Transforming Uncertainty into Opportunity

Investigating Stakeholder Perceptions Across the Value Chain in Denmark's Circular Building Material Waste Supply Chain

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Abstract:

The construction industry generates a significant amount of waste and serious environmental impacts. Denmark has an ambitious climate goal to stay within the 1.5-2.0-degree target and transition to a circular economy. However, transitioning away from the well accepted linear take-make-waste model triggers uncertainty and risk among stakeholders across the value chain within the supply chain for building material waste. To identify the root causes of anxiety and develop targeted solutions, a mixed-method approach comprised of a quantitative survey (n=52) and qualitative interviews (n=19) was selected. The research investigated how external political, economic, social, technological, environmental, and legal (PESTEL) factors influence stakeholder perceptions of uncertainty. Findings indicate that external economic factors have the strongest influence on stakeholder perceptions of uncertainty, followed by legal and political factors. Stakeholders expressed genuine concerns towards the economic feasibility of incorporating circular practices to address building material waste, on top of ambiguous regulations and the tension between setting ambitious climate goals without a robust legal framework. Without addressing the uncertainties faced by stakeholders across the value chain, scaling up circular practices will continue to face roadblocks. A systems-level approach that acknowledges the interconnectedness of the PESTEL factors to address the root causes of stakeholder's anxieties across the value chain can transform uncertainty into opportunity, creating a sustainable built environment in Denmark.

Risk, Uncertainty, and the Circular Transition in Denmark's Building Sector

In times of resource scarcity and environmental destruction, the construction sector is one of the major drivers pushing the planet to ecological limits. The industrial footprint is deep, with almost 50 percent of extracted material and 35 percent of the EU's generated waste attributed to the building industry (European Commission, n.d.). We are currently on track to exceed the global temperature threshold of 1.5°C-2.0°C, a trajectory triggering devastating environmental consequences and resource scarcity. If we are to meet the ambitious goal of limiting warming to 1.5°C by 2030 urgent action is imperative. The future of the built environment requires a mindset shift, reimagining design and value from the take-make-waste linear model to a circular one.

The spaces we build and inhabit profoundly impact the planet, and a circular transition takes these factors into account. Circular systems aim to redefine waste, reuse materials, and regenerate natural systems (Ellen MacArthur Foundation, n.d.). To successfully transition, strategies addressing the root causes of existing barriers will need to be developed. Therefore, a deeper understanding of the risks and uncertainties associated with moving away from the widely accepted linear business model is essential. In Denmark, there is massive potential to reduce the environmental impact of the building industry and drive innovation for a circular systematic change.

One-third of waste production occurs in the construction and building sector in Denmark (Ellemann-Jensen & Jarlov, 2018). The building industry encompasses a wide range of activities from design and planning, construction, material sourcing, demolition, operation, real estate and regulation and policy (Ghosh et al., 2021)From the extraction of raw materials to the astronomical amount of waste produced during development it is undeniable that we cannot continue this way, our practices must change. It's true that we have already passed a threshold that will have consequences on future generations to come, but there is still a chance to reject business as usual and transition to a system that prioritises sustainability, circularity, trust, and respect for our finite resources.

Linear business models (LBM) encourage the take-make-waste framework and have never been sustainable (Cheshire, 2019). LBMs thrive on intensive resource extraction, rapid production, and disposal rates which continuously degrades the environment, and create mounting waste challenges (Cheshire, 2019). Obvious concerns over resource scarcity, construction, and demolition waste (C&D) and the sector's immense carbon footprint demand a radical shift. Various innovative alternatives are being proposed to replace the linear model such as bio-based materials, performance-based contracting, and lean construction methods (Melles & Wölfel, 2024). All these alternatives help guide the conversation in the right direction. However, the concept of a circular economy offers a compelling alternative to the linear way of conducting business. Not only does a circular system in the building industry emphasise regenerative design, material reuse and maintaining resources within a closed loop, but it also provides a framework to reimagine and redesign the future of the built environment.

The built environment refers to the physical structures we inhabit such as buildings and infrastructure that make up the world we live in. In the industry, especially in Denmark, a substantial amount of research, and policy is incentivising the circular transformation for the built environment, all with the effort to be climate-neutral by 2050 (The Danish Energy Agency, 2016). The nation stepped into a leadership role by launching initiatives such as the *National Strategy for Circular Economy* to set targets addressing resource efficiency and waste reduction (The Danish Government, 2018). Research efforts from the construction industry are publishing reports identifying the risks to help create roadmaps, explore innovative techniques, and reuse strategies. Additionally, economic incentives, like reduced rates for recycled materials and subsidies for construction projects are being implemented to promote the adoption of circularity within the supply chain. Overall, Denmark is demonstrating a national commitment to shift away from the traditional linear business model and transition towards a circular economy.

The transition to a circular system in the building sector is not going to be easy. The supply chain faces a complex landscape of political, economic, social, technological, environmental, and legal factors that shape stakeholder perceptions impacting decision making and the potential for widespread adoption. A supply chain (SC) refers to the complex network of individuals, activities, resources, technologies, and organisations involved in the creation of a product or service (Waters, 2011). Each step across the supply chain from material extraction to the delivery of the final product represents a link in the chain. The circular paradigm shift within the supply chain for building material waste is investigated in this research to draw attention to stakeholder perceptions of risk and uncertainty across the value chain (VC). The value chain represents the network of stakeholders and services that deliver value to the business and the end product illustrated by Linde et al. (n.d.) in Figure 1. By investigating the perspectives across the value chain, the research will provide an all-encompassing picture of the external environment leading to the development of a more sustainable supply chain.

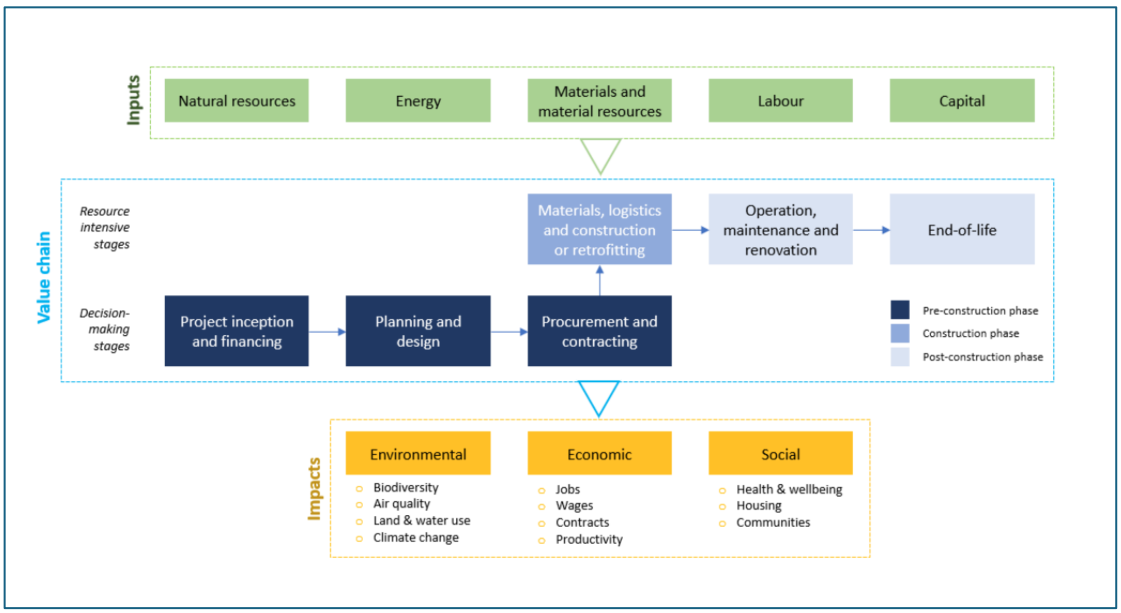

FIGURE 1. THE CONSTRUCTION VALUE CHAIN (LINDE ET AL., N.D., FIGURE 1).

This research aims to provide an inclusive picture of the external environment influencing stakeholder perceptions of uncertainty and risk, identify the root causes of these anxieties to develop targeted solutions and reveal the commonalties between stakeholders to capture the diverse experiences across the value chain. 16 stakeholder categories were identified across the value chain: Architect, Circular Tech Developer, Consumer, Contractor, Material Reuse Specialist, Demolition Contractor, Designer, Educational Outreach Specialist, Engineer, Investor, Legal Expert, Manufacturer, Politically Affiliated, Public Participant, Researcher and Sustainability Consultant. A mixed method approach was adopted, utilising a quantitative survey and qualitative interviews to investigate the following research question:

> *How do external factors (political, economic, social, technological, environmental, and legal) influence stakeholder perceptions of uncertainty across the value chain within the circular supply chain for building material waste?*

This research explores the external environment influencing stakeholder perceptions of uncertainty across the value chain within the circular supply chain for building material waste. The imperative of a systems change in the building industry is discussed in Chapter Two through sustainable development, sustainable business models and circular economy. Circular economy is contextualised through a historic lens along with the ambitions in Denmark to transition in Chapter Three. Chapter Four defines the pivotal theoretical research concepts of risk and uncertainty, the PESTEL framework, and outlines the mixed method research approach of a quantitative survey and qualitative interviews. The PESTEL analysis is outlined in the following chapter revealing the influence of external factors on stakeholder perceptions of uncertainty in Denmark. Each factor is explored in the subsequent chapters to show the complex dynamics in the external environment. The concluding chapter highlights a variety of challenges and opportunities that exist for a circular transition in Denmark. By continuing to address these challenges, Denmark can be a global leader by transforming uncertainty into an opportunity and design a built environment that is sustainable, equitable and just.

The Imperative of Systems Change

To completely transform the entire structure of how we build the world around us, a bold approach that transcends isolated solutions is needed. Complex, interconnected challenges require both individual and collective efforts that focus on transforming the underlying structures that govern our relationship with the environment (Clayton & Radcliffe, 1996). Climate related issues are not isolated occurrences, they represent the larger imbalance between our relationship with the planet. To address the imbalance, a systems change is needed to tackle the underlying root causes exposing the ongoing ecological unequal exchange and material flows that exist in the building industry. We are stuck in a routine that continuously wreaks havoc on the environment, and to change the routine we need to rewrite the structure.

The linear routine of take-make-waste has gone on for too long. Naomi Klein puts it simply "we are left with a stark choice: allow climate disruption to change everything about our world, or change pretty much everything about our economy to avoid that fate." (Klein, 2015, p. 14). Business as usual no longer works and minor tweaks to the system will not be even remotely successful. With a crisis that has economic, social, environmental, geopolitical, and ideological aspects, a drastic change is needed to address the range of issues we are facing. Manufactured solutions such as carbon offsetting and geoengineering are only ecological band-aids creating short term solutions producing a veil of false hope.

A sustainable transformation requires a new economic model, one that does not follow the capitalist model of circulation and accumulation where profit is prioritised over the planet (Wainwright & Mann, 2018). Under capitalism, every aspect of society is organised to "increase the production and sale of commodities and facilitate accumulation of money" (Wainwright & Mann, 2018, p. 93). Our current economic model views nature as a profitable resource producing limitless opportunities for economic gain. Clinging to the notion that 'this is the way it's always been' only perpetuates a deceptive narrative that delays change. In reality, "humans have lived in capitalist societies for only approximately 0.01 percent of our natural history" (Wainwright & Mann, 2018, p. 93). Within this short amount of time, irreversible damage has been done to the planet and if we continue operating in a linear manner, we will have nothing to look forward to other than catastrophe.

The fossil economy, run by the existing economic model, is a linear model driven by the continuous expansion and ever-increasing use of fossil fuels contributing to a steady rise in greenhouse gas emissions (GHG) (Malm, 2016, p. 16). Most of the manufactured steel, concrete and aluminum is consumed in the construction industry; concrete alone accounts for eight percent of global CO^2 emissions (Schefte, 2022). The materials used in the construction industry account for almost half of all materials extracted worldwide (European Commission, n.d.) The entire lifecycle of building materials, from extraction to demolition contributes to a staggering amount of greenhouse gas emissions (GHG) estimated at five to 12 percent (European Commission, n.d.). The fossil economy disproportionately exports its pollution and resource extraction unequally across the globe, bypassing accountability for the damage done (Hornborg, 2011). We are stuck in a loop where our desire for growth comes with the cost of killing the environment.

The linear business model is illustrated in Figure 2. R represents the resources input to the economic system; P represents the production of those resources, and C represents the outcome of producing consumer goods. The linear model developed out of the Second World War when the rapid expansion of the economy lead to a massive influx of consumption of raw materials and resources resulting in the accumulation of waste materials (Aggeri, 2021). Historically, the linear model has been proven to drive economic growth. Unfortunately, due to the inherent reliance on finite resources and generation of waste, it is proven to be ecologically unsustainable.

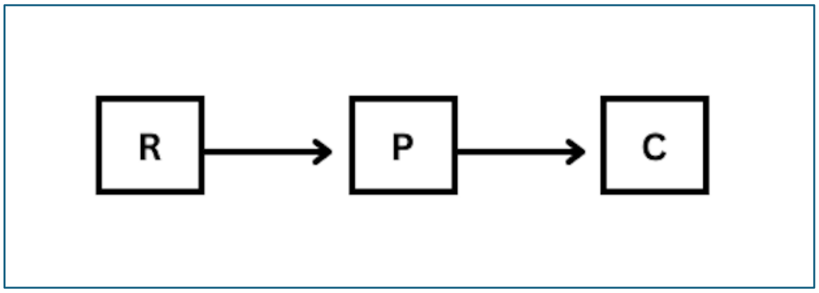

FIGURE 2. THE LINEAR BUSINESS MODEL ADAPTED BY PEARCE & TURNER (1990, P. 36).

Mapping material flows using the linear model exposes the global connections for building materials which raise significant sustainability concerns (Heisel & Hebel, 2022; Plank et al., 2022). To apply the linear business model to the traditional supply chain for building materials: R represents the extraction of raw materials such as timber, stone, metal, and minerals; P represents the construction and building operation phase where transportation, waste generation and energy consumption are generated, and C represents demolition and waste management where a vast amount of waste is produced. In other words, building materials such as concrete, steel and timber are processed in large quantities using virgin resources to create our buildings which are given a limited lifespan. At the end of a building's life, the structure is demolished, and a significant amount of construction and demolition waste (C&D) is most often transported to a landfill.

A choice must be made, to accept the status quo and consider incremental changes as sufficient, or fundamentally transform the world entirely through our economic and social systems. As Malm highlights,

> The tradition of the dead is breathing down the necks of the living, leaving [us] with two choices: smash [our] way out of business-as-usual – and the heavier the breath, the more extreme the measures must be – or succumb to an accumulated, unbearable destiny (2016, p. 12).

Getting at the root causes of environmental degradation is a necessity to support balance on the planet. While reducing our carbon footprint is crucial, it is only a fraction of the issue at hand. Placing growth and profit over planetary well-being is no longer an option as the catastrophe clock is ticking. Building a sustainable future requires a new economic system and a revolutionary relationship with our planet.

A Circular History

While it might seem radical to restructure the existing economic model to one that emphasises resourcefulness and reduction of waste, it is nothing novel in the context of human history. One could even argue that it was the dominant model until the 19th century (Aggeri, 2021). The concept of waste did not exist as everything could either be reused or decompose naturally. It wasn't until three major shifts phased out the historical circular model and introduced the linear business model. The first shift can be linked to the Industrial Revolution, specifically the invention of the coal-fired steam engine that reduced the cost of extracting materials (Aggeri, 2021, p. 11; Malm, 2016). With the ability to extract raw materials at a lower cost and transport them farther distances it became easier to outsource labor and redefine the market. The second major shift was the rise of the hygienist movement in the late 19th century which "stigmatised the circulation of waste and organic matter, claiming it to be the primary cause of epidemics" (Aggeri, 2021, p. 11). Waste bins became a household staple, and materials were disposed of at a higher rate leading to the creation of the landfill. The final shift that finalised the separation from historical circular practices was the establishment of the consumer society in the 1930's (Aggeri, 2021). As a result, circular practices were drowned out by disposability and mass production allowing the linear business model to dominate.

From an archaeological perspective, circular building practices were utilised in the past out of necessity. There is a traceable history of cultures in the past employing circular methods such as material reuse and adaptability, multi-functionality, using local materials, and utilising building lifecycles through transformation. Denmark's archaeological record offers a glimpse into how Viking communities took an early approach to sustainable building practices. At the Hedeby settlement site, excavations revealed the reuse of timber and stone for new construction (Schmidt, 1990). Longhouses, the primary dwelling unit, served multiple purposes for maximising the utility of a building throughout its lifetime. The post and beam construction method was employed for Viking structures to allow for easy modification and disassembly. Although archaeological data is useful for drawing circular parallels with modern practices, historic practices are representative of their own specific social and cultural contexts. Regardless, it is worthwhile to use historic building practices as a foundation and inspiration for developing circular building methods that fit the social-cultural contexts of today.

Defining a Circular Economy

In response to the environmental consequences of resource depletion, biodiversity loss and increasing GHG emissions, the concept of a circular economy is increasingly gaining traction. It was in the 1990 book *Economics of Natural Resources and the Environment* that the term circular economy was first introduced. Pearce & Turner applied the First Law of Thermodynamics to the linear economic model which states that "whatever we use up by way of resources must end up in the environmental system. It cannot be destroyed" (Pearce & Turner, 1990, p. 36). In the construction industry, waste is generated along every stage of a building's life cycle. The extraction of raw materials such as minerals and wood leaves behind scarred landscapes. Construction activities generate waste through material offcuts and common mistakes. Once a building is functional, the everyday operations produce waste. All of which lead to the demolition phase where a massive influx of materials are discarded as waste. A closed economic system that bridges the disconnected phases across the building lifecycle is needed to redefine waste as a resource through a closed economic system illustrated by in Figure 3.

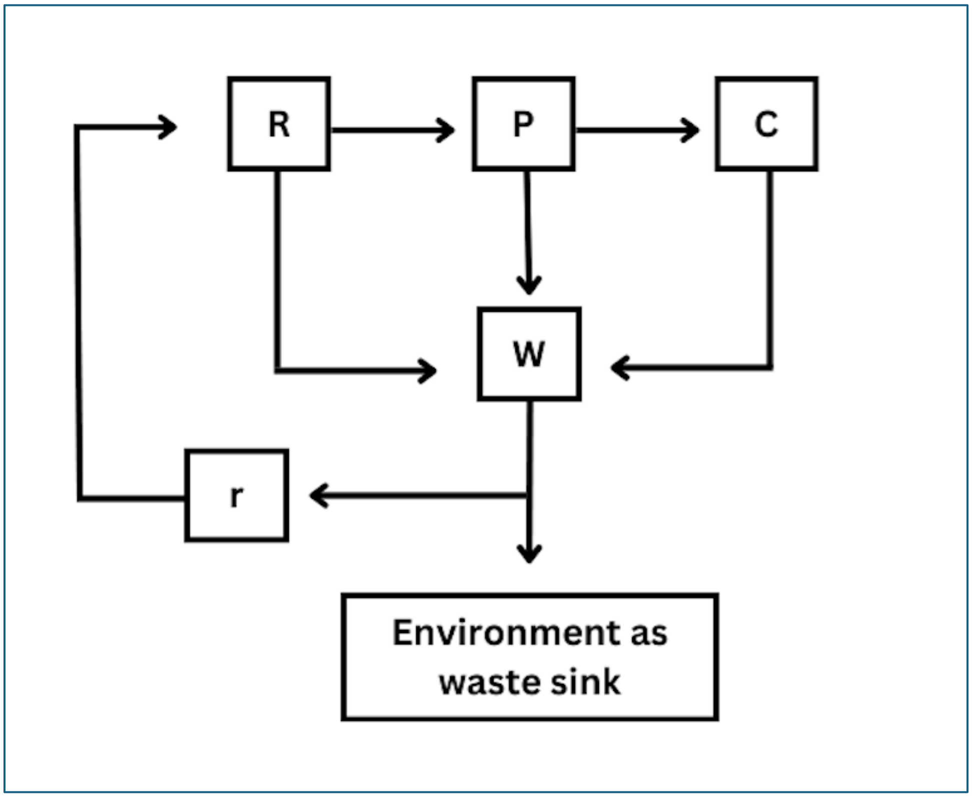

FIGURE 3. THE CIRCULAR BUSINESS MODEL ADAPTED BY PEARCE & TURNER (1990, P. 38).

It wasn't until the late 2000s when circularity began to rise after three events created an ideal setting for its development (Aggeri, 2021). First was the drastic rise of commodity prices between 2000 and 2010, which was a wake-up call for policymakers and businesses to face the reality of our dependence on finite resources. The second was China's embargo on rare earth metals which caused major supply chain disruptions exposing the vulnerabilities in linear resource use. Lastly, throughout this period, we saw a steady rise in environmental indicators that stressed the urgency of the ecological crisis.

