in construction is material leasing. One of the main problems to develop a truly circular economy in construction is the involvement of several actors. Due to the long lifecycle of buildings, materials like construction sands are going through a number of actor's hands, from being mined by a mining company, to being processed by a material manufacturer, to being used in construction projects by construction companies to then being recycled by recycling companies. In a linear economy, it is almost impossible to reuse materials that were manufactured by a company, that did not think of circular usage in the first place. That is why material leasing is an interesting initiative to ensure the material manufacturers get their material back to reuse it in a closed loop (I.10: 3). According to industry experts, however, this might be an unrealistic initiative, since companies may not exist after the long-term usage and consumption of building materials, which can be +50 years and moreover, could work as a misleading incentive since it motivates involved actors to demolishing buildings instead of extending lifecycles of buildings and their materials (I. 3: 10).

A central activity to reduce construction's demand for construction sand is to adapt old buildings into new applications without demolishing the whole building, which represents circular activity 10 (Adaptive reuse of buildings). With this approach, a degrowth perspective can be achieved, since the adaptation of old buildings would be a first aim to not build more in order to grow and instead degrowing from a resource consumption point of view. The "Be Circular – Be Brussels" construction project aims at preserving resources through an adaptive reuse of buildings in Brussels. Several architects and planners are collaborating to plan buildings which are adapted into existing buildings and therefore support the reuse-dimension of circular economy. The project, which consists out of more than 14 smaller construction projects in Brussels, underlines the importance of partnerships across the industry to close material loops (Maerckx et al. 2019: 2ff.).

Sanchez and Haas present a framework for the adaptive reuse of buildings (Figure 26) as a potential to lower environmental loads but underline the lack of knowledge about the implementation. Moreover, the impacts are difficult to measure, which makes the adaptive reuse of buildings a common activity in construction, which lacks specific applications to a real sustainable resource consumption (Sanchez/Haas 2018: 1000ff.).

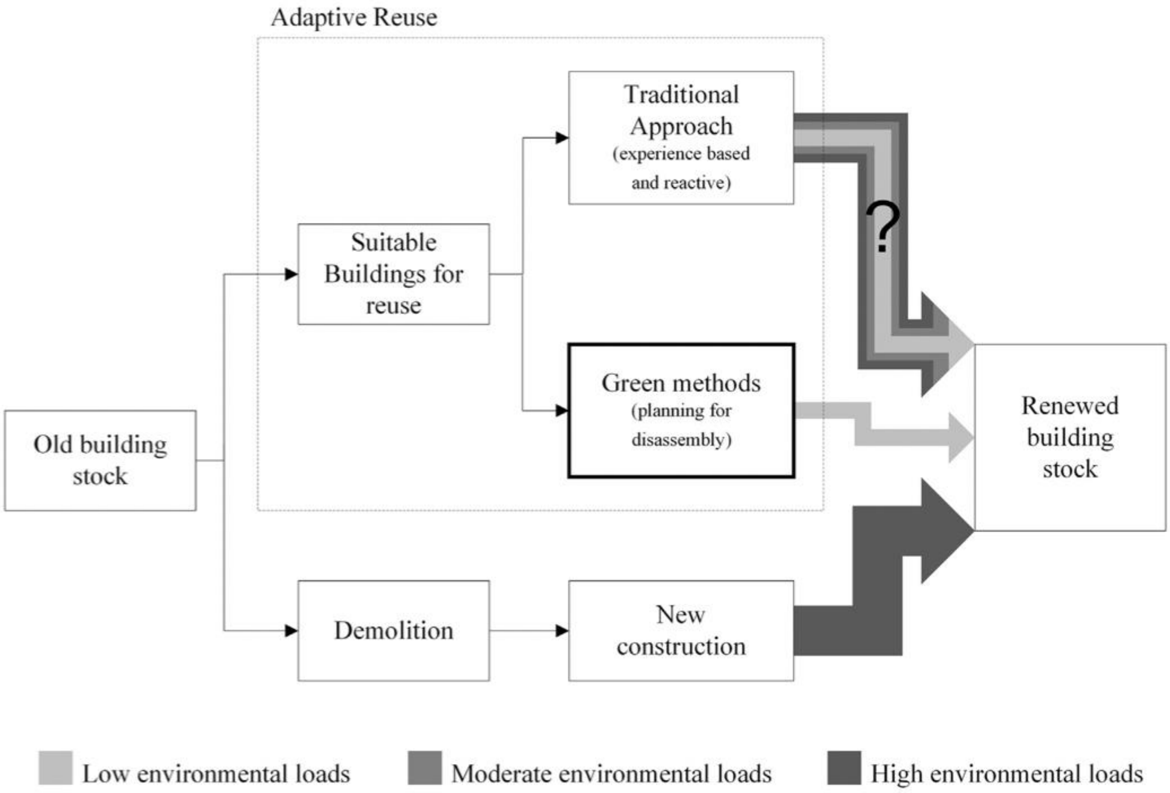

Figure 26. Adaptive reuse concept (Sanchez/Haas 2018: 1001).

To sum up, the circular activities in construction focus on recycling and reusing primary materials such as construction sand as secondary materials for new construction. This applies for concrete recycling, processing demolition waste on site, advanced sorting system for construction and demolition waste, as well as processing soil excavation on site. Other circular activities such as precast concrete, material passports, modular building and alternative building materials try to shape a new framework of building through planning buildings in a more sustainable way right from scratch in the planning and design phase. Material leasing aims to create flows back to the supplier to keep resources such as construction sand in the production system. The adaptive reuse of buildings, however, is the only circular activity that was reported in this empirical study that really aims to reduce construction activity, instead of building more. Nevertheless, according to current construction activity data, most construction projects still demolishes and builds new from scratch without thinking about adaptively reusing existing buildings.

5.4.Limitations of Circular Economy in the Construction Sand Value Chain

There are several limitations when it comes to implementing circular business models in construction. The industry, research and NGO experts provided a total of seven limitations, which will be outlined in this chapter.

The following table summarizes the seven main limitations of circular economy in construction which were reported by the interviewed experts.

Table 8. Limitations of circular economy in construction

#	Limitation	Involved actors
1	Lack of data and awareness	Industry actors, political actors, NGOs, research actors
2	Focus on recycling and problems of recycling	Industry actors (especially recycling actors), political actors, NGOs, research actors
2a	Demand cannot be covered by secondary materials	Industry actors (especially recycling actors), political actors, NGOs, research actors
2b	Downcycling	Industry actors (especially recycling actors), political actors, NGOs, research actors
2c	High price of secondary materials	Industry actors (especially recycling actors), political actors, NGOs, research actors
3	Technology	Industry actors, political actors, NGOs, research actors
4	Lack of circular planning	Industry actors (especially architects and planners), political actors
5	Lack of mining focus	Industry actors, political actors, NGOs, research actors
6	Lack of distributive questions	Industry actors, political actors, NGOs, research actors
7	Degrowth	Industry actors, political actors, NGOs, research actors

Circular economy has several limitations when it comes to solving problems along the construction sand supply chain. Several experts agree that circular economy following a capitalistic framework will stick to a growth mindset that will lead to more resource consumption instead of reducing it (I. 1; I. 2; I. 3; I. 4; I. 5; I. 8). The awareness that circular economy should do exactly that, reducing resource consumption is widely spread but not completely understood in terms of sand, especially in the construction industry. The construction industry has a broad knowledge about consuming most of the natural resources and being a main trigger of consumption, hence the awareness that this intense resource consumption needs to be reduced is being recognized. Still, the drastic problem of sand consumption is not fully known, especially with industry actors in Austria and Germany.

Therefore, the first main limitation of circular economy in construction is the lack of awareness and the resulting lack of data on sand mining, sand trading and sand consumption in general. To analyze the construction sand value chain, reliable data from mining to construction is needed, which is currently not available. If the construction industry really aims to reduce primary resources, it needs to document properly which amounts of resources are used (I. 1; I. 2; I. 3). In addition to that, we also have little to no data about how much sand resources are saved through concrete recycling and using secondary aggregates. To analyze the impact of circular economy the industry must change towards a transparent and open mindset. According to industry experts the construction industry is avoiding transparency mainly because of high margins and earnings at the end of the construction sand value chain and because of its conservative way of operating (I. 8: 13; I. 7: 1).

Two NGO experts express their view on the lack of data and transparency:

> "The honest answer (…) is that I don't think anyone knows the complete picture yet. And this is a very problematic issue because it is not transparent at all. It depends on the end use and depending on the use a lot of information is on the private sector, so it is not known to the public. In other areas we just don't collect the data." (I. 2: 1)

> "The first step will be to collect more data, to increase academic projects on that area. Implementing those would be key, and then policies will hopefully follow." (I. 2: 5)

> "It is really hard to find a solution for sand because we do not know what we are talking about. Some years back I tried to understand how much marine sand is extracted and I asked the industry, and they told me they just not know. There is also a lack of traceability. And even if we know how much sand is extracted somewhere how do we trace that sand into its final use? (…) So it is not just transparency it is also traceability. But also does two things are just not enough and sufficient. So ultimately increasing

> those in the sand value chain will enable higher accountability. So if you know who does what and where then you can start moving the needle on the regulatory landscape.“ (I. 1: 6)

In addition to the lack of data and awareness the labeling of resources as “waste” is problematic. According to industry and NGO experts (I. 5; I. 2; I. 4), it is crucial to change that way of thinking and talking about secondary resources:

> “Also the labeling of the products as waste, (…), there is simply an acceptance problem when you say you have to pay the same amount or sometimes even more for a waste product, it will be in the broad masses, where the problem is not so well known and conscious, there will not be the same, the same demand as for fresh material, so to speak” (I. 5: 6)

An NGO expert also highlights this problem and speaks of an “image problem” (Pereira 2020: 165). According to her, the word “recycled” appears as a stigma (Pereira 2020: 165).

Because of that, there is a strong hesitation amongst construction actors to use recycled concrete for buildings due to a lack of information about safety and liability of the material (I. 9: 2). The construction industry needs incentives for pilot projects, that cover the first risks to ensure that other actors can rely on those project outcomes. According to one industry expert this is crucial for the success of circular economy in construction (I. 9: 2). Hence, major limitations are statics and compression strengths, that are defined through industry standards and regulations (I. 3: 8). Research experts reply to those comments that research and science is already providing those projects to show that recycled concrete has the same liabilities as primary concrete, but the industry is not willing to hold the risks of such new way of buildings. According to one research expert, industry standards and regulations must change to support this transition towards circular building (I. 5: 8).

The second limitation of circular economy in construction is the focus on recycling and the several problems of recycling which are currently not solved and hinder the full coverage of primary aggregates through secondary aggregates.

When talking about circular economy in construction, the main activity is concrete recycling. To enable the full potential of circular business models in order to reduce resource consumption, the industry needs to implement other circular potentials, such as reducing or reusing materials, also because recycling comes with several problems.

The main problem of recycling is that it cannot cover the current demand for primary materials such as sand and other aggregates. Several experts across all actor types agree, that as long as a society builds more than it demolishes, we will need primary resources because the demand cannot be covered through secondary materials (I. 2; I. 3; I. 4; I. 5; I. 6; I. 8). One industry expert elaborates that all secondary aggregates in Austria can only cover 10% of the demand, which sums up to a total of 100 million tons needed aggregates per year meaning that the demand is ten times higher than the available 10 million tons of secondary aggregates in Austria. According to him this can be scaled up and compared to almost every European country, also to those with relatively high concrete recycling rates such as Switzerland or Germany (I. 3: 4). Following those numbers, circular economy cannot be an adequate solution solely to solve social and environmental problems of construction sand mining and consumption.

> "But in this case, that we need about 100 million tons of mineral building materials a year in Austria, but only have 10 million tons of recycling material, shows the great challenge when you think about recycling or circular solutions. Because the cycle is difficult to close if I can only cover 10% of the materials that come out of the cycle. Then the logical consequence is that we need to build less, or build leaner, build more resource-efficiently." (I. 3: 4)

Furthermore, alternative building materials such as timber are seen as a renewable resource but cannot cover the excessive demand for construction to fully replace sand. According to a research expert, it is only a resource shift, if we stick to our consumption without reducing the demand for construction materials. Hence, it will not lead to sustainable resource consumption without a socio-economic transformation happening accordingly (I. 7: 2).