In 2013, The Ellen MacArthur Foundation published its first report on circularity. The circular economy was defined as "an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design" (Ellen MacArthur Foundation, 2013, p. 22). It is a transformation of our current linear economic model to one that prioritises restorative practices, and aims to design products for repair, reuse, and recycling, while minimising waste and environmental damage (Figure 4). It draws on inspiration from natural systems emphasising the optimisation of entire systems, not just individual components. Materials are categorised into two cycles: biological which can be returned to the environment and technical which can be brought back into circulation by incentivising durability, disassembly, and refurbishment.

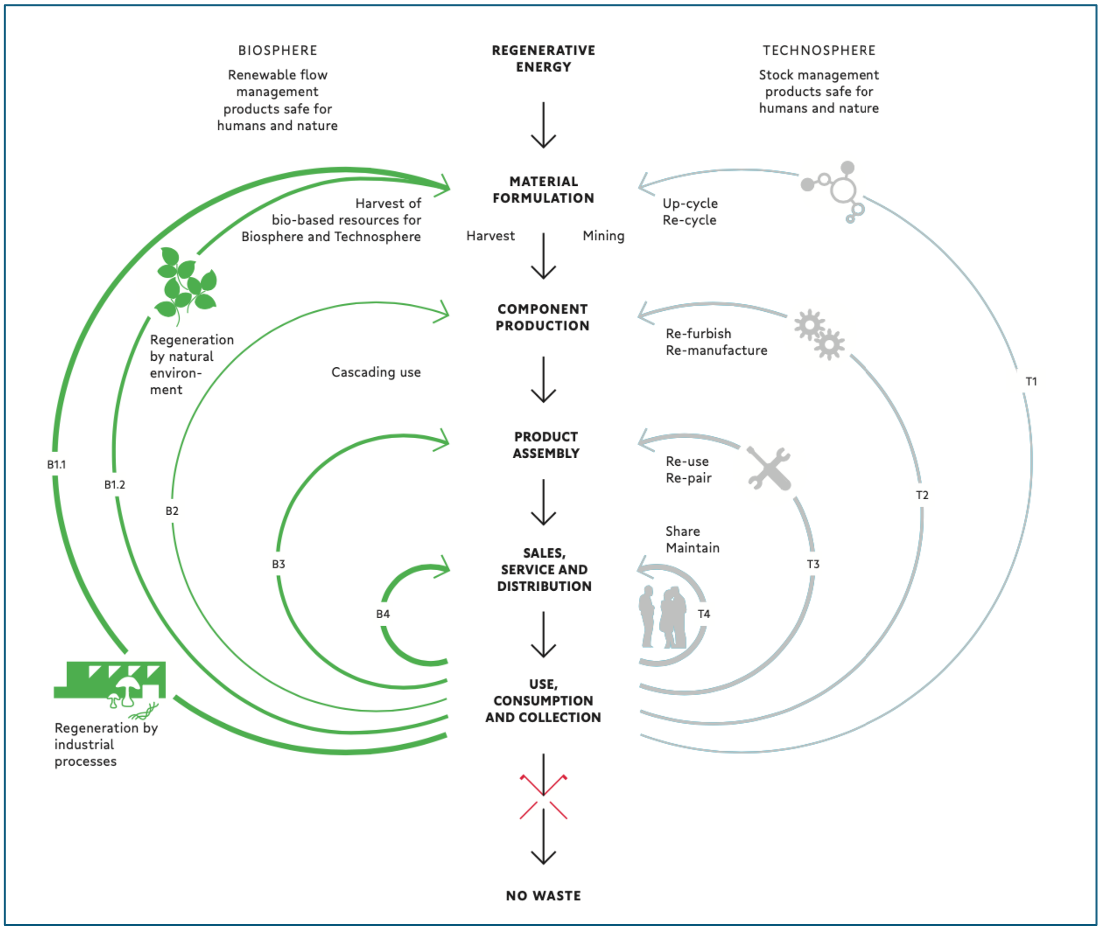

Figure 4. The butterfly diagram representing a circular economy(Heisel & Hebel, 2022, Figure 1).

With the modern concept of circularity still being relatively new, it is important to recognise the conceptual contentions. At some point theory needs to translate into practice otherwise it "may ultimately collapse or remain in a deadlock due to permanent conceptual contention" (Kirchherr et al., 2017, p. 221). The field can be compared to the notion of 'the wild west' where no one can pinpoint or has the authority to define what circularity means exactly which leaves both opportunity and risk for its development. In a Danish context, circular construction is defined as a system where,

> […] materials and products are recirculated, their value is fully utilised, and wastage is minimised. Buildings and products are designed for reuse, repair, and recycling instead of being discarded. It is easy to share and get access to products and services without owning them. Biomass is used for pharmaceuticals, bio-based products, and food ingredients instead of mere energy recovery. Problematic chemicals are phased out in order that waste and wastewater can be recirculated as raw materials of high quality. Surplus production and wastage from one enterprise is used as a valuable raw material in another enterprise (The Danish Government, 2018, p. 6).

Within circular construction central circular strategies have evolved to get to the root of transforming the definition of waste. The end of a building's life is no longer considered the end, but rather the start of its next cycle (Heisel & Hebel, 2022). With this mindset, materials become resources rather than waste. Viewing the built environment to be comprised of "materials banks" where a structure is seen as an assembly set of resources that can be put back into circulation opens abundant opportunities to rely less on virgin materials (Dabaieh, 2023). The well-known strategies for implementing circularity revolve around the 4R approach of reduce, recover, reuse, and recycle (Jakobsen et al., 2024; Khaw-ngern et al., 2021; (Kirchherr et al., 2017). Reducing our reliance on virgin materials to combat the industry norm that 'new is better' is a first and foremost concern. Recovering materials from demolition projects such as timber, steel, and bricks redefines waste as a resource. Through reuse the original value of a material can be kept, for example using from a demolished building to build a new structure. Recycling should be the last option as materials can be transformed into something new but lose their original value. Based on the 4-R approach circular construction practices have been established and consist of design for disassembly and deconstruction, and transformation.

Design for disassembly (DFD) is a modular concept that places life-cycle thinking at the forefront of design (O'Donnell & Pranger, 2021). It is the creation of a circular built system where the city can reproduce itself by reallocating existing resources through material banks rather than having to extract virgin materials. The method behind this strategy consists of designing buildings with a focus on material selection to build structures that can be easily disassembled using standardised connecting elements. Through DFD, materials are given the opportunity to transform and live multiple lives without losing their original value or being considered waste. In addition, transformation is a key principle of circular construction; historic buildings are a prime example of this. They are testaments to adaptive reuse and the value of building for longevity and durability. While DFD is an important method, building new should no longer be the first option, utilising what already exists is an undeniable method for managing waste at its root source.

A Circular Built Denmark

Denmark is a prime candidate for leading the transition towards a circular economy. The shift towards circularity requires ambitious targets and strong leadership to challenge neo-liberal capitalism and establish the status quo as no longer viable. In 2020, Danish Parliament approved the Climate Act which legally binds the nation to reduce GHG emissions 70 percent along with reaching climate neutrality by 2030 but ultimately, by 2050 at the latest (Klimaloven, 2021). With a commitment to climate targets and progressive policy, Denmark provides an ideal setting to experiment with the potential of a circular built environment.

Significant strides are being made in Denmark to implement a circular economy in the building sector successfully. In 2016, the Danish Parliament formed the Utilities Strategy to promote the better utilisation of waste to enhance incentives for recycling before incineration and provide better access to recycling waste (The Danish Government, 2018). By mandating an open bidding process on burnable waste, the strategy promotes a more efficient waste management system that allows recycling plants to compete with incineration plants. To address the current limitations in the recycling system, the strategy proposes to create a secure market around recycled materials to promote investment in sorting plants and allow businesses to participate in take-back programs and innovative recycling models.

In 2018, the Danish Ministry of Environment and Food and the Danish Ministry of Industry, Business and Financial Affairs drafted the official *Strategy for Circular Economy*. The strategy proposes 19 initiatives and six areas of effort to "promote a rethinking of our way of producing and consuming" (The Danish Government, 2018, p. 6). Two of those initiatives are directed at developing a circular economy in the building industry. Initiative 13 aims to develop a voluntary sustainability class to increase resource efficiency, and create value for circular materials through phasing out virgin materials. Initiative 14 focuses on the wider adoption of selective demolition practices through simpler compliance processes to incentivise the reuse of construction materials.

Following the rollout of the national strategy for the circular economy, the Danish government signed the *National Strategy for Sustainable Construction* in 2021 which consists of 21 initiatives following five themes: “1) More climate-friendly construction and construction 2) High quality durable buildings 3) Resource efficient construction 4) Energy efficient and healthy buildings 5) Digitally supported construction” (Indenrigs og Boligministeriet, 2021, p. 6). In 2020, the *Strategy for Green Public Procurement* leveraged government purchasing power over sustainable and circular materials (Ministry of Finance, 2020). Effective tax efforts on landfilling, waste incineration and raw material extraction are in place to make sustainable and circular efforts more financially feasible *(Waste, Materials Management and the Circular Economy*, 2019). Building regulations are becoming stricter towards climate impacts as seen by the 2023 LCA requirements to reduce carbon emissions by requiring all new construction activities to be documented (Social- og Boligstyrelsen, n.d.). Moreover, the Danish government recently approved legislation that mandates any demolition project for buildings over 250 square meters to produce demolition plans which will enhance circular efforts (*In Denmark Old Building Materials Must Be Used Again* | Interreg Europe - Sharing Solutions for Better Policy, 2023).

On top of the stated developments, numerous circular building projects have arisen in Denmark to showcase the potential of circular construction. One is the island of Bornholm, which is being used as a testing ground for circular innovation (Christensen et al., 2022). The Green Solution house on the island was completed in 2015 using circular methods such as DFD, and material selection through upcycling local waste and reused materials (GXN, n.d.). Additionally, The Circle House project, in Aarhus is the first housing project (60 units) in Denmark designed to use 15 strategies for implementing reuse and circular economy strategies (DFD & Material Passports) (GXN, 2018). These two projects are only small representations of the circular efforts from the building industry in Denmark to place attention on the possibilities of circular construction.

Building Material Waste

Construction and demolition (C&D) waste accumulated throughout the supply chain is a significant contributor to environmental issues. The construction industry in Denmark produces a massive amount of waste, estimated at 5 million tons annually and only 36 percent of that waste is being recycled (Schefte, 2022). In the context of this research, building material waste consists of any leftover, unused, or excess material produced throughout a building's lifecycle. (Kumawat et al., 2022). The building lifecycle includes the manufacturing process, construction, operation, and demolition. The material elements with the highest climate impacts are concrete, asphalt, masonry, and wood products as well as metals, plastics, insulation, and paper and cardboard (El-Haggar & Samaha, 2019). The environmental impacts caused by C&D waste are well known by the industry and have even been labeled as the primary cause of environmental pollution (Chen et al., 2021). The most common method of treating C&D material waste is often through landfills which not only has environmental consequences but creates an overload issue. If C&D waste is not handled properly numerous negative effects such as soil erosion, pollution of wells and waterways, and the disturbance of biodiversity are a result (Kumawat et al., 2022).

A considerable amount of research is dedicated to advancing solutions to address C&D waste, yet barriers that hinder recycling rates such as lack of infrastructure, economic disadvantages, knowledge gaps and regulatory hurdles still exist (VCØB, 2023). For instance, a handful of building materials contain toxic elements (asbestos, PCB's, heavy metals, pollutants such as oil, solvents and fuel) that make recirculating the waste back into the supply chain challenging (Kumawat et al., 2022). The official Danish *Bekendtgørelse om Affald* (Notice on Waste) creates limitations for implementing circular practices by using a narrow definition of "by-products" (Klimaloven, 2021). The narrow view restricts the number of materials considered suitable for reuse and discourages the development of processing techniques for waste materials by establishing a burden of proof requiring waste materials to demonstrate a negative impact on the environment. Furthermore, the cost of recirculating C&D waste back into the economy remains uncompetitive against the low cost of purchasing virgin materials (Christensen et al., 2022). A handful of complications arise when considering the reuse of building materials, therefore remaining open to the possibilities of using materials across industries is an innovative way to close material loops.

To ease the transition associated with implementing circular practices for C&D waste technological efforts are continuing to develop. Life Cycle Analysis (LCA) is being utilised by actors across the supply chain to identify how materials can reduce potential climate impacts throughout their entire lifecycle from extraction, demolition and reuse (Christensen et al., 2022). Digital software has created a tracking system of "material passports" to track the properties, origin and potential reuse of materials (Vind et al., 2024). Building Information Modeling (BIM) is transitioning to incorporate features that allow architects and engineers to facilitate easier design for disassembly allowing for easier material recovery during demolition (Christensen et al., 2022). While technological developments are essential to ease the transition it is of great importance to use them as tools rather than all-encompassing solutions.

To incorporate a circular system in the building sector parameters defining what kinds of materials are suitable for re-use are needed. The Upcycl, a circular impact-driven company in Denmark concentrates on recirculating building material waste with two elements: uniformity and continuity (The Upcycl, n.d.). Uniformity refers to materials that are of a consistent type or composition and continuity focuses' on materials that can be produced at a high volume. Examples of materials that fit these two elements are stainless steel pipes, panel boards, timber, galvanised steel, sheet metal, plastic, cardboard, sling straps, cork rubber, polyethylene foam, cellular rubber, and fiber discs. Having a clear understanding of what kinds of materials are suited for circular practices can help ease uncertainty surrounding the potential of reuse.

Identifying the Gap

A surge of interest and a considerable amount of investment and research is happening in the building sector which provides a promising path for scaling up circular practices. Yet, the wider adoption of circularity in the building industry is staggering. Despite Denmark's monumental strides towards a circular transition, a

2023 special report conducted by the European Court of Auditors revealed that between 2015 and 2021 Denmark's circularity rate declined by 0.5 percent in total material use (European Court of Auditors, 2023). To continue moving the circular transition along, understanding the barriers creating stagnation is crucial.

Numerous large-scale research efforts in Denmark have contributed to a circular transition in the building sector (CIRCuIT, 2023; Guldager Jensen & Sommer, 2018; Jakobsen et al., 2024; Keys et al., 2023; Koch-Ørvad & Simonsen, 2023; Oberender et al., 2023; Schefte, 2022; Selman & Gade, 2020; VCØB, 2023; Vind et al., 2024). With support from the Danish Environmental Protection Aagency, the architecture firm GXN published the third edition of *Building a Circular Future* in 2018. The report highlights three recommendations for the construction industry to implement a circular economy: develop a standardised circular building code, incorporate material passports for buildings, structure procurement around material lifecycle costs, and increase the use of selective deconstruction and demolition (Guldager Jensen & Sommer, 2018). In 2020, The Danish Professionshøjskoler conducted research with stakeholders involved in building design to identify the circular barriers faced in the Danish construction sector. Six barriers were identified during the literature review: Economic, Collaboration, Materials Passports (MP) and Digitalisation, Policies, Social and Technical Barriers (Selman & Gade, 2020). The research revealed that while the benefits of adopting circular practices in the building industry are clear, financial risks due to unclear legalities, split incentives, and supply chain challenges hinder widespread adoption.

Rådet for Grøn Omstilling published the report *Cirkulært Byggeri –fra Drøm Til Virkelighed* (Circular Building from Dream to Reality) in 2022 which highlighted that while circular practices are being adopted in the industry, it has yet to become the norm (Schefte, 2022). Additionally, it is a concern that recycled building material waste can't match construction demands unless it scales down significantly, which is why turning to materials from other sectors such as agriculture is a potential option but, these material chains are still underdeveloped making them unviable in the market. In 2023, the construction group Værdibyg, published *Risiko Som Barriere for Bæredygtige Byggematerialer* (Risk as a Barrier for Building Material) to investigate the risks stakeholders face associated with using sustainable building materials. The outcome of the analysis resulted in the identification of six risks: Economy & Insurance, Knowledge about Materials, Materials & Logistics, Human Factor, Framework Conditions, and Time (VCØB, 2023). 10 solution efforts were proposed as a result of the study, Experiments & Demonstration Projects, Knowledge Banks, Financing Structures, Insurance & Risk Coverage, Risk Funds, Political Pushes, Regulations, Authority Processing, Market & Business Models, and Motivation.

CIRCuIT, an EU-funded research project, published a report in 2023 *Circular Construction in Regenerative Cities.* The goal of the project was to promote circular construction practices by addressing three key themes: maximising building lifespans, urban mining, and material reuse, and designing for disassembly and adaptability (CIRCuIT, 2023). The outcome of the project demonstrated that a circular building sector is financially and environmentally beneficial, and achievable through collaboration and new tools, and scalable across various levels with city roadmaps and digital platforms.

Circle Economy, an organisation dedicated to researching solutions for circular economy published *The Circularity Gap Report* aimed at addressing the circularity gap in Denmark. A significant finding of the report indicated that 49.2 percent of materials are locked into stock, meaning most materials won't be available for decades to come (Keys et al., 2023). Due to this, it is crucial to already start incorporating design for durability, repairability, and cyclability to enable circular practices down the road. Highlighting this need, Realdania published the report *Cirkulær Økonomi i Byggeriet* (Circular Economy in Construction) which identified central drivers and barriers facing circular construction practices. Across the supply chain, innovative solutions are being tested and developed in the industry yet, much of the focus remains on maintaining the status quo (Oberender et al., 2023). A significant hurdle in implementation remains to be how to integrate circular practices into large-scale projects when the value of resources beyond their initial use remains the same.

Transition, a sustainability consulting firm, conducted a study in 2024 with municipal departments in Denmark to create a guide for municipalities to promote circular building practices (Jakobsen et al., 2024). The result of the study draws attention to strategies municipalities can implement to promote circular building practices such as setting an example by making a sincere effort to utilise circular materials, reduce anxieties around regulations by streamlining permitting processes for those who use circular practices, treating municipal buildings as material banks and choosing preservation and transformation over demolition as much as possible. Furthermore, BLOXHUB, a collective of companies and organisations contributing to sustainable urbanisation published *Building a Circular Future* in 2024. The interdisciplinary research stresses the importance of a systems change within the building industry by highlighting the importance of collaboration; recognises the complexity of relationships that influence the built environment, and acknowledging the gap between policy and practice (Vind et al., 2024). Both reports highlight the momentum circular practices are gaining in the industry, and through collaboration, policy development and systemic change it will only increase.

The recent research illustrates the dedication of those in the industry advocating for a transition away from the linear model of doing business and transitioning towards circularity. What needs to be further explored is the hesitancy of stakeholders across the value chain toward adopting circular practices. A notable amount of research reveals a circular economy is not only needed but possible. Despite this, a large "circular gap" still exists in the industry (Keys et al., 2023). By focusing on how stakeholder perceptions of uncertainty are influenced by external factors, the specific concerns that hinder scalability can be identified to understand the business-as-usual mentality on a deeper level.

Sustainable Development

As we are facing unprecedented challenges from climate change to social inequality and environmental injustice, the importance of sustainable development can't be overstated. It is irresponsible to not consider these challenges as deeply connected and influenced by the structure of society. Implementing responsible resource management, innovation, and a commitment to intergenerational equity is just the beginning of a much-needed change. The change requires a complete transformation of our current linear model of doing business to a sustainable business model (SBM) like circular economy to foster long-term economic growth and environmental prosperity.

Sustainable development was introduced in the Brundtland Report in 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 8). For a sustainable future, a vast rethinking of economic growth is needed to not only meeting the basic needs of all but provide a better life for every being on this planet. Sustainable development is not an easy or painless process as it requires an entire reworking of how we use resources, invest our money, develop technology, and structure our institutions. It requires those of us in the Global North to come to terms with our role in perpetuating the ongoing climate crisis.

In 2015, at the UN Sustainable Summit, 17 Sustainable Development Goals (SDG) and 169 targets were proposed to guide global and national policy in the green transition. The declaration of the SDGs is a commitment to address the environmental, social and economic dimensions of sustainability by 2030 (Transforming Our World: The 2030 Agenda for Sustainable Development, 2015). In the building sector, the SDGs of most concern include 9 (Industry, innovation, and infrastructure), 11 (Sustainable cities and communities), 12 (Responsible consumption and production), and 13 (Climate action are of most concern) (*Sustainable Built Environments & the UN's Sustainable Development Goals*, n.d.).

While the adoption of global goals that drive sustainable efforts is imperative, it is crucial to be critical of what is considered sustainable, how development is achieved and who benefits from the outcome. The premise of sustainable development and the

SDGs aim to create economic growth while simultaneously eliminating the biggest issues we face in humanity. This begs the question, is it even possible to maintain sustainable economic growth? The notion of development is a Western idea "designed to improve the well-being of people" but in reality "was designed to incorporate developing countries into global capitalism" (Adelman, 2018, p. 17). Developmentalism is founded based on "evangelical ideology of salvation through industrialisation, modernisation and integration into the global political economy through free trade and the exploitation of natural resources" (Adelman, 2018, p. 18). Without addressing the root causes of the systemic issues that perpetuate the climate crisis, sustainable development will only be the newfound method of modern capitalism that grounds itself on the exploitation of the Global South and ultimately colonialism.

One of the biggest critiques of sustainable development is that the term in itself is an oxymoron (D'Alisa et al., 2015; Kothari et al., 2014, p. 366). The idea that decoupling equitable economic growth from environmental impact is "based on a false consensus" rooted in neoclassical economic theory (Hornborg, 2011, p. 143; Kothari et al., 2014). As Hornborg describes "mainstream modern perceptions of 'development' can be viewed as a cultural illusion confusing a privileged position in social space with an advanced position in historical time" (2011, p. 7). This framework of development accepts and promotes the innovation of solutions that do not get to the core of environmental issues. It is the fetishisation of technological inventions as the key to battling climate change. The lack of acknowledgment of the socio-ecological processes of industrial capitalism makes it reasonable to question if the proposed solutions within sustainable development are even within reach.

With only six years remaining to fulfill the officially set goal of the SDGs in 2030, a severe lack of progress threatens the possibility of reaching the target. In the 2023 *Sustainable Development Goals Report Special Edition*, the potential for achieving the goals "are disappearing in the rear-view mirror, as is the hope and rights of current and future generations" (United Nations Department of Economic and Social Affairs, 2023, p. 4). Yet, having spent billions of dollars developing sustainability, we are not close enough to our goals, some might even say moving in the opposite direction (Hornborg, 2011). This alarming trend can be traced back to the role of industrial capitalism on climate change, which relies heavily on resource extraction, and consumption patterns to foster continuous economic growth. The need for rapid systemic change on a massive scale that does not overlook the role of industrial capitalism is ever present and innovative sustainable business models offer a theoretical framework to explore that possibility.

Sustainable Business Models

Business models (BM) are the foundation for any organisation or industry. They are the frameworks that represent the purpose and strategy for how a business does business (Ensign, 2022). Business model innovation (BMI) offers a creative space for exploring strategy and implementation through innovation by "depicting current realities ("as is") or used for simulations to decide on a preferred future ("to be")" (Aagaard, 2019, p. 2). BMs reflect the theoretical underpinnings behind the tactical choices and strategic decisions an industry makes to function and create value.

Three core elements define a business model, Value Proposition, Value Creation and Delivery, and Value Capture (Aagaard, 2019; Elkington, 1997). In the construction industry value proposition is concerned with offering unique and appealing projects, services, or projects to clients such as improved sustainability features. Value creation focuses on how to deliver the value proposition to the client through activities, resources, and partnerships, one example is utilising innovative building techniques. Value capture refers to how a construction company or stakeholders capture the economic benefits of a project to ensure a return on investment.

Linear BMs view value through an economic lens where success is measured by maximising profit and minimising cost. The linear hyperfocus on economic value creates a blind spot where "the business of business is about the creation of economic value, and not about social or ethical values" (Elkington, 1997, p. 7). Stakeholder interests are the primary concern of traditional LBM and the environmental and social consequences are disregarded as just the cost of doing business.

A business model that expands value to incorporate environmental, economic, and social demands is desperately needed in the construction industry as climate pressures are becoming increasingly urgent. In contrast to the traditional linear business model, sustainable business models place value on prioritising environmental and social responsibility through strategies such as maximising resource utilisation, deriving value from waste, promoting the use of renewable resources, and shifting towards products as a service (Bocken et al., 2014). A SBM adopts the logic in which economically oriented value propositions are combined with environmentally and socially oriented value propositions (Aagaard, 2019). Circular business models (CBM) are quickly gaining popularity within the SBM world, and "aim to loop, or retain, value which has been already created in the system" (Kyrö & Lundgren, 2023). The lifespan of materials can be extended through prioritising resource efficiency through a closed-loop system. CBM are the theoretical frameworks that guide the operation of a circular supply chain (CSC).

Circular Supply Chains

The transition away from linear business models is pioneered by the development and innovation of SBM. One solution gaining traction is circular business models (CBM). CBM is an alternative to the linear business model and aims to redefine waste as a resource by continuously cycling materials back into the loop.

To provide some background, it is useful to know the basics of supply chains, what they are, and how they work. A supply chain (SC) can be defined as a global network that "assists in the movement of raw materials from the initial suppliers to the manufacturers and finished products from the manufacturers to the end users" (Orji & Ojadi, 2022, p. 4). Within the SC, there are upstream and downstream flows (Walker, 2005). Upstream activities are related to acquiring raw materials and manufacturing. For instance, mining for stone, sand, and gravel, the production of materials such as bricks, concrete, steel, and insulation, or the process of harvesting trees for lumber. Downstream activities are those related to selling the materials or the actual use of the products. In this case, it would be hardware stores that sell the materials, construction companies that purchase and manage the materials, or subcontractors that specialise in using specific materials.

A common misunderstanding within supply chains is the term value chain. The supply chain is concerned with the physical movement of goods between the raw material to the end consumer (Walker, 2005,; Priya et al., 2021; Ayers, 2004). Whereas the value chain is the complex interconnected network of stakeholders and activities that create and determine value within the supply chain (Ayers, 2004). The main actors involved in each stage across the value chain in circular construction are presented in Figure 5 by Huovila & Westerholm (2022).

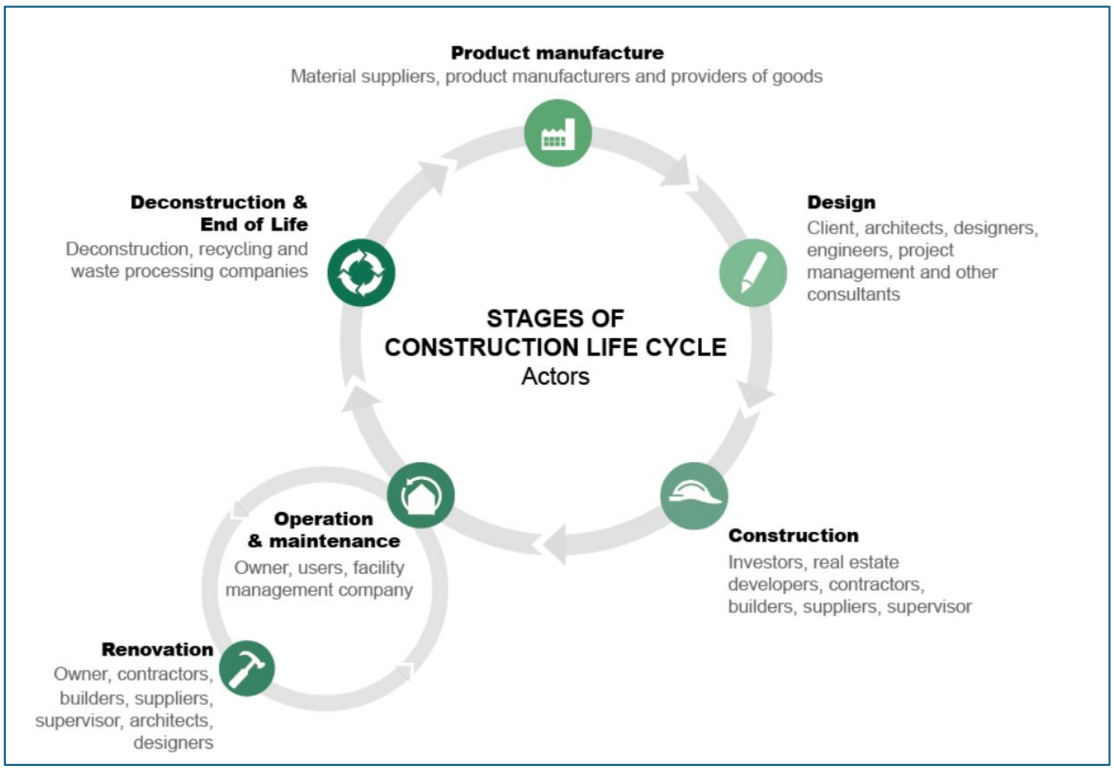

FIGURE 5. STAKEHOLDERS ACROSS THE VALUE CHAIN IN THE BUILDING INDUSTRY (HUOVILA & WESTERHOLM, 2022, FIGURE 2)

In comparison to a traditional SC, circular supply chains (CSC) move away from the take-make-waste linear model and focus on reducing the demand for virgin materials and minimising the environmental footprint of production processes (Orji &

Ojadi, 2022). By designing products for reuse, repair, and recycling lifespans are optimised, allowing materials to be recirculated back into the economy rather than ending up as waste. The circular supply chain for building material waste consists of six key stages highlighted in Figure 6 by Heisel & Hebel (2022). It begins with prioritising the preservation of materials such as timber, bricks, metal, windows and fixtures through deconstruction or selective demolition. The reclaimed materials are then sorted, cleaned, and refurbished for reuse and if direct reuse is not possible, the materials are processed into a raw format to be used in new construction projects. If the materials are going to be reused in a new construction project, they must undergo a rigorous testing and recertification process to ensure safety and performance. Reclaimed materials re-enter the economy through various avenues via online and physical marketplaces most often managed by demolition or upcycling companies. The overall mission of implementing circular practices for building material waste is to recover and return all materials to their original cycles.

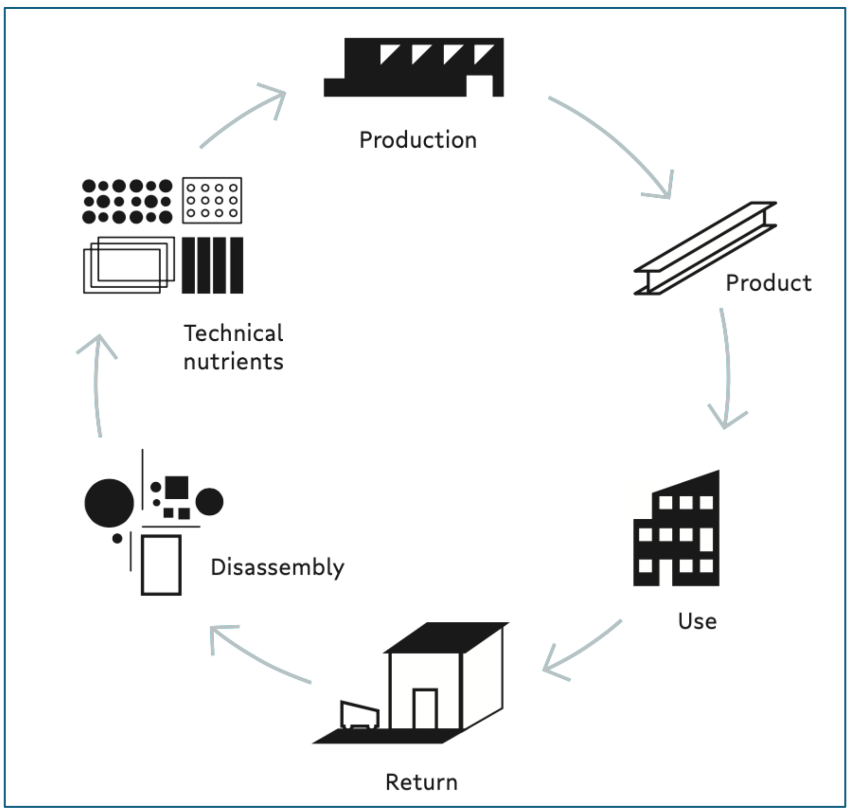

FIGURE 6. THE CIRCULAR SUPPLY CHAIN FOR BUILDING MATERIAL WASTE (HEISEL & HEBEL, 2022, FIGURE 4)

The notions of risk and uncertainty are prominent in discussions around supply chains, specifically for circular supply chains because they are business models that are still being developed and tested. It is undeniable that transitioning away from the ingrained linear business model creates significant uncertainty and risk for stakeholders. Whether it be the cost of materials or the legal barriers surrounding the reuse of building material waste, an assortment of risks and uncertainties need to be addressed to scale up circular practices in the industry. This research specifically investigates stakeholder perceptions of risk and uncertainty; therefore, it is important to situate the terms in their contexts. In his book *Risk and Supply Chain Management,* Waters (2011) provides a clear framework for understanding risk and uncertainty. Simply put, risks are defined as "unforeseen events [that] may happen in the future" (Waters, 2011, p. 15). Risks can occur due to a variety of factors:

> Some arise from external effects in the environment, while others come from internal operations; some are long-term that might strike at any point far into the future, and others are short-term and soon disappear; some have minor impact, while others destroy entire supply chains; some appear regular in normal operations, and others are one off disruptions such as natural disasters (Waters, 2011, p. 15).

Uncertainty is closely entwined with risk, as it is uncertainty about the future that creates risk for stakeholders. Uncertainty is the lack of precise knowledge related to future events, outcomes, or the consequences of decisions (Waters, 2011). It is the acknowledgment that multiple possibilities exist in this world and have the potential to unfold. Uncertainty can trigger risk however, it is not inherently negative. Opportunities for transformation lie within uncertainty. For example, the evolving and ambiguous regulations surrounding circular practices for building materials waste create uncertainty for stakeholders. At the same time, the uncertainty leaves space for innovation encouraging the industry to develop frameworks that allow circular practices to meet standards. The important difference between risk and uncertainty is that risk "can list the events that might happen in the future, and give each a probability" whereas uncertainty "means that we can list the events that might happen in the future, but have no idea about which will actually happen or their relative likelihoods" (Waters, 2011, p. 18). By delving deep to expose the root causes of uncertainty for stakeholders, it becomes possible to develop solutions that strengthen circular practices.

The PESTEL Framework

In 1967, Aguilar wrote his dissertation on scanning the business environment. Little did he know at the time that his method of environmental scanning would become the theoretical basis for the widely used PESTEL framework. In the context of his research, environmental scanning refers to mapping the external environment to identify the cause and effect of the external environment on managerial decisions (Aguilar, 1967). Aguilar identified four factors of the external environment, Economic, Technological, Political, and Social (ETPS). ETPS is a practical tool used by businesses to create opportunities for improvement by identifying the type of information that is needed, creating a structure for organising data, and facilitating the proper use of information to create a positive impact. It is noteworthy to mention that environmental scanning is a continuous imperfect process that is never complete "for the world is to extensive and complex ever to be completely summarised" (Aguilar, 1967, p. 9).

The PESTEL framework is built on the understanding that beyond our observations, an external reality exists which influences our perceptions and the decisions we make (Aguilar, 1967). Over time, it has evolved more into a practical tool rather than a deep philosophical approach. Discussions in literature surrounding the theoretical underpinnings of PESTEL are limited, but it is understood that external factors can be observed and categorised through trends in data to help illustrate the indirect or direct impacts of external factors on decision-making processes (Madsen & Grønseth, 2022; Nayak & Kayarkatte, 2020; Qiu et al., 2022; Tijani et al., 2022; Yüksel, 2012; Ordóñez et al., 2023).

Since 1967, several variations of ETPS emerged, each emphasising different external factors: PEST, STEP, SLEPT, PEST-E, PESTEL, and PESTELS. This research adopts the PESTEL framework to address the Political, Economic, Social, Technological, Environmental, Social and Legal factors which comprise the external environment. The PESTEL variation is widely adopted because it is a highly versatile framework easily adaptable to various fields (Madsen & Grønseth, 2022). PESTEL is utilised by a variety of industries including fashion, tourism, manufacturing, healthcare, and technology. Identifying the external factors that exist in the macroenvironment, can be useful for predicting and identifying the barriers, risks, and uncertainties faced by an industry. Table 1 outlines the definitions of each external factor analysed in this research, which are adapted and tailored specifically for the this study.

EXTERNAL FACTOR	DEFINITION
Political Factors	Elections, political parties, and campaigns that relate to the political discourse in Denmark which influence the adoption and utilization of circular practices for building material waste.
Economic Factors	Market trends, investment opportunities, material costs which influence the adoption and utilization of circular practices for building material waste.
Social Factors	Societal attitudes, behaviors and cultural norms surrounding sustainability in the building industry and in Denmark which influence the adoption and utilization of circular practices for building material waste
Technological Factors	The availability of recycling methods, innovative reuse techniques, Modeling systems, circular platforms and data availability influence the adoption and utilization of circular practices for building material waste.
Environmental Factors	Resource depletion, pollution, and climate change influence the adoption and utilization of circular practices for building material waste.
Legal Factors	Building regulations, laws and legal frameworks that influence the adoption and utilization of circular practices for building material waste.

TABLE 1. THE DEFINED EXTERNAL PESTEL FACTORS

A Mixed-Method Approach

Our perceptions are influenced by the external factors which create the world we live in. The risks and uncertainties associated with each external faction influence the circular building material supply chain. These external factors are mechanisms "which are capable of making things happen in the world" and shape conceptions of risk and uncertainty (Alvesson, 2018, p. 51). Within each external factor are elements that affect the stakeholder decision-making processes. *Political factors* shape the landscape and discourse surrounding a circular economy. *Economic factors* such as material costs and market trends determine financial feasibility. *Social factors* influence the societal and industry norms around sustainability, quality, and value. *Technological factors* create opportunities for standardisation and innovation highlighting the potential of circular practices. *Environmental factors* such as exceeding planetary boundaries influence the risk of continuing business as usual and *Legal factors* affect the parameters in which circular practices can operate.

Uncovering the complex relationships between external factors involves investigating the different mechanisms at play, the impacts and outcomes they produce, and the effects they trigger across different structural levels (Alvesson, 2018). However, it is crucial to remember that "what is important is not just to explain the world but to also change it" (Alvesson, 2018, p. 48). The questions we ask are pivotal for solving the problems we have in relation to the world around us. Getting to the root of how social, ideological, and political conditions produce scientific understanding "independently of their discovery" is key to further developing circular supply chains so that operating under an LBM is viewed as no longer optimal (Alvesson, 2018, p. 49).

Researching circular supply chains through a social science lens allows for a deeper understanding of the complex cultural, social, political, and economic conditions that influence their development. In social science, we may not "not always able to present clear and definitive conclusions"(Gronmo, 2019, p. 13). However, we gain a more holistic perspective on the complicated conditions in society Traditionally, supply chains are studied based on efficiency and optimisation using quantitative modeling and network analysis (Priya et al., 2021). Although beneficial, strictly sticking to this approach is limiting for gaining insight into the adaptation, environmental and social impacts, along with the role of culture and institutions on supply chains. Since this research is focused on analysing stakeholder perceptions, it is only fitting that a mixed-method approach through a social science lens is adopted.

The initial intention behind this research was to conduct a case study on a company in Denmark that specialised in circular building materials to identify their risks and uncertainties to help build resilience in their supply chain. One company was willing to collaborate on this project, which inspired the initial research question of investigating uncertainty across the supply chain. However, due to a lack of resources, the collaboration was not able to continue. As a result, the research aims, questions, and methods were reframed to focus on the broader stakeholders across the value chain, utilising Denmark as the case study.

A mixed-method approach provides the opportunity to incorporate a diverse range of perspectives across the value chain (Tashakkori & Teddlie, 2003). Combining qualitative and quantitative data enables the simultaneous exploration of confirmatory and exploratory questions which result in stronger inferences. As mentioned by Tashakkori & Teddlie, "One method gives greater depth, while the other gives greater breadth" (2003, p. 16). Nonetheless, the limitations to this approach such as cohesiveness, standards, and quality when combining quantitative and qualitative data are present (Gronmo, 2019, p. 23; Tashakkori & Teddlie, 2003, p. 39). Supply chains are complex networks that are influenced by various external factors (Waters, 2011). To investigate the external environment that impacts stakeholder perceptions, the following research question was identified:

> *How do external factors (political, economic, social, technological, environmental, and legal) influence stakeholder perceptions of uncertainty across the value chain within the circular supply chain for building material waste?*

The phenomena under study are stakeholder perceptions of uncertainty surrounding building material waste in the circular supply chain. This phenomenon relates to human ecology in several ways by investigating human-environmental relations, understanding the interconnectedness of PESTEL factors, and focusing on sustainability and planetary balance all through an interdisciplinary perspective. To investigate this phenomenon, qualitative semi-structured interviews and a quantitative survey were incorporated. Engaging with individuals is a key element of the research since it involves stakeholder perceptions. Identifying the stakeholders involved across the value chain required utilising supply chain network mapping. Supply chain network mapping breaks down the activities, actors, resources, and geographical aspects to encompass the upstream and downstream flows of products and information to provide a comprehensive view of the whole network (Mubarik et al., 2023). When broken down, the typical journey of building material waste in a circular supply chain consists of deconstruction and demolition, sorting and processing, testing and recertification, transportation and logistics, and material upcycling, followed by design and new construction.