In addition to the 10:1 ratio of needed aggregates and available secondary aggregates, another problem is the continuous growth in the construction industry. According to industry experts, the Austrian construction industry builds ten times more buildings than it demolishes per day. Hence, the construction industry still grows exponentially which will lead to even more resource extraction and consumption (I. 3: 8).

> "Recycling, as you know, can only cover a small part of the demand. So, we simply have the problem in the construction industry that we need three times as much material as we would have available in waste management." (I. 4: 1)

Other industry and NGO experts agree that the current demand for construction sand cannot be covered through recycling and is far from ever being able to due to the ongoing construction boom and the steadily increasing resource consumption (I. 2: 2; I. 3: 4).

Paradoxically, there is a widely spread narrative that there are enough natural sand resources in Austria and Germany because it is mined through open pits directly from the ground (I. 2; I. 4). But this procedure has several limitations itself, since there is a rising number of land conflicts in most of the land areas due to agricultural and social land use conflicts. Moreover, the extensive sealing of land especially through construction is reducing the potential number of pits in the future. Several industry experts highlight the importance of land conflicts in the future in Europe (I. 3: 3; I. 4: 10; I. 5: 9). According to one industry expert, there are already land conflicts in Austria and Germany, because of the excessive construction activities and the land sealing (I. 3: 3), another industry expert highlights land conflicts because of wind power utilization and agriculture (I. 4: 10). Furthermore, several industry and NGO experts reported environmental damages of pit mining in the Global North in chapter 4.2 (Social, Economic, and Environmental Problems of Sand Mining). One NGO expert comments that this narrative of non-damaging soil excavation of the Global North is an extremely shortsighted view, that needs to be changed. Moreover, the general awareness needs to be raised, that the extensive construction sand demand causes global damages for the society as well as the environment (I. 2: 3).

> “Well, I know there is already a lack of sand in Europe, for example in Sweden. They have a lack of sand, while the French tend to have gravel. We are lucky in Germany, I would say, we have gravel in the south and sand in the north. We can still balance it out to some extent. But what is almost impossible is to get a permit for the new gravel pit in Germany, a new sand pit and that's where the lack of sand comes from.” (I. 5: 9)

When it comes to recycling, the second problem is downcycling. As of today, most of the recycled concrete and demolition waste is used for road fill and therefore does not maintain an equivalent quality (Pereira 2020: 160). Other experts, however, responds to the downcycling narrative, that nevertheless, natural resources get saved because no primary resources are then used for road fill (I. 3: 7; I. 4: 1). According to one NGO expert, materials that are used in lower value applications cannot be recycled again afterwards. When demolition waste is downcycled for road fill, it is almost impossible to recycle the aggregates again, which disables a closed loop system for this material (Pereira 2020: 160).

> "So more often than not, those buildings are being deconstructed, most of it is downcycled, but not upcycled or used on an equal level. So we are losing a big value, that is in those material, those resources cost a lot of social and environmental damages but if we lose that value than, all of those costs are externalized on society and the environment. It's a crime in today's context." (I. 2: 2)

Weak or non-existing policies to support the usage of recycled materials and to promote its opportunity further limit the potential of circular economy. Having regulations in place, that specify and guarantee the quality of materials, especially of recycled materials or sustainable mined materials could have huge impacts on the sustainability of the whole construction sand supply chain:

> "Thomas Kasper and I have long agreed that we need regulatory sustainability, just as we do for other basic requirements for buildings. Why is structural engineering, i.e., the stability of a building, a basic requirement and sustainability is not?" (I. 4: 6)

The third problem of recycling is the high price of recycled materials. One of the reasons for the mismatch of supply and demand in terms of pricing is, that customers simply do expect secondary materials to be cheaper than the natural aggregate. But natural sand is so cheap already, that there is not even much of a range for recycling companies to offer recycled aggregates for a competitive price (Pereira 2020: 166).

> "Well, it is a policy issue. When recycling concrete is so expensive, because a whole infrastructure is needed, and a lot of energy is needed, and the consumer pays more than for fresh concrete, no one will do it. We can currently not cover the demand of a single country with recycled concrete. (…) currently we cannot cover the demand with recycled concrete, but it is because of contributing factors. The problem is not the technology, we do have the technology. But the use of the technology is limited by misleading incentives." (I. 2: 2)

In addition to the high demand of primary aggregates on the one side and the high prices of secondary materials on the other side, another substantial problem are misleading monetary incentives (I. 2: 2). As long as demolition of construction materials is cheaper than recycling, circular economy will not work on a large scale (I. 2: 2). This means, that in addition to a changing economy we need policy actions that address those misleading incentives (I. 2: 2). This also plays a central role because recycled concrete is up to 20% more expensive than regular concrete from primary resources. According to industry experts, this is a huge problem because the construction industry is cost-driven, and every builder tries to reduce material costs at any stage of a construction project (I. 3: 7). If those incentives mislead the industry towards throwing resources away and turning them into waste, no construction actor will pay more to build their projects sustainably.

> “As a manufacturer who is very committed to this topic, we naturally also have to deal with a certain amount of effort and of course we face additional hurdles here. And as a company that thinks economically, this is always a hurdle that has to be overcome. That means it is also reflected somewhere in the value of our products. This means that the product is of a higher quality, but unfortunately this higher quality is not yet recognized by the client or the user, so we always have to struggle with the fact that we have an economic disadvantage.” (I. 13: 1)

The third limitation of circular economy in construction is the cost-intensive technologies which need to be in place in order to produce and use secondary materials as a replacement for primary aggregates such as sand. Small and medium enterprises cannot adapt circular business models as easily as large organizations, due to outdated equipment and technologies, a lack of skills and the lack of financial resources to update facilities, logistics and factories. Hence the transition from linear to circular business models is not equally accessible to all actors in the construction sector (Hofstetter et al. 2021: 37).