By mapping the circular supply chain, key primary and secondary stakeholders were able to be identified at each stage of the supply chain. Primary stakeholders are individuals directly involved in single or multiple stages of the supply chain such as architects or contractors. Secondary stakeholders are individuals with indirect impact or potential influence on the supply chain, such as sustainability consultants or researchers. Based on this, 16 stakeholder categories were identified: Architect, Circular Tech Developer, Consumer, Contractor, Circular Materials Market, Designer, Demolition Contractor, Educational Outreach Specialist, Engineer, Investor, Legal Expert, Manufacturer, Politically Affiliated, Public Participant, Researcher, and Sustainability Consultant.

Having defined stakeholder categories across the value chain, the next step involved contacting individuals. A targeted online search consisting of strategically searching through industry directories, company websites, professional networking platforms (LinkedIn), and government and industry reports helped to identify individuals to contact. In total 505 individuals were contacted through Lund University Gmail to participate in the research project. As a result, the survey respondents (n=52) and the interviews (n=19) offer a rich variety of perspectives that contribute to an inclusive picture of the external environment that impacts uncertainty and risk in the supply chain for circular building materials (Table 3).

STAKEHOLDER	SURVEY	INTERVIEW
ARCHITECT	7	3
CIRCULAR TECH DEVELOPER	2	3
CONSUMER	6	0
CONTRACTOR	0	1
DEMOLITION CONTRACTOR	2	2
DESIGNER	0	1
EDUCATIONAL OUTREACH SPECIALIST	5	0
ENGINEER	2	2
INVESTOR	1	0
LEGAL EXPERT	0	0
MANUFACTURER	4	1
POLITICALLY AFFILIATED	3	1
PUBLIC PARTICIPANT	2	0
RESEARCHER	9	2
SUSTAINABILITY CONSULTANT	9	2
MATERIAL RESUSE SPECIALIST	0	1

TABLE 2. STAKEHOLDER COUNTS REPRESENTED IN THE SURVEY AND INTERVIEWS.

The quantitative survey was created through the survey platform Artologik Survey & Report with access from Lund University (Appendix A). To ensure anonymity the platform randomly created respondent IDs which are referred to in the analysis. Probability sampling was selected as the method for survey distribution to ensure that within the defined population, every stakeholder had an opportunity to participate (Gronmo, 2019). The purpose of the survey was to be distributed to stakeholders in Denmark with a vested interest in circular supply chains for building material waste. Before the survey was published, it was pretested by selected individuals for readability and structure. After changes were made to the survey according to the feedback, the survey was published from 29/02/2024 to 08/04/2024. The survey was designed to follow the PESTEL framework. Respondents completed the survey anonymously by accessing the link provided in the email. Since the respondents were responsible for completing the survey on their own time, it was designed to be simple and completed within five to 10 minutes. The survey consisted of two sections: stakeholder perceptions of external factors and risk evaluation. The first section consisted of a series of 10 questions exploring the perceived influence of external factors on the adoption of circular practices for building materials. Respondents rated their level of agreement with each statement on a Likert scale ranging from one (Strongly Disagree / Not Important) to five (Strongly Agree / Very Important). The second half of the survey respondents evaluated the perceived impact of each external factor considering risk and uncertainty using a Likert scale of zero (No Impact) to five (Very High Impact). In all, the survey consisted of 15 structured questions that were in single-answer format. None of the questions were mandatory to avoid leading the participants to choose an answer based on convenience. In both sections, an optional open-ended question was provided to allow respondents to elaborate on their responses or share specific examples. The open-ended responses from respondents were copied verbatim directly from the survey and used in the analysis. In total, the survey received 52 responses.

The survey was designed to provide quantifiable ratio data to identify the impact level of external factors on stakeholder perceptions (Gray, 2014). The data from the survey was collected, cleaned, and coded using Microsoft Excel. Exploratory analysis was selected to analyse the survey data because the research aims to discover the relationship between stakeholder perceptions and external factors by identifying trends, central tendencies, and potential relationships (Robson, 2011). The ordinal data responses were analysed through simple descriptive statistics to calculate the measures of central tendency (mean, median, mode) and frequency distribution. The findings from the descriptive statistical analysis were then integrated into the PESTEL analysis to provide a deeper understanding of the impact of external factors on stakeholder perceptions of uncertainty.

Throughout contacting stakeholders, individuals were also asked to participate in a 30-minute interview to explore external factors more in-depth. This method of convenience sampling relied on individuals willing to participate (Gray, 2014). The interviews were designed to follow the PESTEL framework however, they remained semi-structured to provide freedom throughout the interview process (Gray, 2014). For consistency, the interviews aimed to follow the sequence of an introduction that reestablished the purpose of the research and the interview; identifying the challenges the interviewer experienced in relation to the circular supply chain; investigating the impact of external factors on their perception; and ending on opportunities for the future. Interviews were primarily conducted online through Google Meet or Microsoft Teams, but site visits were made when the opportunity arose. With participant consent, interviews were audio-recorded using a recorder application. When participant consent was not provided, note-taking was the next best method for collecting the data. In total 19 interviews were conducted.

To help the analysis process, each interview was transcribed to provide the opportunity to pick up on any information that may have been missed during the live interview. In alignment with the PESTEL framework, each interview transcript was coded using the PESTEL factors in Excel. *Political factors* were identified when participants discussed the political climate in Denmark related to the building industry. When stakeholders mentioned investment opportunities, economic challenges, market or material prices, and the overall economic climate for building material waste it was coded as *Economic factors.* Discussions related to industry culture, awareness of circular practices, and perceptions of value, aesthetics, or quality were coded as *Social factors.* Mentions of developing circular technologies such as data collection on materials, reuse and manufacturing techniques, material passports, lifecycle analysis and building strategies were coded as *Technological factors. Environmental factors* were identified during discussions of climate change and resource depletion. Dialogue related to building regulations, policy development, laws around sustainable building practices, and existing legal frameworks were identified as *Legal factors.*

To conclude the analysis and achieve a more robust understanding of the causes of anxieties for stakeholders, the collected data from the survey, the short responses from the survey, and the coded interview data were cross compared. Triangulating the data helped identify the broad and overarching themes related to each PESTEL factor. Also, this process revealed how the survey and interviews reinforced the significant points and discrepancies between stakeholder groups. It was then the research question could be addressed, with a comprehensive picture of the external environment.

Limitations

While this study depicts a picture of the external landscape that influences stakeholder perceptions of uncertainty around circular practices for building material waste, certain limitations of the research should be acknowledged. First, the research was conducted in a non-native language which may have led to missed cultural nuances or contextual understandings that could have developed the research and influenced the findings. Most of the legislation and reports in the industry are written in Danish, which were translated but keywords and connections may have been missed. Secondly, although a sincere effort was placed on including a diverse range of perspectives, only a relatively small sample size is accounted for. 505 individuals were contacted to participate in the survey or an interview. With a response rate of 10.3 (Survey) and 3.8 (Interviews), the research does not fully represent all perspectives across the value chain. For instance, investors, legal experts, designers, and distributors are underrepresented. Uncertainties within these groups are left unaccounted for. It is noteworthy to mention that while stakeholders from every group were contacted, often individuals did not see the relevance of their work to the research.

The timeframe of the research severely limits the depth of possible investigations. The research was conducted from January to May which created pressure to streamline the research process as smoothly as possible to meet the deadline. A heavy focus placed on addressing data deemed significant to the research question limited the opportunity to delve down interesting avenues of research. In addition, this topic aims to address a monumental challenge within the building industry. Questions related to ethics, responsibility, uncertainty, value, and larger systems change require in-depth continuous conversations from various stakeholders over a considerable amount of time. This research is representative of the specific time and locational contexts it takes place in and by no means is suggesting a one-size-fits-all solution.

A quantitative survey was chosen to provide a simple and time-effective method for participants to potentially increase the response rate however, the questions being asked were related to their perspectives which are not often measured through numeric format. By having participants self-report their perceptions, the potential for response bias is introduced because quantifying perceptions may not fully account for their true lived experiences (Gronmo, 2019). The survey also aimed to address complex topics of uncertainty, risk, and the external environment which may have led to respondents struggling to distinguish deeper meanings jeopardizing the results due to a loss of intended nuances. The option to provide a short answer response was provided in the survey to combat this limitation but the issue remains that it is an impersonal way of collecting data. Interviews were incorporated into the research process to allow the opportunity to delve deeper into the influence of PESTEL factors on stakeholder perceptions, but the interviews were coded through interpretative categories which can lead to bias and misinterpretations of respondents.

The research takes place in Denmark because of its progressive stance towards implementing climate policy and the robust amount of investment and research given to exploring circular construction practices. Yet, material flows do not exist within borders but rather span over the planet in a complex range of networks. The outcomes of this research do not account for the complex material flows beyond Danish borders which are essential to supply chains. It is a representation of a snapshot in time, in a specific place that could be altered at any moment by shifts in policy, market dynamics, and culture.

Stakeholder Perceptions of Risk & Uncertainty

To grasp the uncertainties and risks the building sector in Denmark faces in the adoption of a circular economy, stepping back to view the entire landscape is key. An intricate web of political factors, economic pressures, social currents, technological innovations, environmental conditions, and evolving legal frameworks impact stakeholder perceptions across the value chain. To get to the root cause of uncertainty among stakeholders, delving deep into the complex relationship between external factors exposes the pressure points that need to be addressed to scale up circular practices in the building industry.

Each external PESTEL factor was investigated to determine the levels of influence on stakeholder perceptions regarding uncertainty across the value chain within the circular supply chain for building material waste. While each individual external factor has unique elements, they do not act independently from one another. Together they make up an external environment that impacts the adoption of CE in the building sector. It is within these complex interactions that risk and uncertainty can flourish. However, these should not just be considered barriers but also opportunities to transform the industry.

Political factors are perceived as impacting stakeholder perceptions highly since the political landscape in Denmark presents a mix of positive drivers and potential obstacles. The impact level rated by respondents in the survey exceeds the neutral point indicating that political factors create uncertainty and risk for stakeholders (Appendix B, Figure 1-2, 21-22, 33-34). Interviews with stakeholders point out the ambitious goals and shared perspectives across the value chain, but the lack of leadership and tension between sustainability goals and practical solutions create uncertainty around the potential of scaling up circular practices.

Economic factors such as cost of materials, economic feasibility, and investment opportunities are ranked across the value chain as the factor with the highest impact on stakeholder perceptions of risk and uncertainty. 49 percent of survey respondents selected economic factors as having the highest impact on their perceptions of risk and uncertainty. Among the stakeholders interviewed, economic conditions are a primary concern, specifically surrounding market volatility, investment capacity, material demand, and technology access (Appendix B, Figures 3-6, 23-24, 35-36). Variation regarding emphasis on economic factors exists among stakeholders, even so, overarching agreement that scaling up circular practices for economic viability is essential for its success.

Stakeholders are divided on the perceived impact of *Social factor*s on stakeholder perceptions of uncertainty. Politically affiliated individuals and educational outreach specialists ranked social factors as having a high impact whereas engineers ranked them considerably lower. Survey responses indicate that social factors are viewed as less likely to create uncertainty around the circular supply chain (Appendix B, Figures 7-10, 25-26, 37-38). Interviews with stakeholders indicate that the industry's time and money mindset, societal norms around value and quality along with throwaway culture clashes with the nature of circular practices which contribute to uncertainty but may not be necessarily the main drivers.

Technological factors are recognised by stakeholders as having the potential to drive circular practices while at the same time creating uncertainty. Demolition contractors, engineers, as well as politically affiliated individuals and public participants see a strong influence of technology impacting perceptions of uncertainty in the CSC. Most survey respondents perceive a moderate to significant risk stemming from technological factors with means exceeding the neutral point of 2.5 (Appendix B, Figures 11-12). The impact of technological factors on uncertainty for survey respondents is also ranked high with means exceeding the neutral point of 3 (Appendix B, Figures 39-40). Interviews with stakeholders revealed that key technological factors contributing to uncertainty and risk are gaps in material data, testing, and certification bottlenecks, the tension between standardisation and innovation, and a limited toolkit to fully account for the broader benefits of circularity.

Environmental factors are seen as sources of risk and uncertainty for the CSC but the level of impact varies across stakeholders. Participants working in circular tech and educational outreach express a particular concern about the impact of environmental factors whereas demolition contractors and the investor perceive the factors as having a lower impact (Appendix B, Figures 15-16, 29-30, 41-42). The strains between environmental aspirations and economic feasibility according to interviewed stakeholders, create a conflict between vested interests. Additionally, the lack of clarity surrounding the terminology of "circularity" creates uncertainty on whether circular practices can deliver the environmental benefits that some stakeholders are seeking.

Legal factors are in line with economic factors when impacting stakeholder perceptions of risk and uncertainty. 26 percent of survey respondents selected legal factors as having the highest impact on their perceptions. As evidenced by the consistent high means across questions, uncertainty around legal ambiguity poses a major risk for implementing circular practices (Appendix B, Figures 17-20, 31-32, 43-44). Additionally, the uncertainty surrounding potential regulatory changes impacts all stakeholders across the value chain. During interviews, liability concerns, ambiguous and outdated regulations, lack of standardisation, a lack of trust, and policy gaps were mentioned as key legal factors that contribute to perceptions of risk and uncertainty for stakeholders. Even with the encouraging political landscape in Denmark, undeniable challenges created by economic concerns, legal ambiguity, and the lack of technological advancements which must be addressed to ease stakeholder anxieties and enable widespread adoption.

Voices from The Value Chain

Established practices and proven methods are the foundation of the building industry. Time is money in this industry, so projects are structured to prioritise speed and cost-effectiveness to deliver on budget and on time. "If you look at the construction industry, it's a super conservative industry, right? And at the end of the day, there's one thing that is most important, how much does it cost?" (Manufacturer 1). Circular practices are a disruption to the industry mindset, it takes time, money, and trial and error to develop new methods which inherently go against the existing business model. When discussing how the industry operates an architect mentioned "There's a very, methodical process which has been used for many, many years, and that hasn't really been changed for a while" (Architect 1). Conservatism in the industry creates caution around any new underdeveloped methods which restrict innovation. The industry values around cost, technical feasibility, and long-term performance need to be challenged to break down resistance against circular practices.

Not only do the industry norms of efficiency and cost create uncertainty for stakeholders, but also a sincere lack of trust. One construction project comprises a multiplicity of stakeholders that can have competing interests. Industry relationships are created for contractual reasons with the aim of profit in mind. Adopting an ethical code founded on honesty and transparency can put a stakeholder in a vulnerable position since the industry fosters a conflicting mindset. For instance, an individual working at a company prioritising trust along their supply chain mentioned how vulnerable they feel because of the lack of legal frameworks to support them in an industry that fosters distrust (Material Reuse Specialist 1). Another company concentrating on transparency pointed out that being an open book has consequences because it has been used against them in the past (Manufacturer 1). The lack of trust in the industry creates uncertainties for stakeholders as it can be difficult to indicate who is being genuine or who is using trust to their own personal advantage.

With a lack of trust between stakeholders across the value chain, it is difficult to strengthen relationships and create a stronger network to bridge knowledge gaps. Throughout multiple interviews, the need for stronger collaboration between stakeholders, especially in a project's early design phase, was highlighted. During an interview one stakeholder mentioned,

> I think it's key that there would be an early collaboration between the architects and engineers and a better collaboration because if not, then there is a risk of the architects having really great ideas and maybe not understanding fully the material properties, how they can be used or how they cannot be used, especially when they are reused (Structural Engineer 2).

Without strong collaboration, the value chain will remain fragmented, complicating stakeholders' ability to address uncertainties and risks early on. Knowing the risks and uncertainties faced by fellow stakeholders allows the value chain to navigate the complexity of perspectives and stakes involved in a building project.

When navigating a new paradigm like circular construction, stakeholder perception of risk and uncertainty naturally increases. New is used in the sense that we are aiming to fundamentally change the way we design, construct, and deconstruct the built environment. Mistakes will happen because some of these ideas have never been done before. “Everything we do. We do for the first time. Which obviously you know comes with a lot of risk but also a lot of challenges.” (Manufacturer 1). As with any emerging concept, various ambiguities can lead to varied interpretations. When discussing the notion of circularity, a contractor who builds using circular strategies mentioned “Everyone's kind of doing their own thing, which is great. But, you know, it could lead to just not doing exactly what we intend, like, specifically circularity as when everyone has a different understanding of it.” (Contractor 1). Without a clear consensus on the parameters of circular practices in the industry, there is a risk the entire concept may collapse.

The findings from the survey and the interviews revealed that external Environmental factors do not seem to be a key driver in creating uncertainty for stakeholders. With a strong understanding of the impacts of climate change, it appears that environmental factors such as resource scarcity are closely linked to other factors indicating the need for systems-level thinking in the transition. What is more significant is the uncertainty of the future, which is motivating stakeholders to consider the environmental impacts of their actions and decisions as highlighted during an interview,

> A tendency that I've noted is that stakeholders don't act on Environmental Factors in terms of themselves but in terms of future generations, i.e., their children or grandchildren (intergenerational factor). Leaving the planet a little less bad than now is a big motivator (Educational Outreach Specialist 13, Survey).

Stakeholder perceptions are being shaped by the urgent reality of the consequences associated with exceeding multiple planetary boundaries, which highlights the overall risks of continuing to operate under business as usual.

In Denmark, ideas around waste and sustainability are noticeably progressing. “I believe that the industry, at least in Denmark, there's a lot of people who really want it.” (Structural Engineer 2). A social push is happening where not only those in the industry want to see better practices but also those who work, rent, and live in the built environment. When asked about how social norms are changing in the industry an architect commented “people are becoming smarter and smarter and more conscious on buildings and, the environmental impacts that it's having.” (Architect 1). New standards are being established where “stakeholders and tenants want to then associate themselves with a building that is a representation of who they are” (Architect 1). This directly influences building practices because “developers that are actually building sustainably because they will sell better apartments or their buildings because of that.” (Architect 2). By setting higher social sustainability standards for the building industry, the demand for incorporating circular practices is impacting the supply chain.

The political leaders in Denmark are setting ambitious climate targets. From the National Circular Economy Strategy, funding and investment strategies, and the legally binding goal of climate neutrality by 2030, a broad political consensus within Denmark is clear. Prioritising sustainability initiatives are essential for accelerating the transition. A member of Copenhagen’s municipality mentioned “This is why we have a political system. To set up those, ambitions” (Municipality 1). Without the push and support from those in government, there is a slimmer chance of scaling circular practices beyond a hot topic. “For the moment, the politics in general are more encouraging” stated an architect when referring to the potential for circular practices in Denmark (Architect 2). Having government leaders who represent and advocate for sustainable practices in the building sector helps to alleviate the uncertainty that comes along with spearheading an entirely new way of doing business.

Although significant emphasis is being placed on conversations regarding the sustainable transition in Denmark, the topic of building material waste is lacking in the political discourse. One manufacturer commented,

> Politicians are talking about reuse and environment. However, they do not describe to use reused material in new public buildings. They do not support

> the work to make upcycling profitable. The public community does not even pay us to receive the waste, which otherwise will be burned, and burden the CO2 account (Manufacturer 23, Survey).

This highlights a gap between political ambitions and real-world implementation. With building material waste constituting almost 30 percent of total waste produced globally the relevance of incorporating discussions around the topic is further highlighted (Kumawat et al., 2022). Even so, relying solely on the political landscape to propel discussions, may not be the sole driving factor as one individual mentioned,

> In the Municipality of Copenhagen, we can only advocate to use more circular solutions, if it has value for the money or a sense of scaling potential for later use (Sustainability Consultant 111, Survey).

Factors in the external environment do not act independently of one another but rather have push and pull effects toward one another. This means that relying on the political landscape in Denmark to solely drive a circular transition will most likely create more uncertainty and could even slow down progress. This point is emphasised by an individual who purchases building material waste,

> To be honest, I believe if we allow the political landscape to dictate our actions in addressing the circular economy and waste management issues, little progress will be made (Consumer 2, Survey).

Economically, the cost of doing business as usual is still outcompeting circular business models. Stakeholders across the value chain agree that at the end of the day, it comes down to price. “It is still very difficult to find customers that will pay a little extra to get a greener product. Sometimes the uncertainty and risk is higher and if the cost is also higher - it is very difficult to sell." (Manufacturer 33, Survey) Without an incentive to incorporate circular practices, there is a risk of creating a niche circular market that is catered to select businesses and individuals who choose the circular way of business out of preference rather than necessity. A member of Copenhagen municipality gives a good example of how the cost of upcycled bricks creates economic uncertainty around adoption:

> The problem in Denmark is actually that since we produce the bricks ourselves, now you have a competition between, somebody who needs to, pay extra, spend extra time on taking the building down, separating them, clean them, put them in storage for some duration, and then afterwards, have to sell them probably still with that uncertainty tag on it, that normally would require the price to be a bit lower (Municipality 1).