Industry experts therefore also mention the cost-intensive side of circular economy and the socio-economic transition that needs to happen in order to enable circular economy as a real solution to tackle non-sustainable resource consumption. The construction industry needs to be aware that economic growth cannot be the only priority anymore when constructing buildings:

> “Because it's nice to say, okay, this solution is going to save the world, but if only 1% of the population can afford it, what is the point? And that is why I say that we have to recognize as society that this transition is going to cost something, it's going to cost money, it's going to cost probably the (…) way of living welfare. But if we don't do that, if we are not able to accept it for a limited time, I think that we are just postponing, (…) and making things too slow to really solve the problems, which are, I would say when we talk about ten, 20 years is tomorrow.” (I. 8: 11)

The fourth limitation is that today's industry is currently not set up for circular activities (I. 2: 3). This is also underlined by a recent study of the DGNB that shows that the construction industry is currently not prepared for circular economy activities (DGNB 2023: 8).

The fifth limitation is one of the key limitations for all problems of construction sand mining that were highlighted in this thesis, being that today's circular activities do not address any problems of the mining phase of construction sand. Improving working conditions and safety, increasing data transparency and avoiding environmental destruction is about monitoring and political enforcement, which is not caused by today's circular economy activities in construction such as concrete recycling or reducing the demand of primary resources in general:

> "(…) it (is) so interesting that the circular economy is already functioning to some extent in countries where scarcity is not the big problem. And in the countries where there is a shortage, the infrastructure is not yet in place (...). The amount of concrete that could be recycled is not the same. That is, (...) here perhaps a functioning solution to deal more sustainably with the raw materials that we need for building, but the major ecological problems that happen in the world, in terms of sand mining for the construction industry, is actually only slightly affected by the circular economy." (I. 4: 8)

The sixth limitation of circular economy is the lack of addressing global inequalities insufficiently. Rich countries in the Global North already dominate the world economy and its structures and without a specific concept on how circular economy activities can change that, those power asymmetries and inequalities will persevere. Powerful countries will most likely continue to capture the capital and resources they need to keep their economies growing while increasing inequalities (Schroeder et al. 2018: 77). This argument is also supported by a recent report of Saliba et al. (2023). According to the authors, the lack of social focus on people and working conditions of the Global South leads also to the neglection of job losses that will happen through circular economy if the actors fail to include this perspective into their activities. In mining sectors that produce raw materials for construction all relevant studies predict job losses for small-scale miners in sand mines of the Global South (Saliba et al. 2023: 28).

The sand construction value chain must be seen as a policy issue, that cannot be solved singly through economic shifts towards a circular economy (I. 2: 2). Improving the working conditions in sand mines, enabling a social upgrading and economic upgrading through empowering people in the Global South to take over more valuable activities from the construction sand value chain should be the main focus of making global value chains more sustainable. Instead, construction companies from the Global North are taking over the complete circular processes such as recycling, implementing it into the existing business model and earning even more profit through saving resources, increasing efficiency and not changing power relations with mining companies. As it was introduced by Gereffi (2018) it is especially difficult to enable social upgrading for global value chains like the construction sand value chain with large amounts of irregular workers and weak employer attachment.

Finally, the seventh limitation is the lack of degrowth perspectives and the socio-economic transformation, which needs to accompany an industry shift towards a circular economy. One huge paradoxical is inherent in the concept of circular economy itself: circular economy motivates actors to give their material back as soon as possible, to make sure the demand for building materials can be covered with secondary materials. However, buildings need to last as long as possible to extend the lifecycle of crucial resources (I. 3: 7). Therefore, construction actors get motivated to use secondary resources at one hand but cannot demolish enough buildings to cover that demand on the other hand.

According to industry experts, the social transformation that needs to complement a circular economy is currently not sufficiently addressed. This means also expanding public transportation to avoid new streets, which consume a large share of primary aggregates in construction (I. 3: 8).

> “That's why we depend on recycled materials and it's our job as a manufacturer to transfer this to society. That the buyer or builder or owner knows that he buys a product that avoids waste on the one hand, but also protects nature on the other (...). This works quite well with household waste with recycling, but why doesn't it work on the construction site?” (I. 13: 1)

> “It always comes down to education. We need to raise this idea in schools, universities, we have to work more on this. Because it is very hard for the industry to educate itself afterwards. This would be the best, if we can somehow reach younger generations to know about these problems.” (I. 14: 1)

Theory underlines and confirms the empirical results mentioned above and especially highlight the focus on recycling (Benachio et al. 2020), the high price of recycled materials, the missing degrowth perspectives in the social transformation which needs to happen (Korhonen et al.

2018; Hillebrandt 2018; Pereira 2020; Hofstetter et al. 2021), and the lack of circular planning (DGNB 2023).

Benachio et al. (2020) point out that all the other dimensions of circular economy activities besides recycling are underrepresented in the construction sector, especially in research and practical implementation. Future research must therefore primarily address the aspect of reducing materials in general (Reduce) and reusing materials (Reuse) before materials are being recycled in a costly and energy-intensive manner (Benachio et al 2020: 9).

Korhonen et al. (2018) try to critically evaluate circular activities. A change in consumer behavior is essential, even despite the successful implementation of closed-loop models. In economic theory, circular concepts result in a more effective use of resources which then leads to an increase in production efficiency in the long term, which is reducing production costs. When production costs are reduced, it also lowers the prices for the end consumer, which in turn leads to increased demand and consumption. As even a circular model does not enable a completely sustainable use of resources, damage to the environment and social inequalities persist. All economic activities consume energy and resources, and this will not be able to be prevented in the future, even by a circular economy. According to the authors, these problems are not sufficiently addressed by mainstream research on circular economy (Korhonen et al. 2018: 43).

> "The most flexible and efficient construction methods will remain ineffective if the trend toward increased land consumption per capita continues. This Rebound effect destroys any efficiency success in the area of resource conservation." (Hillebrandt 2018: 11)

This quote by Hillebrandt supports the critique by Korhonen et al. (2018). If circular economy will be used for efficiency increases the resource consumption is far from ever becoming sustainable.