In a capitalist system where "money drives change" emphasising what specific economic factors create uncertainty and risk for stakeholders is essential (Manufacturer 33, Survey). Traditionally in the industry value is placed on short-term profits in contrast to the premise of a circular economy which is aimed at "Proving investment, in the planet, essentially" (Circular Tech Developer 3). Scaling circular practices to be economically viable where the risk of upfront costs, and uncertainty in market transformations are addressed remains a central element for the interviewed stakeholders. As an architect mentioned,

> Unfortunately, at the end of the day, the budget will be the main driving and limiting force for construction materials and waste, so tax benefits, subsidies, and investment opportunities would reduce the potential limitation regarding cost. (Architect 12)

Not only does the cost of using circular building materials create a lot of uncertainty for stakeholders, but also the legal ambiguity surrounding utilisation. Insurance and liability are key elements of uncertainty for stakeholders. Strict building regulations exist to ensure proven and safe methods of construction. Building standards are based on rigorous material testing and data collection done through the industry's historical development. Putting new materials through the certification and testing process is a costly venture limiting the innovation of new methods for building material waste. For instance, a contractor at a circular construction company elaborated on the regulatory hoops they must jump through to get materials approved,

> If we were to change up anything in the product right now, it would cost us half 1000000 DK, just to get the minimum required tests, if they are successful, and if they're unsuccessful, you can just repeat it, it's half a 1000000 DK every time

> you want to retest something that you just changed up just one single component. (Contractor 1, personal communication, 13 March 2024)

Large legal gaps need to be filled to help transition the industry's linear business model to a circular one. During the stakeholder contact phase, a sincere effort was placed into reaching legal experts in Denmark who specialised in construction law; however, many of the individuals that were contacted did not see the relevance of the topic to their line of work. This limitation reinforces the high impact legal ambiguity has on stakeholder's perceptions of risk and uncertainty (Appendix B, Figures 17-20, 31-32, 43-44) As expressed by one survey respondent: "As these new sustainability regulations are still rather new, it is hard to find the metrics we are all supposed to follow to prove compliance." (Architect 12, Survey). A standardised legal framework that provides clarity on the possibility and potential of building material waste has yet to be developed. This missing element generates uncertainty and risk for stakeholders which cascades throughout the other external factors.

Developing a standardised legal framework requires collecting a significant amount of material data. Circular tech platforms such as Zupply and Milva in Denmark help contractors and demolition companies map out material resources, yet large-scale reliable data on the potential and capabilities of building material waste in a circular context needs to be collected. An individual working on an EU project specifically for creating roadmaps in circular construction in Denmark highlighted what is missing, "It needs to be, levels of the network, big elements of data that kind of is universal, standardised, that can be shared with everyone." (Researcher 2). Without reliable data, stakeholders face uncertainty when weighing the benefits. Innovative waste technologies and the development of platforms that simplify techniques of managing material waste impact stakeholder's perceptions of adopting circular practices for building material waste (Appendix B, Figures 11-14).

The absence of a network that connects stakeholders not only to each other but to other projects creates uncertainty around the potential for building material waste. This element is highlighted by Heisel & Hebel who mention that the construction industry has no foundation to represent the "stocks, flows, specifications and values of its materials over time, nor has it prepared this data for future use" (2022, p. 38). Digital tools such as life cycle analysis (LCA) and material passports aid in collecting data on materials. Despite this, stakeholders need evolving information on properties, load-bearing capacity, and previous use to confidently integrate circular practices at a scalable continuous level. When looking closer at the root of this anxiety it comes down to addressing the tension between innovation and standardisation (Structural Engineer 1). This is closely entwined with education as one stakeholder mentions “you can't really track the entire service life, and we're kind of lacking that technology to do that. Or maybe it's not, technology that is needed but maybe just better, frameworks, and education.” (Contractor 1). To innovate technologies that support circular practices, the industry needs to develop standardised solutions “Because technology is going to help support a lot of it, but it needs to be as super simple as possible” to reduce uncertainty (Architect 1).

At the end of the survey, stakeholders were asked to select the external factor that has the highest impact on their perceptions of risk and uncertainty. Economic factors were ranked the highest at 49 percent, legal factors ranked second at 26 percent followed by 11 percent who ranked economic factors. Deeply rooted anxieties related to economic factors are a serious concern for stakeholders. The cost of upcycled materials, profit margins, and financial feasibility weigh heavily on the minds of stakeholders when considering implementing circular practices. While legal frameworks are developing, the ambiguity surrounding utilisation creates uncertainty for stakeholders as it is difficult to embrace circular practices without certainty about the parameters to operate within. Although ranked last, the political landscape in Denmark creates uncertainty for stakeholders due to the ever-evolving nature of discussions around sustainable development. As circular practices continue to develop for the building industry in Denmark, a focus on creating economic incentives, robust legal frameworks, and targeted political support is needed to ease stakeholder uncertainties to reduce the risk of transitioning to a circular economy.

Going Beyond Business as Usual

Denmark's building sector stands at a pivotal point. It is undeniable that a clear effort to transform the linear business model into a circular one is being made. Evolving roadmaps, targeted incentives, and an increased focus on reducing building material waste are building the foundation for a circular transformation. Yet, perceptions of uncertainty and risk weigh heavily on stakeholders' minds creating barriers for the transition, leaving space for the linear business model to continue to dominate in the industry.

The research demonstrates that stakeholders across the value chain in the circular supply chain for building material waste face interconnected risks and uncertainties stemming from external factors. *Political factors* in the Danish political landscape create a mix of positive drivers and potential obstacles for stakeholders, specifically due to tensions between setting ambitious goals and not having a robust legal economic or legal framework. The tension creates uncertainty around the possibility of scaling up circular practices. The cost of materials, economic feasibility, and investment potential are all *Economic factors* with the highest influence on stakeholder perceptions of uncertainty. Without a solid economic foundation to incentivise the industry to transition, the linear model will continue to outcompete a circular one. A divide among stakeholders indicates *Social factors* such as the industry mindset surrounding time and money, and the norms around value and quality contribute to uncertainty. Significant gaps in material data, testing, and certification requirements, and aligning innovation with standardisation are *Technological factors* that create uncertainty for stakeholders. Without accessible tools to facilitate the transition, it is challenging to encourage circular practices.

While the ever-increasing need to address *Ecological factors* is present in stakeholders' minds, alone they do not create much uncertainty. What is more significant is the tension between setting climate targets without proper economic incentives and legal frameworks in place. Setting climate targets is necessary but without proper direction, those goals may not reflect the reality of the circumstances we are working in. Similarly, a lack of clarity around the circular economy creates uncertainty regarding whether efforts have a truly positive environmental effect or if they are being greenwashed. Additionally, the lack of clarity around what is considered circular in the industry creates uncertainty related to whether the goals have positive environmental impacts.

Lastly, *Legal factors*, undoubtedly influence stakeholder perceptions of uncertainty. The legal parameters surrounding circular building materials remain underdeveloped which restricts the potential for a larger-scale transition. Between the certification and testing process to the lack of circular legal frameworks, there are numerous legal hoops that stakeholders must jump through to adopt circular practices. Between all external factors, uncertainty plays a critical role in influencing stakeholder perceptions. When uncertainties are left unaddressed risks arise creating barriers to implementation. This dynamic creates a risk-averse mindset, resulting in hesitancy towards the potential of circular strategies, despite the clear benefits.

This research demonstrates that stakeholders across the value chain in the circular supply chain for building material waste face interconnected risks and uncertainties stemming from external factors. Nearly half of survey respondents cited economic factors as having the most significant impact on their perception. Without any economic incentive, it becomes infeasible for most stakeholders to incorporate circular practices. From the cost of materials to competing in a market that is built to waste, circular practices need to be economically advantageous. The aim of a circular economy is not to create a niche market, but rather replace the existing linear economy as it is. The lack of clear, standardised legal frameworks creates a significant obstacle to the transition because of the uncertainties it creates for stakeholders. While Denmark's National Circular Economy Strategy, and continuous development of policy and regulation incentivises circular building practices, a significant number of stakeholders still feel insecure about the transition. To ease the legal uncertainties, we need to continue collecting data that proves the potential of building waste materials along with pushing innovation for building standards that are designed with only new materials in mind.

Further research related to this topic could focus on exploring economic viability by identifying the benefits of the long-term value associated with circular practices compared to the conventional model of doing business as well as exploring how policy levers can incentivise circular practices. More emphasis could be placed on the systems-level change by conducting studies that highlight successful transitions and models to ease the anxieties that come with an entirely new way of doing business. Most importantly, this research suggests that building trust is a key dimension for transitioning to circular supply chains for building material waste. Developed frameworks of trust are severely lacking in the industry as expressed by many participants in this research. In hindsight, placing greater emphasis in my research on the role of trust in mitigating uncertainty could have yielded more valuable insights for a successful transition to a circular economy.

Shifting away from the linear business model to a truly circular one requires a complete system change. To align with Denmark's ambitious climate goals, a radical change is needed: bigger than business as usual through a greener lens. The change must acknowledge the uncertainties that stakeholders face when adopting a new way of conducting business. Scaling up circularity in Denmark hinges on these key elements 1) addressing root causes of anxieties for stakeholders across the value chain; 2) embracing collaboration and establishing trust; and 3) the adoption of a systems change perspective.

Setting up incentives that offset upfront costs and redefining value for stakeholders to focus on the long-term perspective of profitability will ease economic anxieties. Although efforts on multiple fronts are developing a robust circular legal framework for the building industry, a concerted effort needs to be placed on reducing ambiguity, addressing liability, and building trust.

Stakeholders across the value chain play a role in driving the transition. We need leaders in the industry to take the risk and embrace innovative circular business models regardless of the uncertainties that come along with it. Be transparent with one another, it's okay to make mistakes, be honest about them because we are all in the same place trying to navigate in a world of uncertainty. It will take redefining value creation and reimagining supply chains to push circularity in the direction it needs to go. This is not a task to take lightly as it will require a significant amount of work from everyone across the value chain.

None of these external factors act independently from one another. A systems-level perspective acknowledges the interconnectedness of external factors to create a holistic approach that addresses the political, economic, social, technological, environmental, and legal landscape as an integrated system. Without it, solutions will be isolated which is counterproductive to closing the loop and reconnecting through a circular system.

Denmark is in a unique place; a significant amount of effort is being placed on transitioning to a circular economy which puts the nation in a position to lead the rest of the world and show that sustainability goals are not an idealistic dream, but possible. A circular transition demands bold action, targeted interventions, and the acceptance that uncertainties have an impact but can also provide opportunity. Stakeholders across the value chain in the circular supply chain for building material waste can pave the way for a more resilient built environment, not only for Denmark but as a model for global transformation.

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Appendix A – Survey

$FirstName$ $LastName$

Thank you for taking the time to participate in the Survey!

What is the project about?

I am a Master's student in the Department of Human Ecology at Lund University, currently writing my thesis, which aims to investigate resilient circular supply chains with building material waste in Denmark.

Participation in the project

You have been selected to participate in this survey because I believe your insights as a stakeholderare crucial to understanding the challenges and opportunities related to circularity in building material supply chains. Your response will help develop a deeper understanding of how external factors such as political, environmental, social, technological, economic, and legal (PESTEL) influence perceptions of risk and uncertainty in circular supply chains. Your response will contribute to a comprehensive analysis that aims to identify impacts, patterns, and potential solutions that will help increase the adoption of circular practices.

Participation is voluntary and you can choose to not answer a question if you do not wish to.

The gathered data will be anonymous and it will not be possible to identify who has given each answer.

What do you need to do?

Filling out this 15 single-answer questionnaire will take approximately 5-15 minutes. You are kindly asked to reply to the questions from your perspective based on your professional knowledge and expertise.

For your help, at the beginning of each section there are brief explanations, please read them before answering the questions. I encourage you to use the optional text boxes to provide any further insights or comments if you are interested.

Context

To provide context to this research:

Circular supply chains are understood as a system that prioritizes the reuse, recycle and repurposing of resources and products to minimize waste and maximize resource efficiency throughout the entire lifecycle, from design to end-of-life.

Building waste materials used in circular supply chains are considered secondary resources or recovered materials that can easily be reintegrated into building or design projects. The materials in this context must be consistently available and uniform in size, for example, bricks, timber, metals, and glass.

I deeply appreciate you taking the time to participate in the survey to help me with my thesis project.

Please contact me if you have any questions about the survey or the research project.

Emily Hill

em7287hi-s@student.lu.se

Department of Human Ecology

2

$FirstName$ $LastName$

Indicate which of the following best represents your professional experience and knowledge

- ☐ Consumer of Building Materials: Your projects or designs use building materials
- ☐ Manufacturer of Building Materials: You produce the raw components and fabricated elements essential for constructing buildings and other structures.
- ☐ Distributer of Building Material : You facilitate the collection, transportation and processing of building waste materials
- ☐ Politically Affiliated: You are involved in developing or have knowledge of legislation or regulation related to environmental policy
- ☐ Educational Outreach Specialist: You promote awareness and education on implementing circular economy practices
- ☐ Engineer: You design, analyze, and oversee the construction of safe and functional structures.
- ☐ Architect: You design the form, space, and functionality of buildings.
- ☐ Legal Expert: You navigate legal issues related to construction projects, contracts, regulations, and disputes.
- ☐ Investor: You provides financial resources for the development or acquisition of buildings and related projects.
- ☐ Sustainability Consultant: You help projects source and utilize materials responsibly, minimizing environmental impact and promoting resource efficiency.
- ☐ Researcher: You are part of an academic institution with knowledge related to the relevant field
- ☐ Public Participant: You have in interest in the research topic

If N/A please describe here...

Section 1 External Factors

Instructions: Indicate your level of agreement or importance for each statement by selecting the appropriate response on a scale of 1 to 5   0 = Not Applicable   1 = Strongly Disagree / Not Important 2 = Disagree / Slightly Important   3 = Neutral / Moderately Important   4 = Agree / Important   5 = Strongly Agree / Very Important   Please answer the following questions based on your professional experiences and knowledge in the field

Political Factors The political landscape (i.e. elections, political parties, and campaigns) influences your perception of the use of building material waste in the context of circular economy practices

- ☐ 0 = Not Applicable
- ☐ 1 = Strongly Disagree / Not Important
- ☐ 2 = Disagree / Slightly Important
- ☐ 3 = Neutral / Moderately Important
- ☐ 4 = Agree / Important
- ☐ 5 = Strongly Agree / Very Important

Optional: Can you share any specific examples related to your experience that informed your choice ?

Economic Factors Economic Incentives (i.e. tax benefits, subsidies, investment opportunities) influence your perception of the use of building material waste in the context of circular economy practices

- ☐ 0 = Not Applicable
- ☐ 1 = Strongly Disagree / Not Important
- ☐ 2 = Disagree / Slightly Important
- ☐ 3 = Neutral / Moderately Important
- ☐ 4 = Agree / Important
- ☐ 5 = Strongly Agree / Very Important

Optional: Can you share any specific examples related to your experience that informed your choice?

$FirstName$ $LastName$

Which external factor do you believe to be the largest barrier with regard to the future development of circular economy practices related to the use of building material waste in

- [ ] Political Factors
- [ ] Economic Factors
- [ ] Social Factors
- [ ] Technological Factors
- [ ] Environmental Factors
- [ ] Legal Factors

Optional: Would you like to share any further insights on your response?

Do you have any additional thoughts or suggestions related to the adoption of circular economy practices in Denmark, particularly regarding the use of building material waste?

Thank you for your valuable feedback, I appreciate you taking the time to complete this survey :)

Appendix B

Q1. Political Factors: The political landscape (i.e. elections, political parties, and campaigns) influences your perception of the use of building material waste in the context of circular economy practices

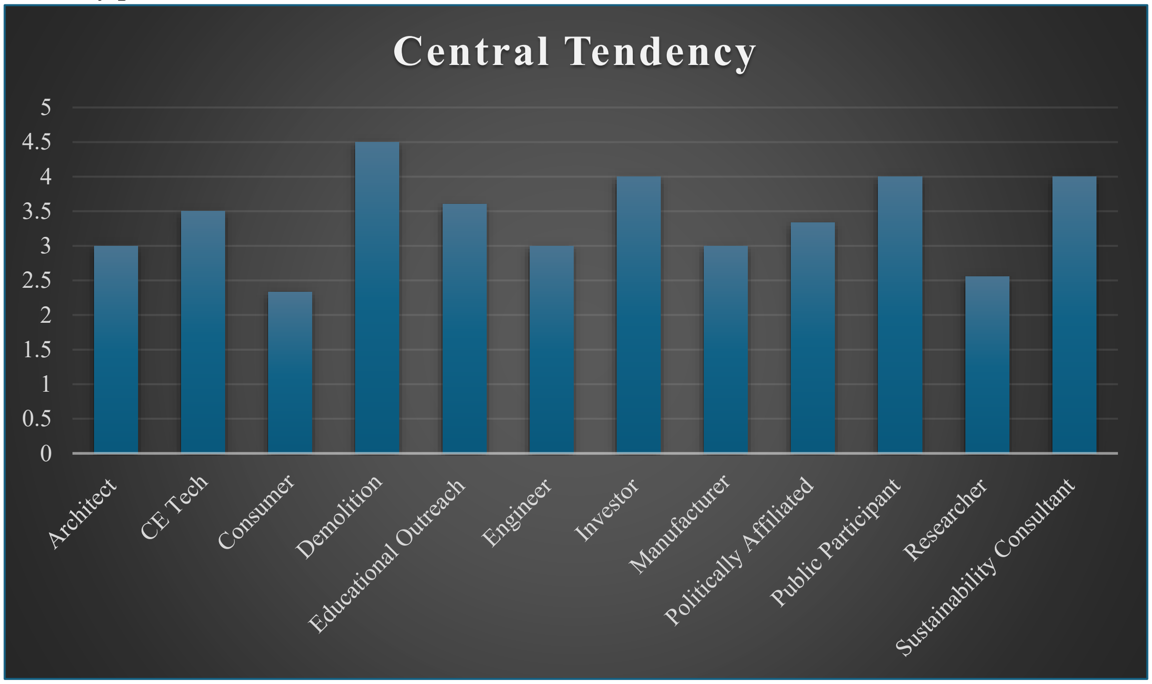

Figure 7. Central Tendency among stakeholder groups in Q1.

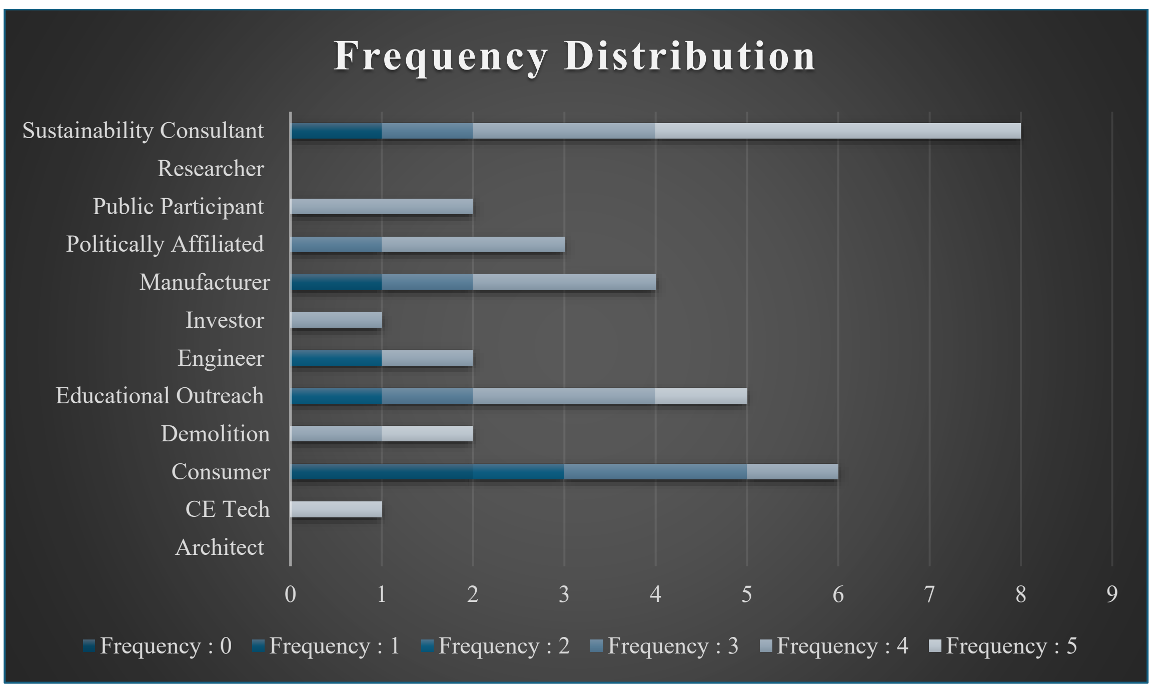

Figure 8. Frequency distribution among stakeholder groups in Q1.

Q2. Economic Factors: Economic Incentives (i.e. tax benefits, subsidies, investment opportunities) influence your perception of the use of building material waste in the context of circular economy practices

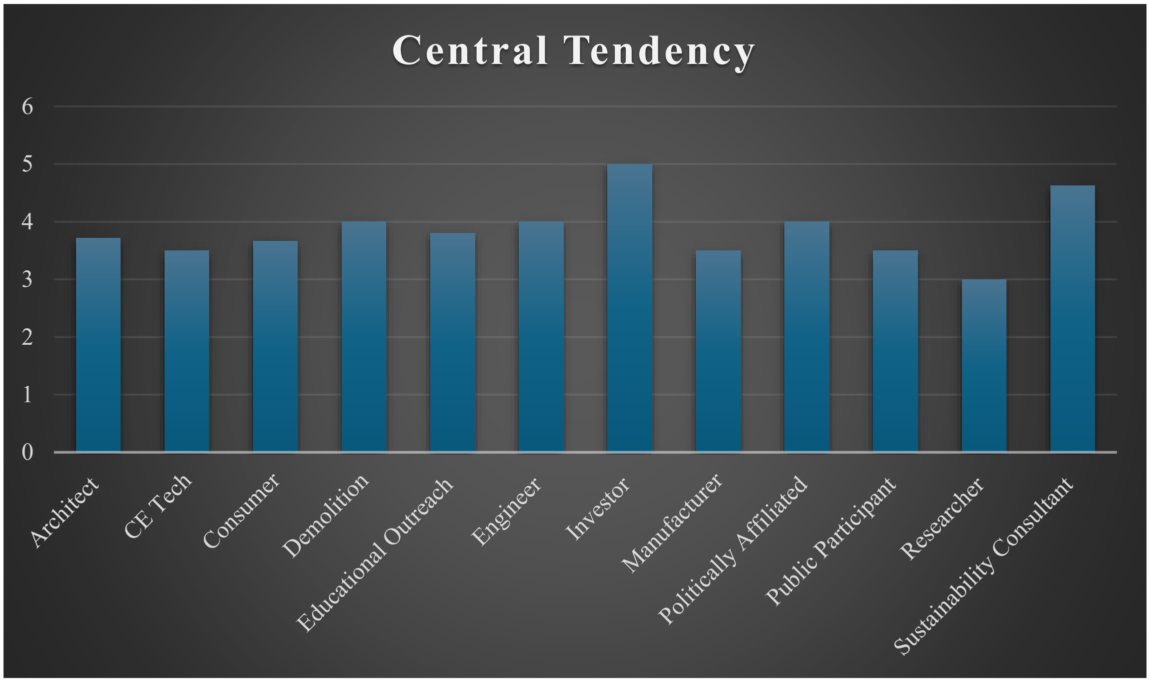

Figure 9. Central Tendency among stakeholder groups in Q2.

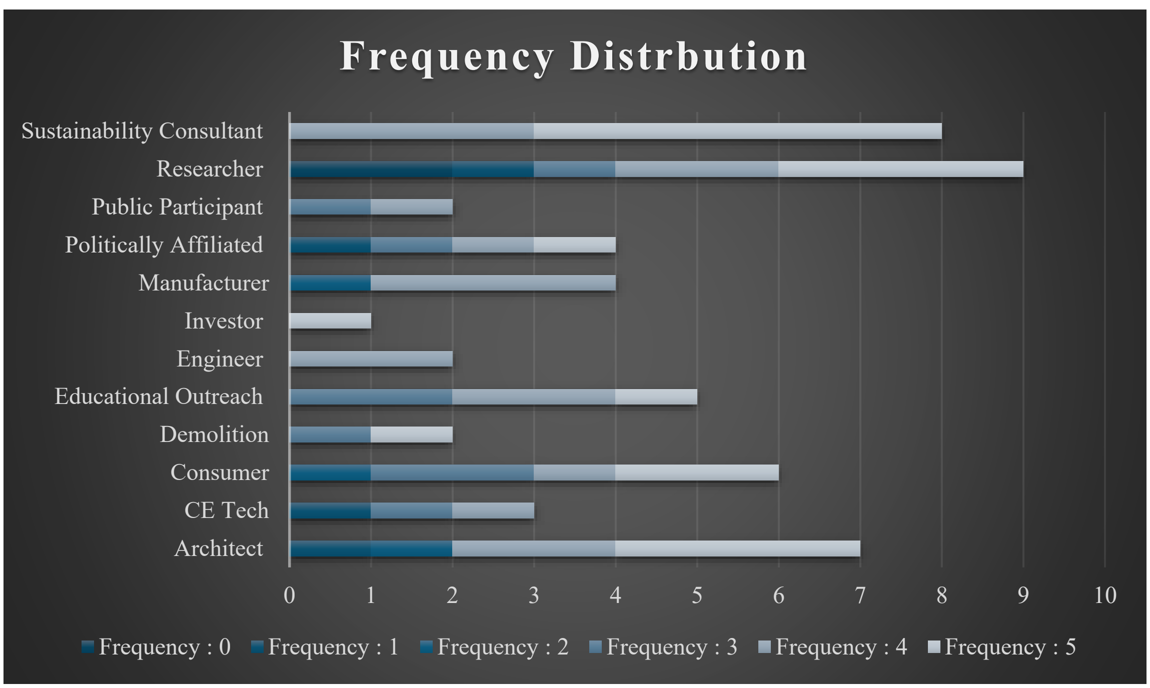

Figure 10. Frequency distribution among stakeholder groups in Q2.

Q3. Economic Factors: The cost of using building material waste influences the adoption of circular economy in construction and design projects

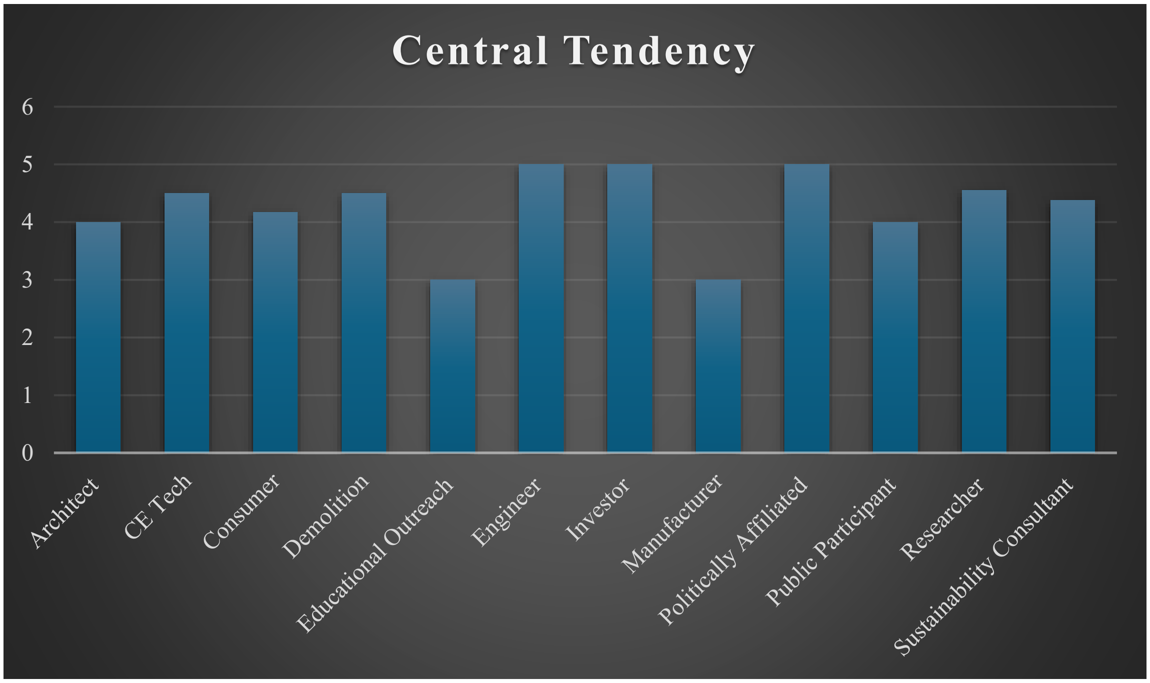

Figure 11. Central Tendency among stakeholder groups in Q3.

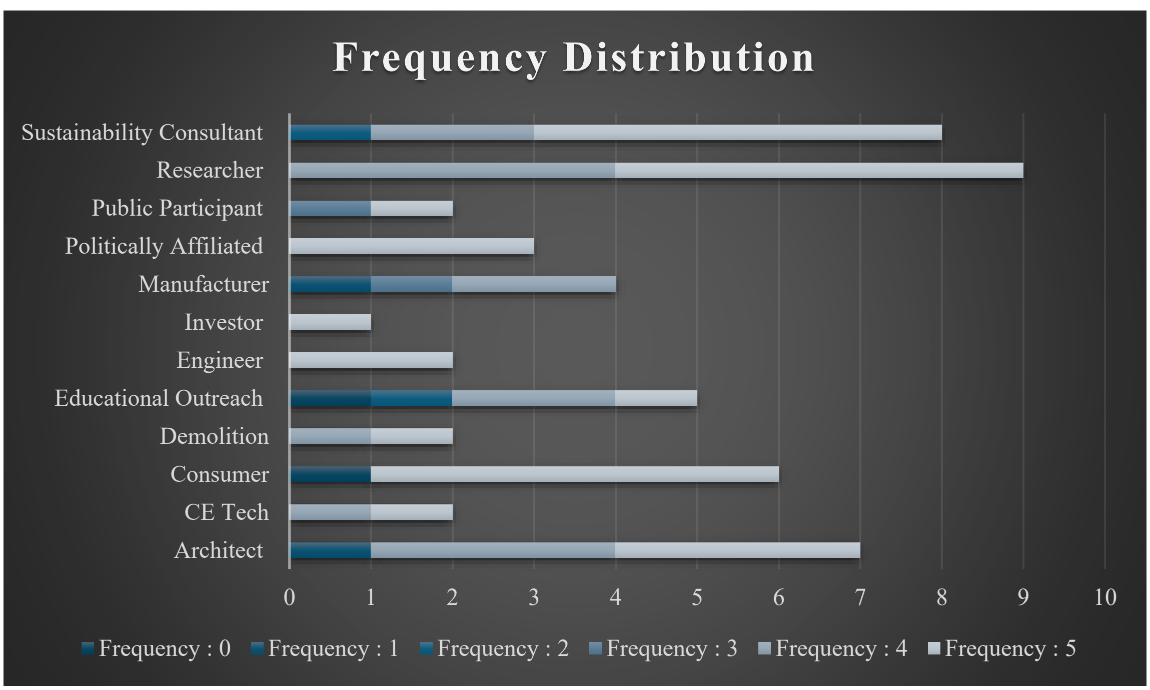

Figure 12. Frequency distribution among stakeholder groups in Q3.

Q4. Social Factors: (i.e. Public awareness around waste, consumer preferences, aesthetics and quality perception) influence your perception of the use of building material waste in the context of circular economy practices

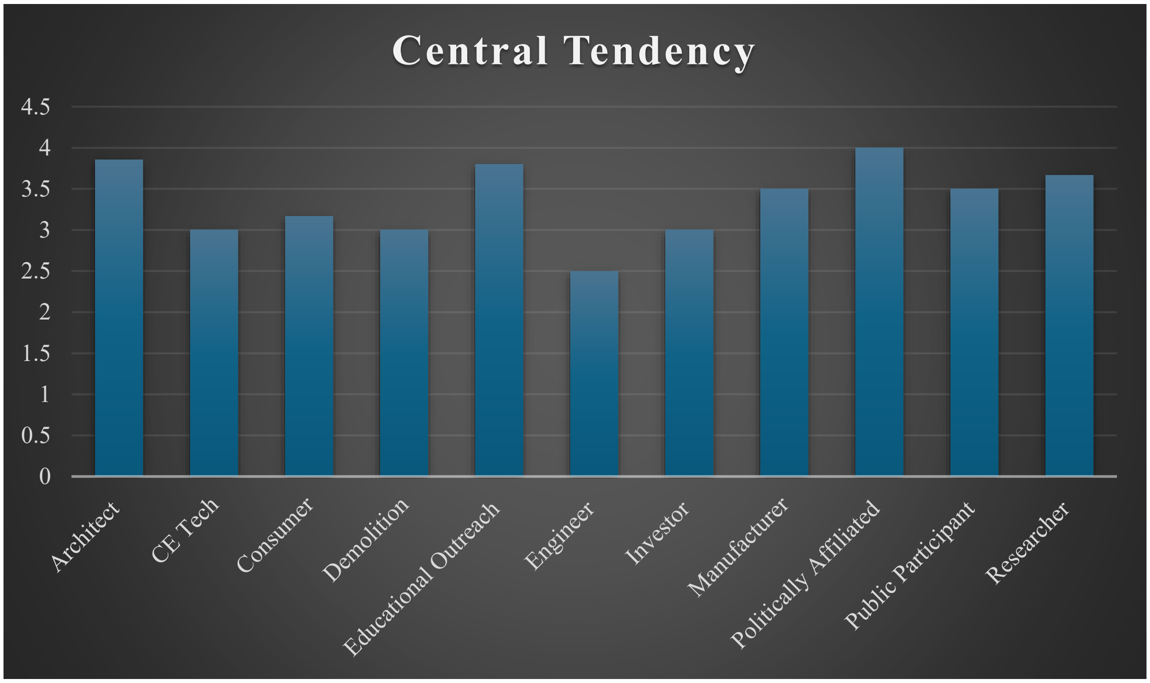

Figure 13.Central Tendency among stakeholder groups in Q4.

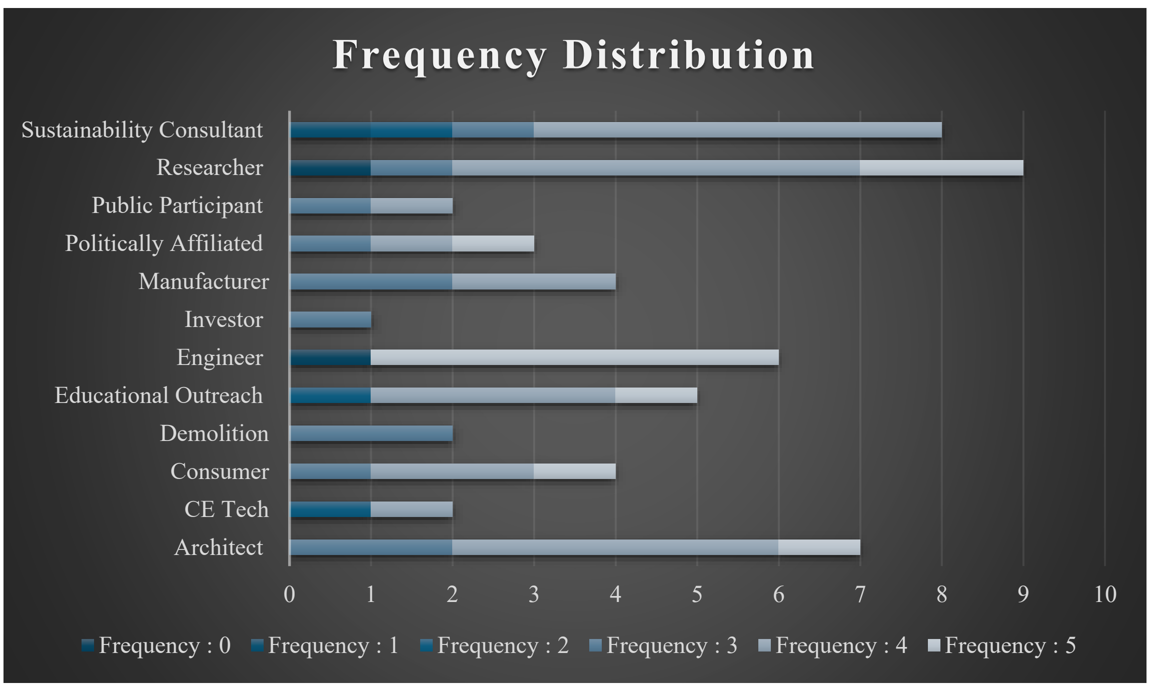

Figure 14. Frequency distribution among stakeholder groups in Q4.

Q5. Social Factors: The level of awareness and education around circular economy influences the use of building material waste in circular economy practices

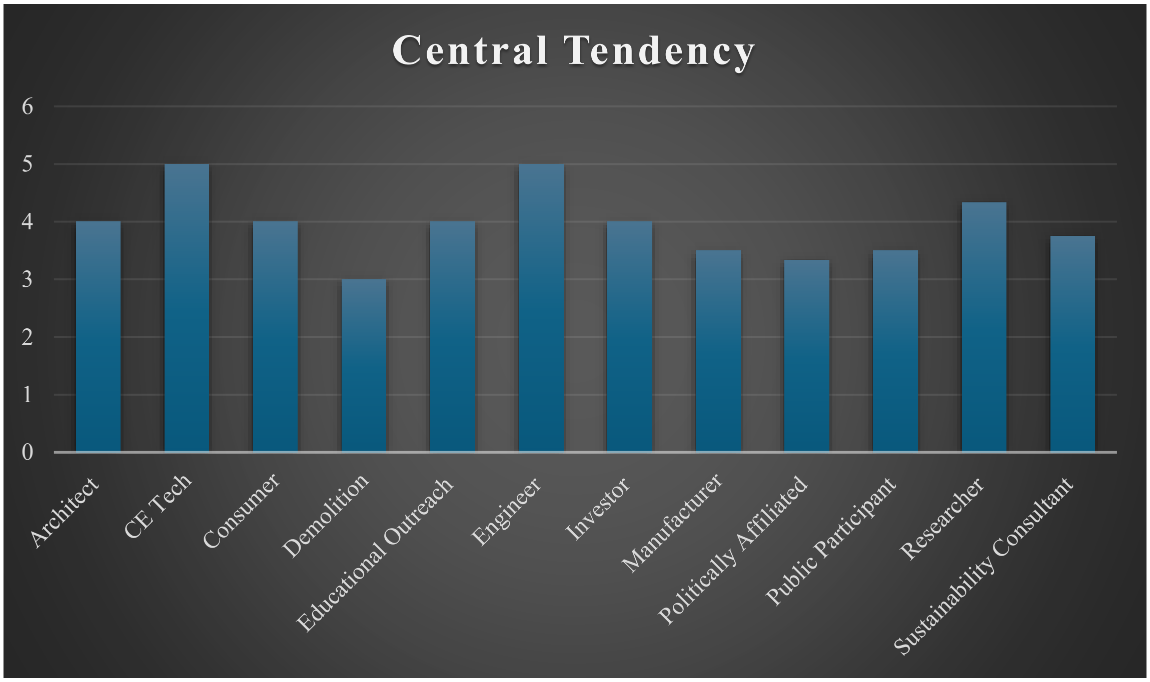

Figure 15. Central Tendency among stakeholder groups in Q5.

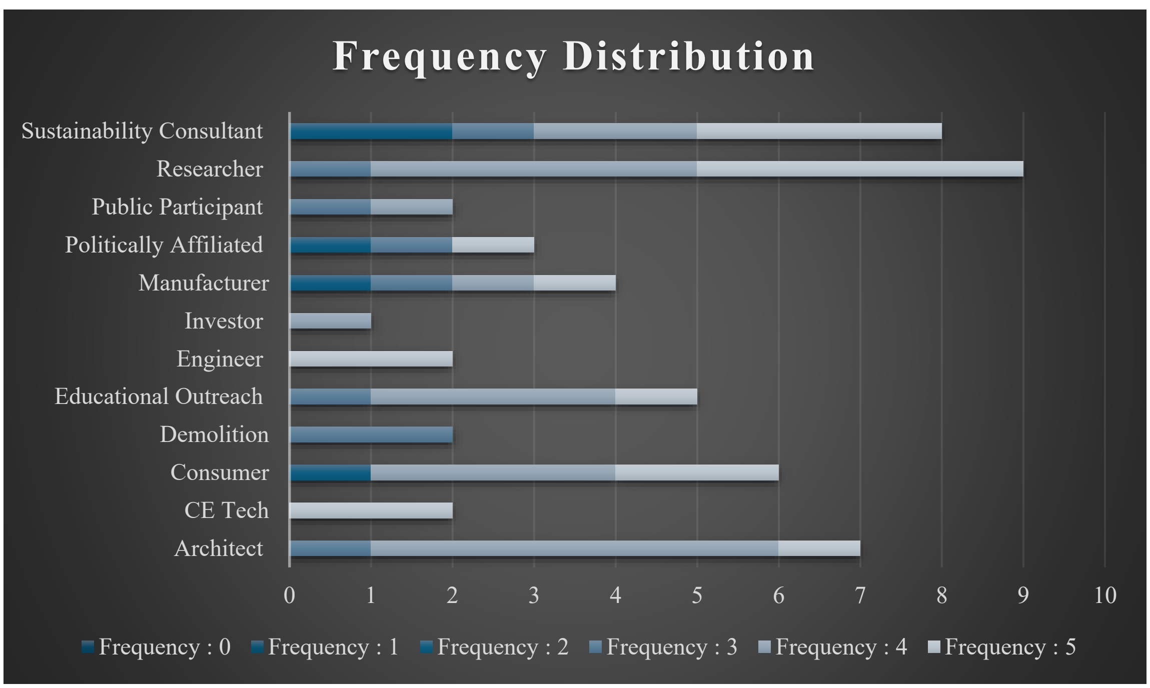

Figure 16. Frequency distribution among stakeholder groups in Q5.