A recent study of "German Council for Sustainable Building" analyzed the challenges in implementing circular economy into construction activities. The main issues are a lack of data and transparency, a lack of know-how for implementation, a lack of circular materials and products and regulatory restrictions. Construction actors mentioned in the study, that as long as there is missing information about the quality of secondary materials together with missing methods and tools to implement circularity into their processes, circular economy cannot exploit its full potential. Moreover, regulations prevent the implementation of circularity and confuse market participants through changing quality requirements for construction materials (DGNB 2023: 17).

The United Nations Sand and Sustainability Report (2022) provides key assumptions on three levels where legal frameworks must take place: Horizontally, which involves aligning objectives across various ministries within a nation, bringing together separate strategies and implementation mechanisms to establish cross-sectoral goals and approaches. Vertically, which entails connecting policy and legal frameworks at different jurisdictional levels, including global, regional/transboundary, sectoral, national, and subnational levels. And lastly intersectionally, which recognizes the interdependence and intricate patterns of interaction that link the intended and unintended consequences of policy and legal actions or inactions. It prompts policymakers and stakeholders to examine established practices, consider diverse needs, and evaluate how different populations are affected (Peduzzi et al. 2022: 23).

Concluding, missing degrowth perspectives hinder an actual reduction of sand consumption. In terms of economic power, one can argue that circular activities such as recycling minerals such as sand is process upgrading instead of social upgrading. Since large construction actors already have the infrastructure for processing concrete, it may be easier for them to unite circular activities with their core business strategy. According to several experts, large construction companies already aim to enter the recycling market because of economic and reputational advantages (I. 9: 4) and not because they have an intrinsic sustainable motivation (Pereira 2020: 167). Using resources efficiently always means an increase in general productivity, too. Therefore, it may also be competitive advantages that move construction actors towards a circular economy. Hofstetter et al. (2021) further state that claiming to act in the circular economy paradigm can work as an excuse for lead firms to only focus on recycling instead of reducing material consumption in general (Hofstetter et al. 2021: 32).

To sum up, the central limitations of circular economy in the construction sand value chain are the insufficient amounts of secondary aggregates, that cannot cover the demand for construction sand as well as misleading financial incentives and the social transformation that needs to accompany circular activities to decrease hesitation of construction actors to use secondary materials. But above all, missing circular activities to tackle social issues are a central limitation of circular economy in the construction sand value chain. No circular activity already implemented was reported neither through empirical interviews nor through literature review that aims to solve mining issues or social inequalities when it comes to negative impacts of sand mining.

5.5.Linking Circular Economy and Global Value Chain

Chapter 4 (The Global Sand Business) has shown that the global sand business is quite complex and difficult to understand, with its many actors especially in the field of sand mining and the lack of data of traded and extracted sand, as well as the numerous social and ecological problems caused by excessive sand mining. Chapter 5 (Circular Economy in Construction) and 5.4 (Limitations of Circular Economy in the Construction Sand Value Chain) has displayed how circular economy is currently implemented into the construction sector and how limited circular economy truly is to tackle social and economic problems that were reported in chapter 4.2 (Social, Economic and Ecological Problems of Sand Mining).

This chapter will now focus on linking the two concepts of circular economy and global value chain of construction sand. How the circular activities can be mapped into the construction sand value chain model of Da and Billon (2022) is presented through the model of the circular supply chain model of Farooque et al. (2019). One main aspect of linking circular economy and global value chain is focusing also on power relations and social and environmental upgrading opportunities through a shift towards a circular business model, since this aspect is missing in current concepts from a business perspective.

The following figure (Figure 27) shows approaches to link the concepts of circular economy and global value chain, as introduced in chapter 2.3. (Circular Supply Chain), with the circular activities mapped into it. The numbers in blue circles represent the circular activities that were displayed and explained in table 7.

The linkage between circular economy and global value chains together with the findings of this study add up to a new framework of building, which is presented in figure 27.