Q6. Technological Factors: Advancements in waste technology (i.e. recycling, reuse and recovery methods, innovative reuse techniques, and waste sorting systems) influence your perception of the use of building material waste in the context of circular economy practices

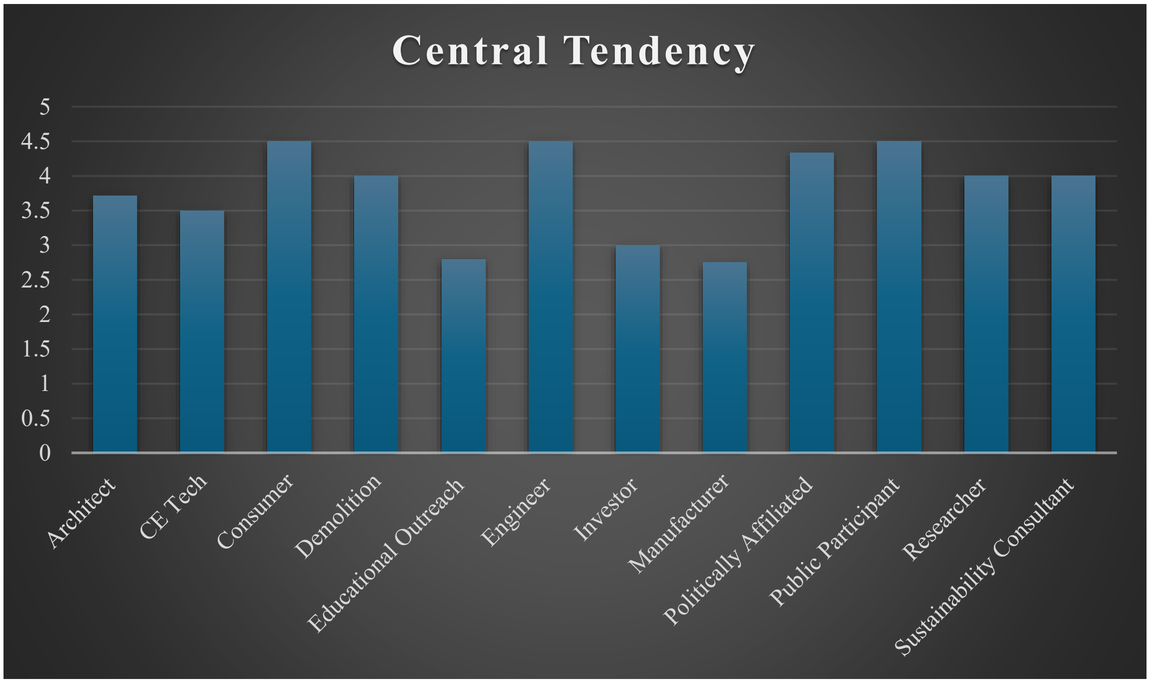

Figure 17. Central Tendency among stakeholder groups in Q6.

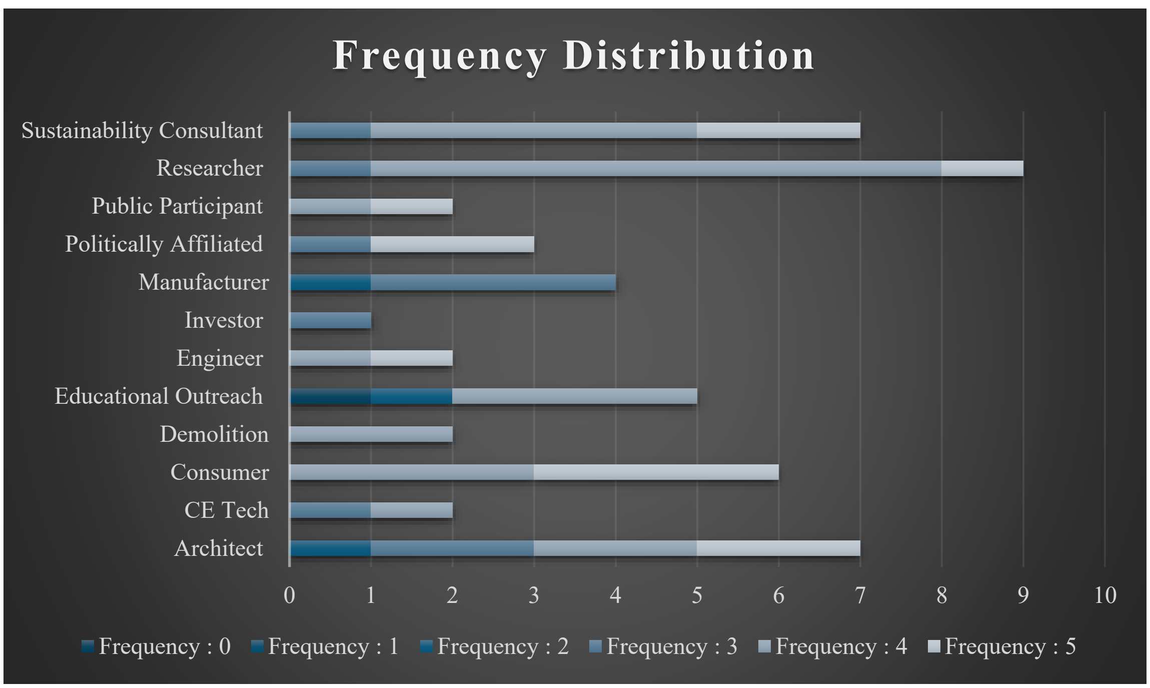

Figure 18. Frequency distribution among stakeholder groups in Q6.

Q7. Technological Factors: The availability of innovative technologies (i.e. Automated sorting and deconstruction, advanced recycling techniques, digital platforms) for processing and manufacturing waste materials influences the use of building material waste in the context of circular economy practices

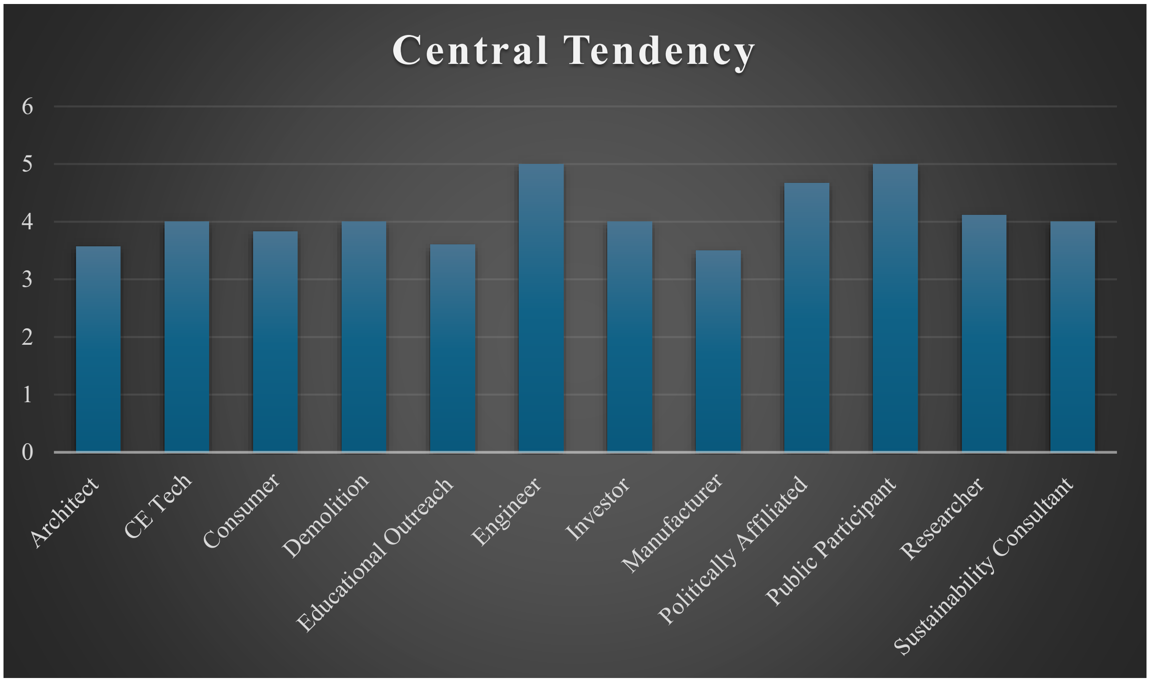

Figure 19. Central Tendency among stakeholder groups in Q7.

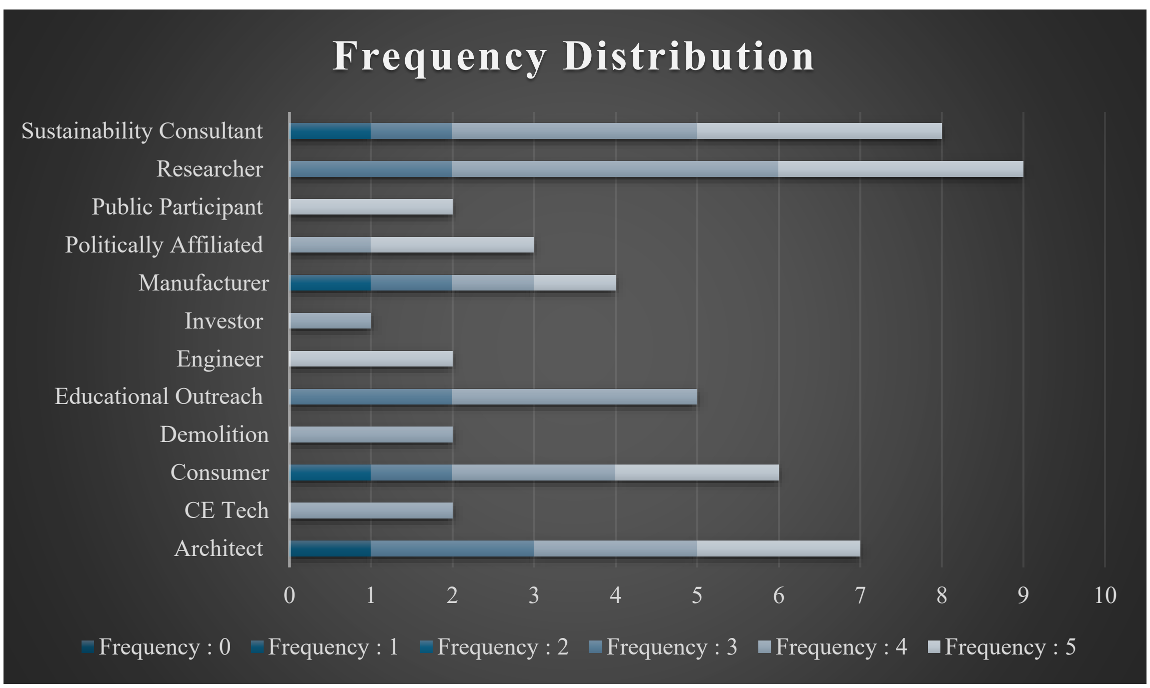

Figure 20. Frequency distribution among stakeholder groups in Q7.

Q8. Environmental Factors: The growing concerns related to climate change (i.e. resource depletion, pollution) influence your perception of the use of building material waste in the context of circular economy practices

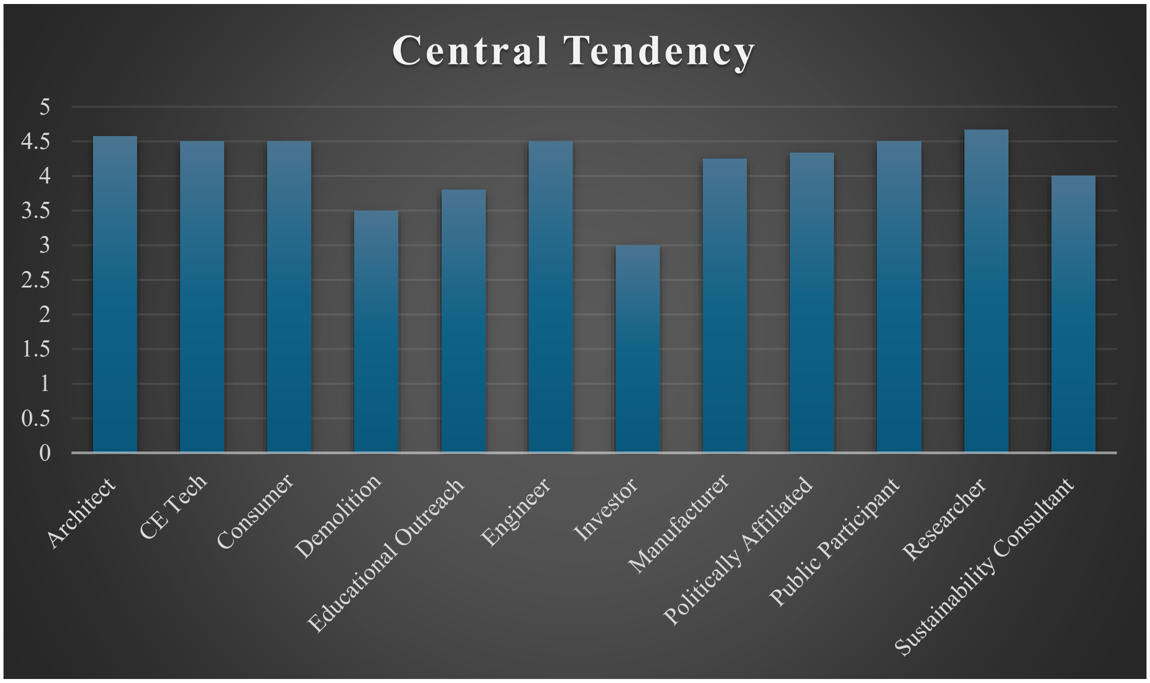

Figure 21. Central Tendency among stakeholder groups in Q8.

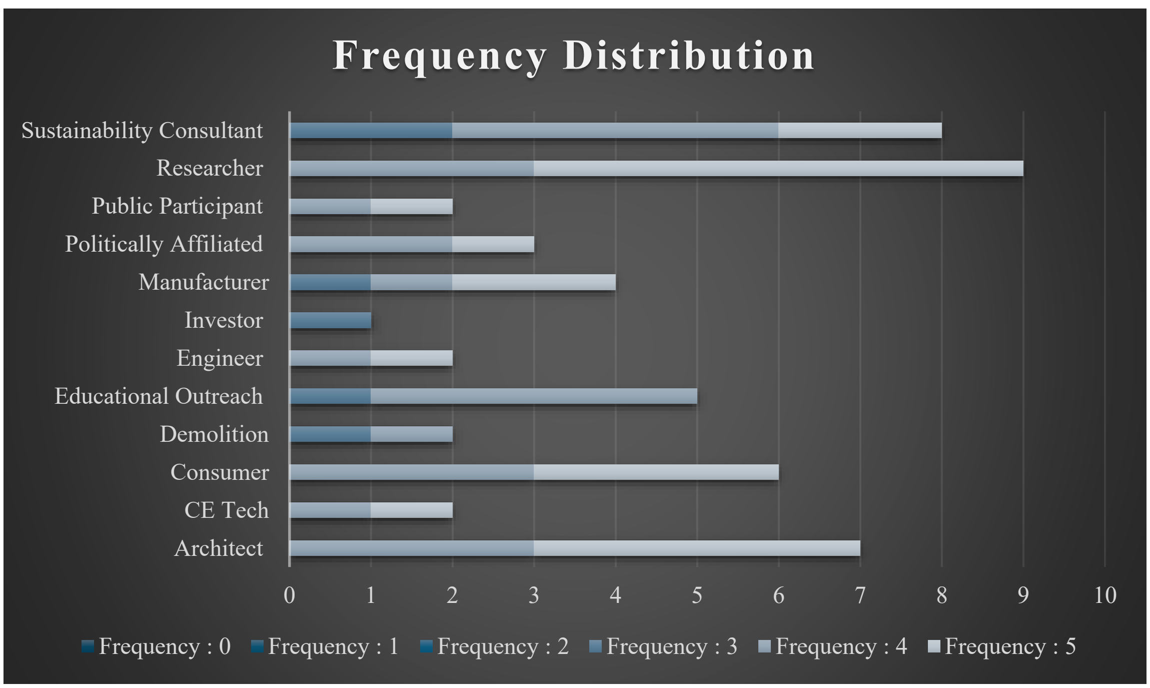

Figure 22. Frequency distribution among stakeholder groups in Q8.

Q9. Legal Factors: Laws and legal frameworks (i.e. building regulations, environmental regulations, safety and quality regulations) influence your perception of the use of building material waste in the context of circular economy practices

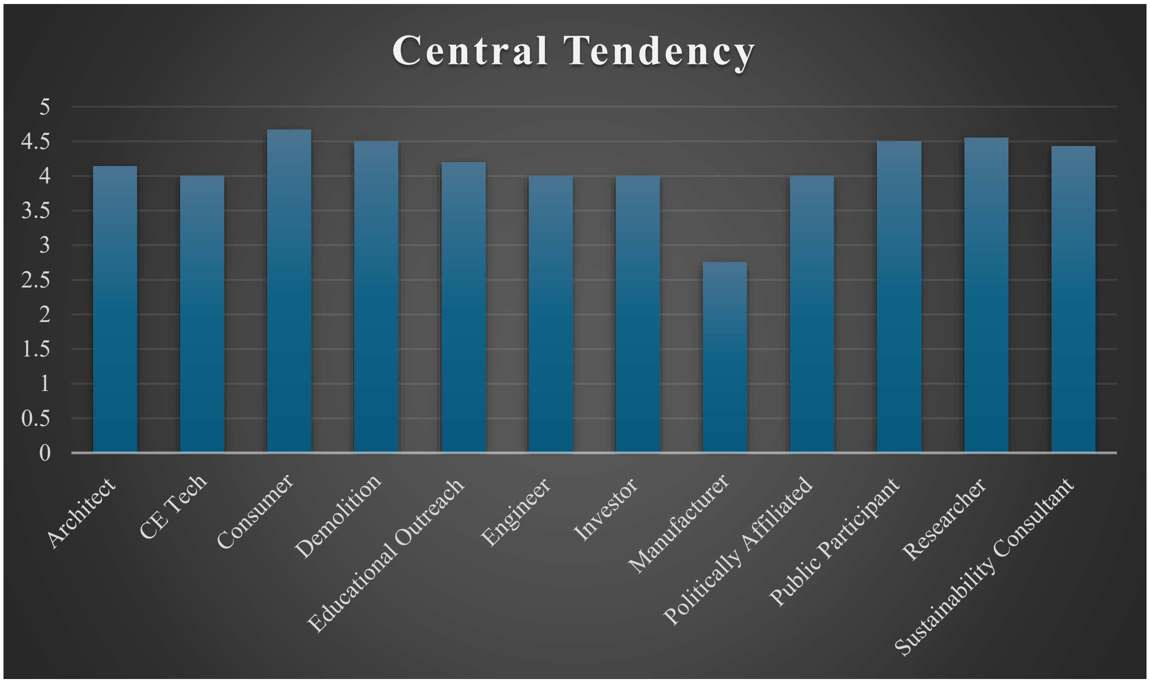

Figure 23. Central Tendency among stakeholder groups in Q9.