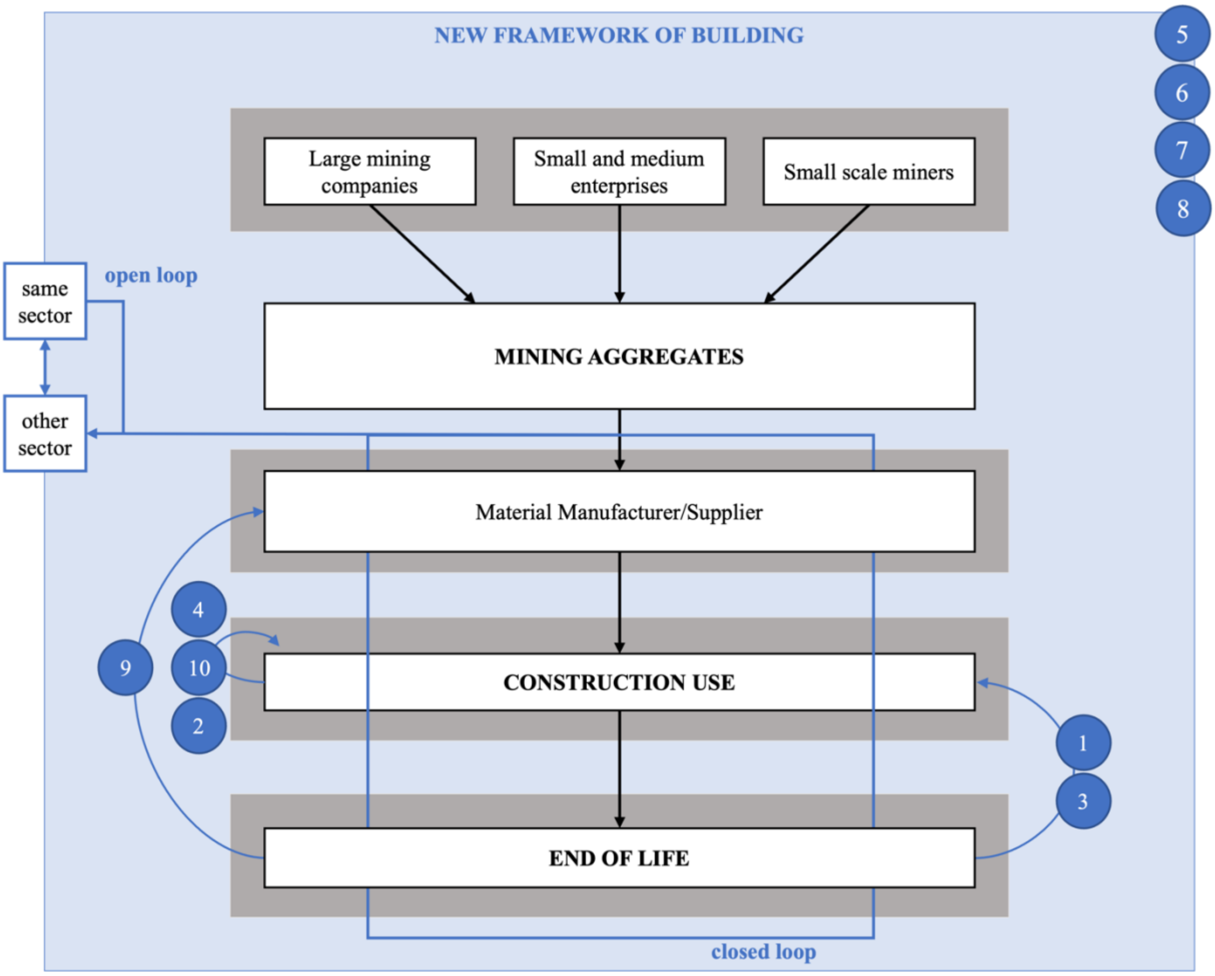

Figure 27. Approaches to link circular economy with the global value chain of construction sand based on the construction sand value chain by Da/Billon (2022) and the circular supply chain model of Farooque et al. (2019) (A.M.)

Figure 27 presents a new framework of building including all circular economy activities that were reported in this empirical study. One central aim of this thesis is the linkage between the construction sand value chain and circular economy activities. The empirical results of this study have been mapped into the construction value chain of Da and Billon (2022) and the circular supply chain model of Farooque et al. (2019). The circular supply chain model interacts with the three value chain stages Supplier, Construction Use and End of Life, which was already explained in detail in chapter 2.3 (Circular Supply Chain). As presented in chapter 5 (Circular Economy in Construction) the central circular economy activities in construction have been mapped into this model.

Circular activity 1 (Concrete Recycling) and 3 (Advanced Sorting System) are playing a central role in the value chain stages of construction use and end of life. Those initiatives have been implemented primarily to reduce the amount of demanded primary aggregates such as construction sand and are done by demolition and recycling companies.

Activity 4 (Processing Soil Excavation) needs to be done right before a building is constructed and is focused on an efficient use of resources that can be found on site. This activity is only implemented into one stage of the value chain, the construction phase since soil excavation is used right away. The same logic applies for circular activity 2 (Processing Demolition Waste on Site) since mobile technologies are needed to process the material right on site. Activity 10 (Adaptive reuse of buildings) aims to reducing the demand for new buildings in the construction stage through adapting old buildings into new applications of buildings.

Activity 9 (Material Leasing) interacts at the value chain stages of material suppliers and material manufacturer and end of life. The idea is, that manufacturers get their material back from the deconstruction site, which enables them to process the material into new concrete or aggregates.

Activity 5 (Precast Concrete), 6 (Urban Mining), 7 (Modular Building), and 8 (Alternative Building Materials) enable a totally new framework of building. Those activities cannot be linked to specific stages of the construction sand value chain since they are changing the fundamental processes of construction.

Interpreting those activities from a circular supply chain perspective from Farooque et al. (2019) it can be summarized, that all the current circular activities remain in the closed loop, instead of creating open loops through material exchange with other sectors. In theory, this step is needed to enable a circular economy with a new way of thinking of using resources. Concluding, one central finding is, that the exchange of secondary resources across other sectors like it is displayed in the circular supply chain theory by Farooque et al. (2019) is currently not happening at all in the construction industry. All circular activities that have been found in the empirical research remain in the closed loop within the construction sector.

> "We must establish a whole new way of cooperation. As a material manufacturer, we cannot solve it alone, the planners cannot solve it alone, the disposal industry is certainly a key player here, but so are other industries. We really have to work together in a whole new way to make this happen." (I. 12: 1)

However, to enable a functioning circular economy, material exchange across all sectors need to happen. Material amounts installed need to be tracked and reported so that it can be used for other products or buildings. Hence to sum up, the initiatives and approaches to link circular economy and construction sand value chain are remaining in a closed loop along the traditional stages of the construction sand value chain, but mainly between the construction stage and end-of-life stage. The approaches aim mostly to reduce the demand for primary sand resources instead of tackling also problems and issues that happen along the whole construction sand value chain but especially in the mining phase. Referring back to Ponte (2022), environmental upgrading can only happen, if this trans-sector approach of using materials and services in other sectors is achieved.

To sum up and answer the overall research question (*To what extent can circular economy activities make the construction sand value chain more sustainable?)* it can be concluded that circular economy activities in construction are limited to reduce the demand for primary resources through recycling and processing aggregates on site to replace primary construction sand. However, in countries such as Germany and Austria secondary aggregates currently cannot cover the demand for primary construction sand. Not one circular activity, that was reported in this empirical study covered the mining stage in terms of improving working conditions or enabling economic or social upgrading for small scale miners in the Global South. Instead, large construction companies in Europe and China are currently taking over the recycling stage to implement the end-of-life stage into their current business model. Therefore, circular economy can act as one of many solutions to decrease the construction sand demand but cannot cover all social and ecological problems along the construction sand value chain that were reported in chapter 4.2 (Social, Economic and Ecological Problems of Sand Mining) without being complemented by legal regulations, certifications and standards and other frameworks to enhance the working conditions in the construction sand value chain. Furthermore, there is no specific relation to changing power relations or dependency structures in the current world system. High-income countries from the Global North will most likely continue to acquire most of the value, regardless of linear or circular business models.

5.6.Synopsis of the Results

To end the presentation of the empirical results of this thesis, I want to outline the reference to the theory presented in chapter 2 (Theoretical Background). The synopsis of the theory in chapter 2.4. (Synopsis) explained how the frameworks of global value chain and circular economy are used in this thesis, however this chapter now draws the reference back to those frameworks with taking the empirical results into account.

First, the global value chain approach highlights the importance of actors and geographical locations to understand power relations and dependencies and inequalities. As presented in chapter 4.1.2. (Geographical Dimension) and 4.1.3. (Actors and Governance Structure) the main geographical locations in the sand sector are China, India, Singapore, Malaysia and the UAE because of the excessive building activities in the Global South. Mining actors, such as large dredging companies and small-scale miners try to cover these large demands while dealing with huge inequalities along the value chain. Small-scale miners are dependent on large construction and cement companies, while large dredging companies have more power along the value chain. While taking large data gaps into consideration, it can be summarized, that those actor structures, as well as the social, economic and environmental issues of sand mining, shown in chapter 4.2. (Social, Economic, and Environmental Problems of Sand Mining), highlight the countries who suffer from the bad mining conditions and the countries who benefit from it because of large margins and values that can be acquired.

Second, the global value chain approach discusses upgrading potentials for countries of the Global South. As highlighted in chapter 5 (Circular Economy in Construction) there are several initiatives to reduce the number of resources used in construction. The reduction of resources and mining activities can be seen as environmental upgrading. The opportunity to take over high-value activities from the construction sand value chain, such as recycling or processing demolition waste on site are aiming at economic upgrading. However, there is little to no initiative focusing on improving mining conditions or reducing illegal labor, and the high-value tasks are most likely acquired by companies in the Global North, who already take over most of the tasks along the value chain. Therefore, there is no social upgrading, which improves the daily working conditions of small-scale miners or aims to reduce the environmental damages which are caused by sand mining.

Third, the global value chain approach aims at understanding governance structures. As presented in chapter 4.1.3. (Actors and Governance Structure) there are two types of governance structures in the construction sand value chain. Value chains with small-scale miners of construction sand can be defined as captive governance structures since the buyer has the whole power of defining the quality and the quantity of the construction sand. If there occur any issues along the buying process, the buyer, often large construction or cement companies, will buy construction sand from another mine. A different picture emerges when one looks into the supply chains of construction sand of large dredging companies. Since the market is regulated by only a hand full European dredging companies their power is enormous. This value chain can be defined as relational, as the dredging companies own high tech knowledge and therefore share a more symmetrical relationship with large construction companies.

These findings support the importance of bringing a global value chain approach into the circular economy discussion, as conducted in this thesis. Since most of the circular activities reported by industry and NGO experts of this study are included easily into the core business of construction actors, there needs to be another perspective developed, which focuses more on power relations and inequalities. This is one large potential of combining circular economy with global value chain approaches.

6. Conclusion

This thesis explored circular economy activities in the construction sector as a possible solution to solve the sand crisis, which is mainly driven through construction. The status quo, however, is a linear construction industry where the extract-produce-waste narrative still dominates construction processes. This chapter summarizes the empirical findings of the thesis, highlights the answers to the research questions and provides some practical implications for future research.

Concluding, the research question 1 (*Who are the key actors and locations in the construction sand value chain and what are the power relations?)* and 2 (*What are the ecological and social problems of sand mining?)* can be answered as followed: Construction sand is mined all over the world across all countries, since it is widely available and does not require advanced technical equipment. However, industrial dredging companies dominate sand mining in the Global North and in the Global South, especially in the field of marine sand mining. Open pit and beach mining in the Global South is mainly done through small scale miners, who are selling their sand to local construction companies. Since there is little to no governance and transparency in trade data, it is not fully known if sand is traded globally or only used locally. Key locations in the construction sand value chain are China, India, Singapore, and UAE due to their excessive construction activities. The power relations are captive between small scale miners and construction companies and relations between large dredging companies and their customers. Sand mining causes many ecological and social issues, from destroying biodiversity and marine ecosystems, to causing livelihoods based on fishery to collapse due to the decline in fish stocks because of mining activities. Social and economic damage is mainly caused through poor mining and working conditions, corruption, and illegal sand trade.

The answer to research questions 3 (*How does the construction industry understand circular economy and how is it currently implemented in the construction sand value chain?)* and 4 (*What are the limitations of circular economy in the construction sand value chain*?) can be summarized as followed: The construction industry understands circular economy primarily as keeping building materials in a loop and reusing it as secondary materials. Therefore, the global value chain of construction sand is addressed mainly within the end-of-life stage or concrete recycling. However, no social and ecological problems that were presented in chapter 4.2 (Social, Economic, and Ecological Problems of Sand Mining) are addressed through circular economy activities within construction. Especially social problems, such as working conditions in sand mines, safety issues of small scall miners and violence through sand mafias are not at all addressed through circular economy.

The linkage between theory and practice was done through a mapping of the empirical results of this study into the concept of circular supply chain to see the relation between circular economy activities in construction and the theoretical concept of circular supply chain. As shown in figure 27 and described in chapter 5.5 (Linking Circular Economy and Global Value Chain), all circular activities that have been reported by experts interact in the closed loop system within the construction sector and range between the value chain stages of material supplier, construction use and end of life.

Circular economy therefore cannot turn the construction sand value chain into a sustainably operating business model to secure economic growth without harming nature and societies. To enable a functioning circular economy however, the circular activities need to also interact with other sectors to enable an optimal usage of natural resources and focus on socioeconomic parameters. If we manage to create a holistic circular economy across all sectors a sustainable consumption of resources may be achieved. Given the current outlook however, the impact of circularity is too small to make a real change in the industries, with the global economy being only 7.2% circular according to a 2023 circularity report. Driven by increasing resource mining this number even dropped from 9.1% in 2018 to 8.6% in 2020, meaning the circularity of today's global economy gets worse year by year due to ongoing extensive growth (Fraser et al. 2023: 9).

Moreover, degrowth perspectives are not addressed. As long as the demand for construction sand keeps rising, the global sand crisis, shortages and non-sustainable mining of sand will continue with its social and environmental impacts. One industry expert summarizes his outlook in the following quote:

> "After all, the demand for minerals is expected to double. So, the focus on sand and aggregates will continue to become more and more important and will continue to be of

> central importance. That's why, on the one hand, we have to look at the durability of our buildings, so that we can use them for longer in order to minimize or reduce the need for new raw materials, but on the other hand, we also have to learn how to use these raw materials in a climate-friendly way so that our cities and buildings can reduce CO2 in the short term, and have no more CO2 emissions at all." (I. 4: 10)

Gavriletea (2017) provides several suggestions to decrease the social and environmental damage that is created through the excessive construction sand demand. One main suggestion is to reduce the overall global sand consumption. Besides reducing the demand, the negative consequences of sand extraction need to be diminished. A huge potential lies in the field of taxation and policies for sand exploitation, that need to be set. Foremost however, environmental laws and regulations must happen in the stage of the sand mining process. Developing standards can have huge impacts on mining conditions according to the author (Gavriletea 2017: 18). The importance of laws and regulations has also been highlighted by several industry, NGO and research experts in this study (I. 1; I. 2; I. 3; I. 4, I. 6; I. 7; I. 9).

Concluding, the circular economy activities in construction face some of the central challenges of the construction sand value chain in reducing sand consumption through substituting primary resources with secondary resources. But still, the remaining challenges, mining issues in particular, need to be addressed. One might argue that a reduction of consumption through recycling might have a positive effect on mining conditions, but since the construction sand market is mainly regional, the positive effects of circular economy on mining conditions do not apply and seem to be very limited on global mining conditions.

As first implications from the interviews conducted it can be summarized, that circular economy activities in the construction sector such as concrete recycling works only for rich countries from the Global North, since a huge amount of already used concrete is necessary to have something to recycle from. Moreover, the infrastructure for recycling concrete is cost intensive. Therefore, it is a very limited solution, that leaves a lot of room for further research.

According to the UNEP Sand and Sustainability Report 2022, replacing and recycling sand and aggregates will be essential to solve the sand crisis. The authors provide key suggestions for policy and economy actors such as the ban of landfilling or increasing the costs of landfilling significantly to enable higher recycling quotas. Moreover, recycling should be encouraged through better demolition plans and selective demolition and by prescribing secondary materials in public tenders. In addition to that, construction actors should be supported in investing into recycling facilities close to construction sites, to enable on site processing of materials to avoid demolition and transportation emissions (Peduzzi et al. 2022: 46).

Researchers identified five prioritized actions for sand governance that need to happen: cross-sector-cooperation on global sand mining standards, alternatives to sand as a primary resource, updating social, environmental, and economic governance frameworks to include sand, raising awareness and collecting global, national and regional data on sand use to enable change and improvement (Meredith 2021). One main challenge for circular economy in construction sand global value chains remains how the Global South can be included in those circular models (Hofstetter et al. 2021: 24).

A circular economy initiative report by Circle Economy, the World bank and the International Labor Organization concludes, that a large share of circular economy research focuses on neoliberal narratives, such as economic growth and prosperity, through resource efficiency increases through circular economy activities. One reason for the lack of focus on the Global South is the missing information and impact data of circular economy on people and workers in the Global South (Saliba et al. 2023: 6ff.). The report also underlines the fact, that social changes such as power relations and asymmetries are neglected by most of the circular economy research (Saliba et al. 2023: 14). However, there is some research that combines circular economy and decent work, but 84% of this research focuses on the Global North and the remaining 16% of Global South research focuses heavily on India, Brazil, and Nigeria. North Africa, Sub-Saharan Africa, the Middle East, and Eastern Europe were the least represented areas of research (Saliba et al. 2023: 20).

As already analyzed in chapter 3 (Methodology) this study has several limitations. I am aware that I can only highlight a small glimpse of the whole global value chain of sand. For further research it would be essential, to analyze the geographic dimension more deeply, to understand what the relations really are. Further limitations are the global trade gaps, the untransparent manner of the value chain itself, the huge number of actors due to low entry barriers in sand mining and more.

Sand needs to get the awareness to be one of the most important resources for human development and economic growth. It must be taught in schools, universities and organizations that sand mining causes numerous social and environmental issues and needs to be addressed in relevant policies. This thesis aimed to add to fill the data information gap in the sand sector as well as highlight the limitations of potential solutions to solve the sand crisis.

This thesis has demonstrated the importance of a degrowth perspective in construction, a sustainable usage of natural resources and a shift towards circular building. As long as the construction industry is set up in a linear way, natural resources such as sand will be mined excessively and go to waste instead of being reused as secondary building materials. Circularity starts with appreciating natural resources again, seeing cities and buildings as material storages and planning buildings in a circular way right from the beginning. Instead of praising circular economy as the solution for all problems without tackling compromises and limitations, the industries should call for a modest and inclusive circular economy that is "based on the principle of a fair distribution of resources" (Corvellec et al. 2021: 429). It needs to take people on a global scale into account and enable a transparent way of connecting activities and solutions with the concrete problem they are solving. Otherwise, circular economy will end up as an optimistic, self-serving narrative that fails to reorganize and transform resource consumption and material flows into a sustainable usage within planetary boundaries.

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Annex

Annex A: Interview Questions

Annex A: Interview Questions

The following interview questions were asked to answer all research questions:

- Who are the key players in the sand supply chain and what are the power relations?
- What are the environmental and social issues along the sand supply chain?

- What circular economy activities are currently done in the construction sector?
- How do you define circular economy in the construction sector?

- How would you evaluate circular economy activities within the construction sector, e.g., concrete recycling to tackle those problems?
- What are the opportunities for circular economy in the construction industry (beyond the current implementation)?

- What do you think are the limits of circular economy within the construction sector?
- Which problems along the sand supply chain are addressed by the circular economy and which are not?
- What are the opportunities and limitations of circular economy activities in the context of the sand supply chain (and in general)?