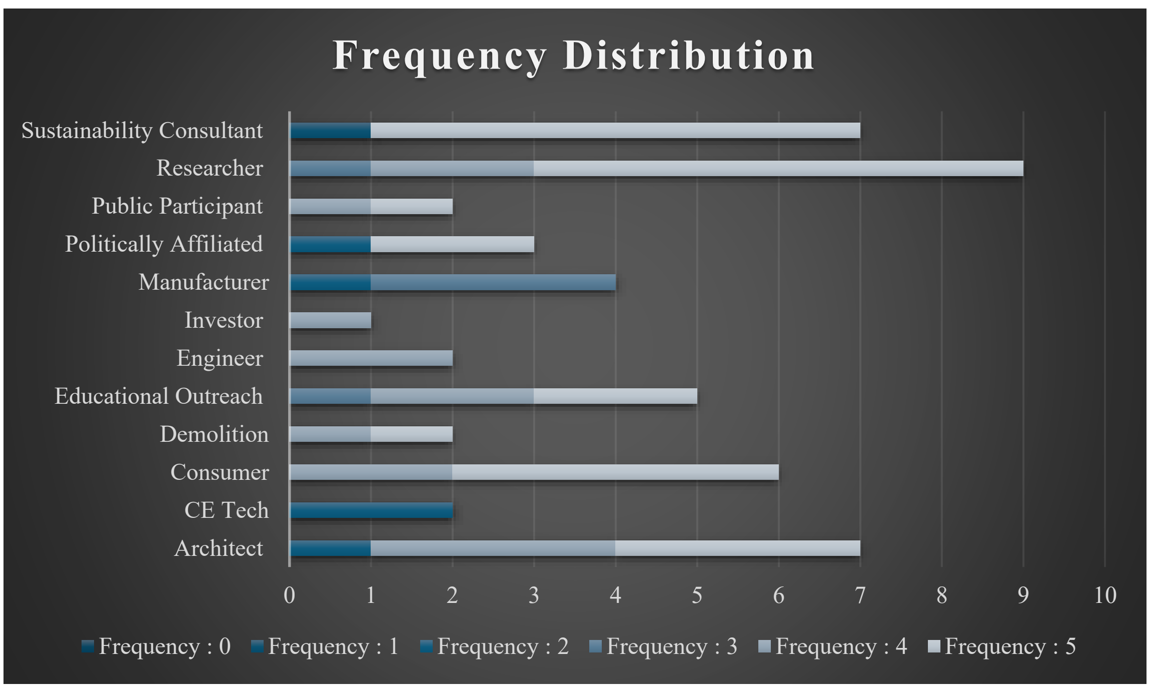

Figure 24. Frequency distribution among stakeholder groups in Q9.

Q10. Legal Factors: Ambiguity or inconsistency in regulatory requirements influence the use of building material waste in the context of circular economy practices

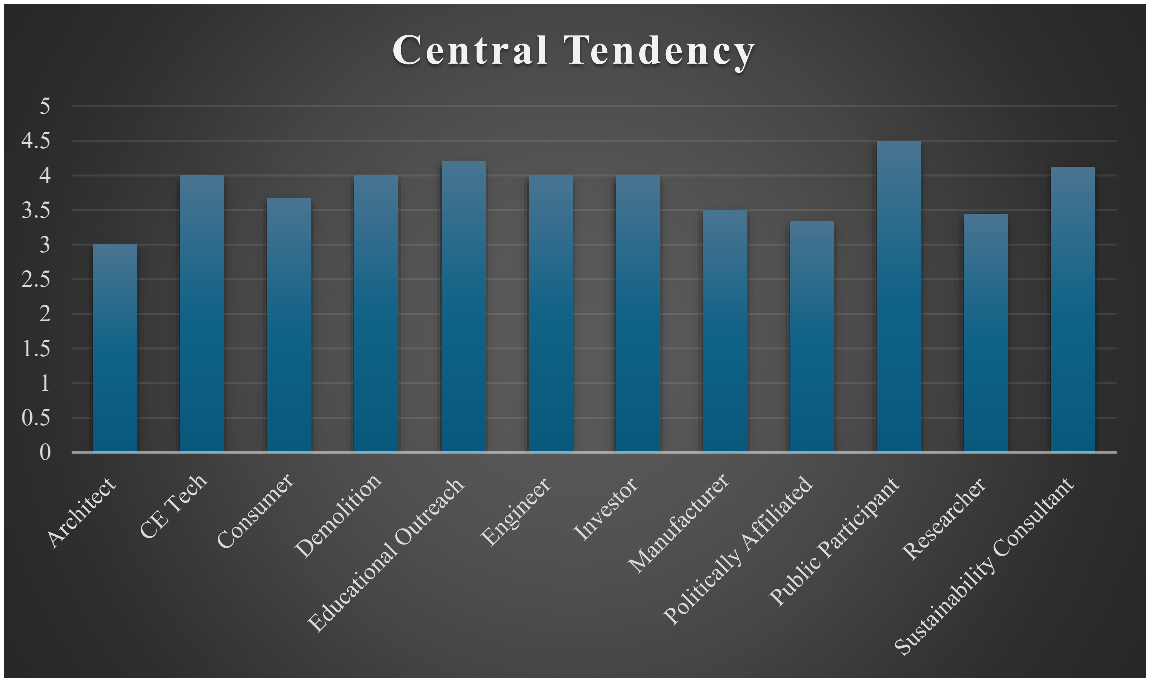

Figure 25. Central Tendency among stakeholder groups in Q10.

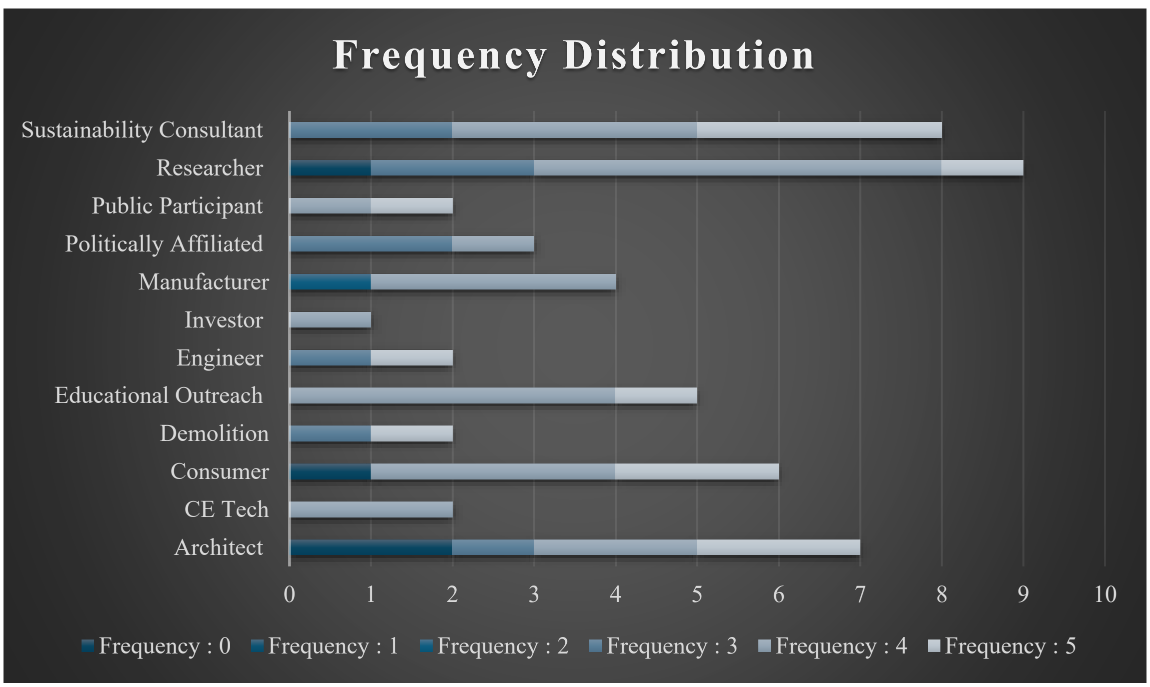

Figure 26. Frequency distribution among stakeholder groups in Q10.

Q11. Political Factors: Consider the likelihood of external political factors posing a risk to the use of building material waste in circular economy practices. Rate each factor on a scale of 0 (No Impact) to 5 (High Impact)

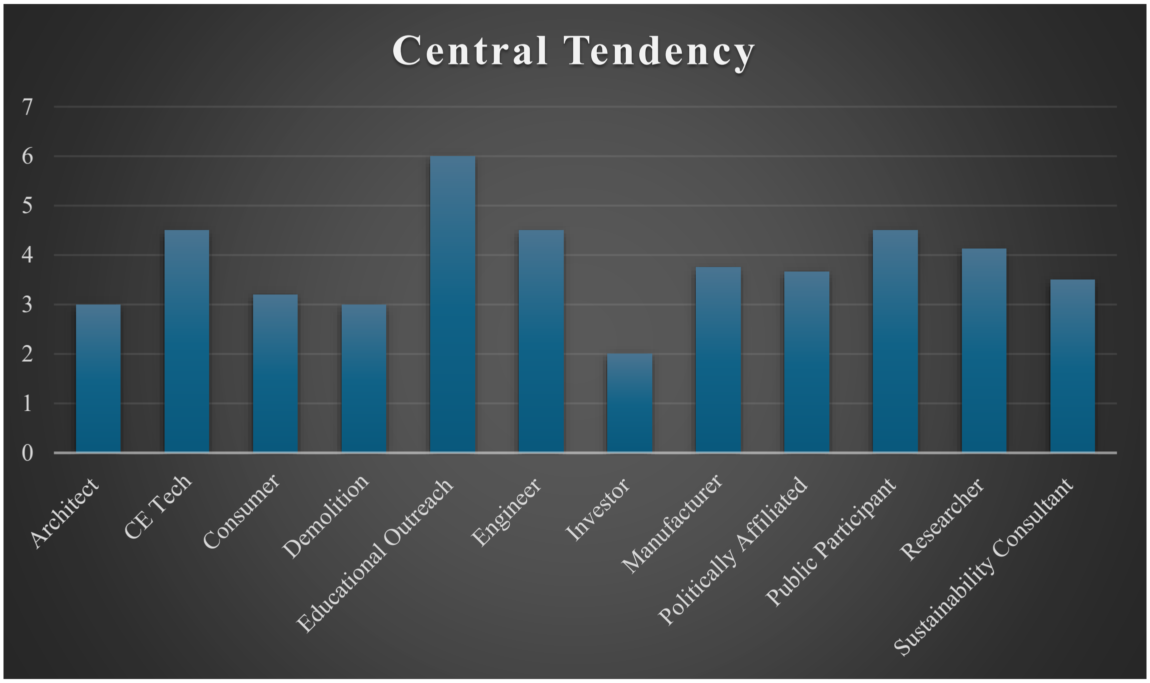

Figure 27. Central Tendency for political factors among stakeholder groups in Q11.

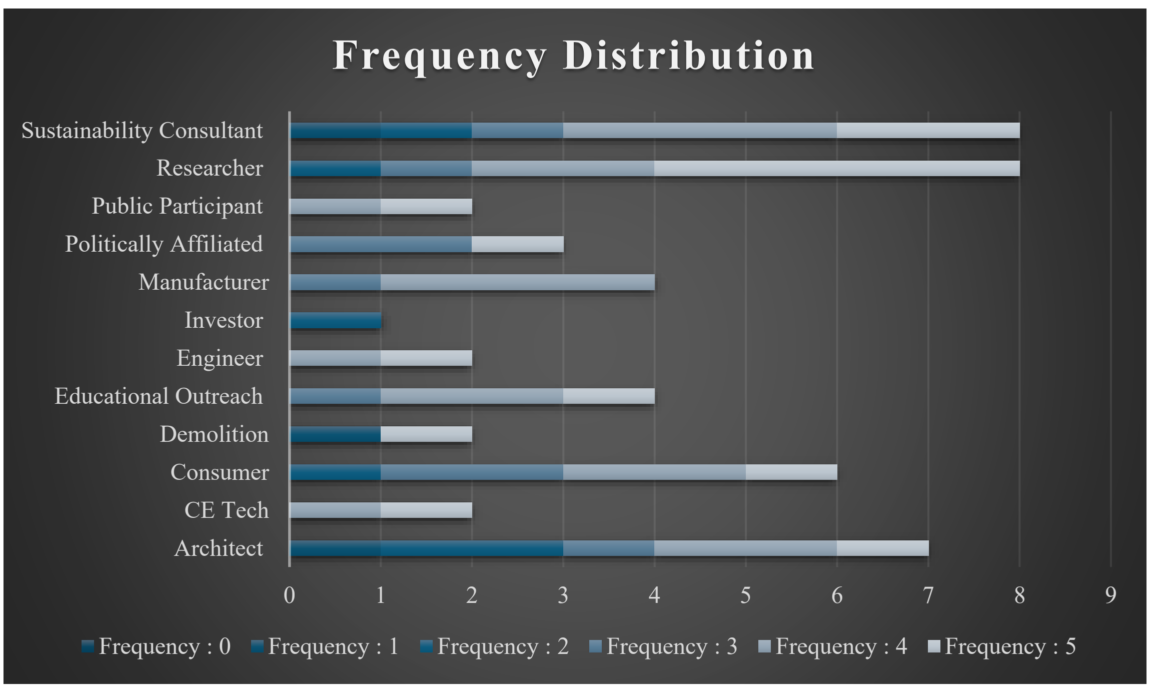

Figure 28. Frequency distribution for political factors among stakeholder groups in Q11.

Q11: Economic- consider the likelihood of external economic factors posing a risk to the use of building material waste in circular economy practices. Rate each factor on a scale of 0 (No Impact) to 5 (High Impact)

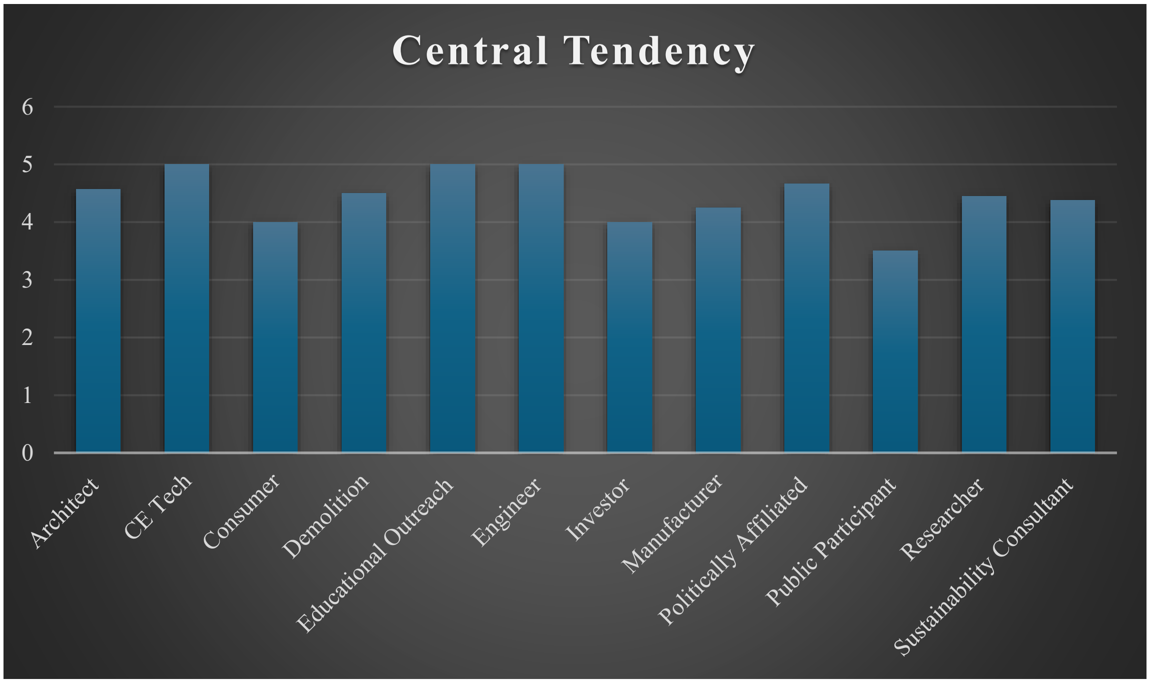

Figure 29. Central Tendency for Economic factors among stakeholder groups in Q11.

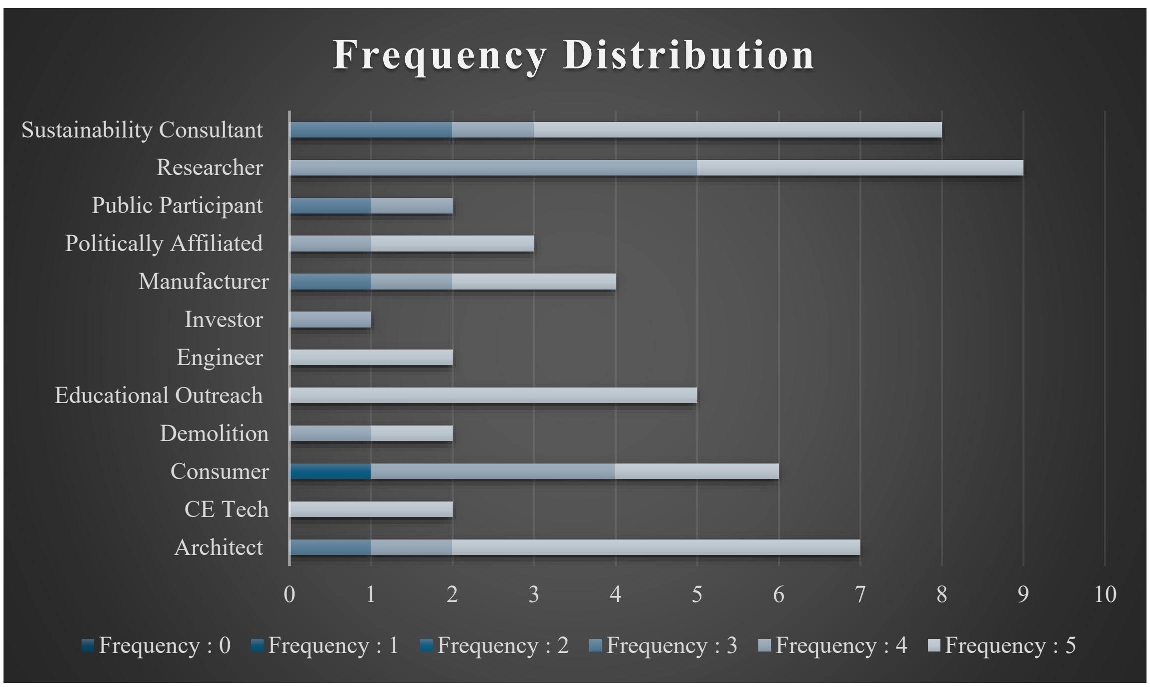

Figure 30. Frequency distribution for Economic factors among stakeholder groups in Q11.

Q11. Social Factors: consider the likelihood of external social factors posing a risk to the use of building material waste in circular economy practices. Rate each factor on a scale of 0 (No Impact) to 5 (High Impact)

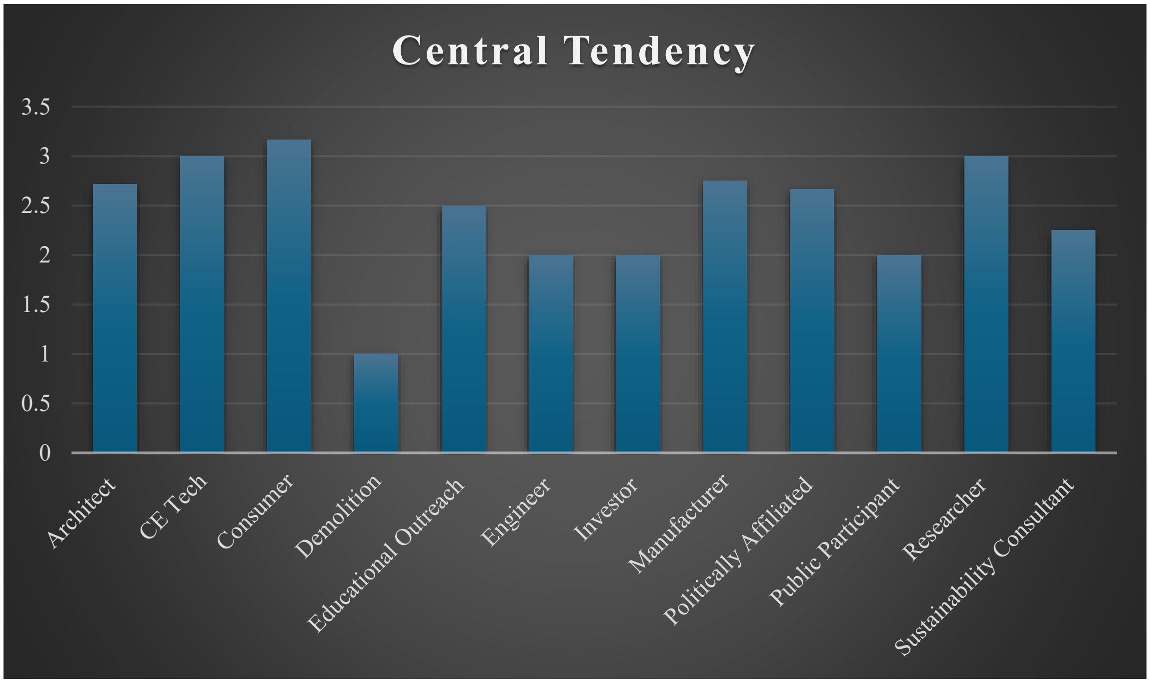

Figure 31. Central Tendency for Social factors among stakeholder groups in Q11.

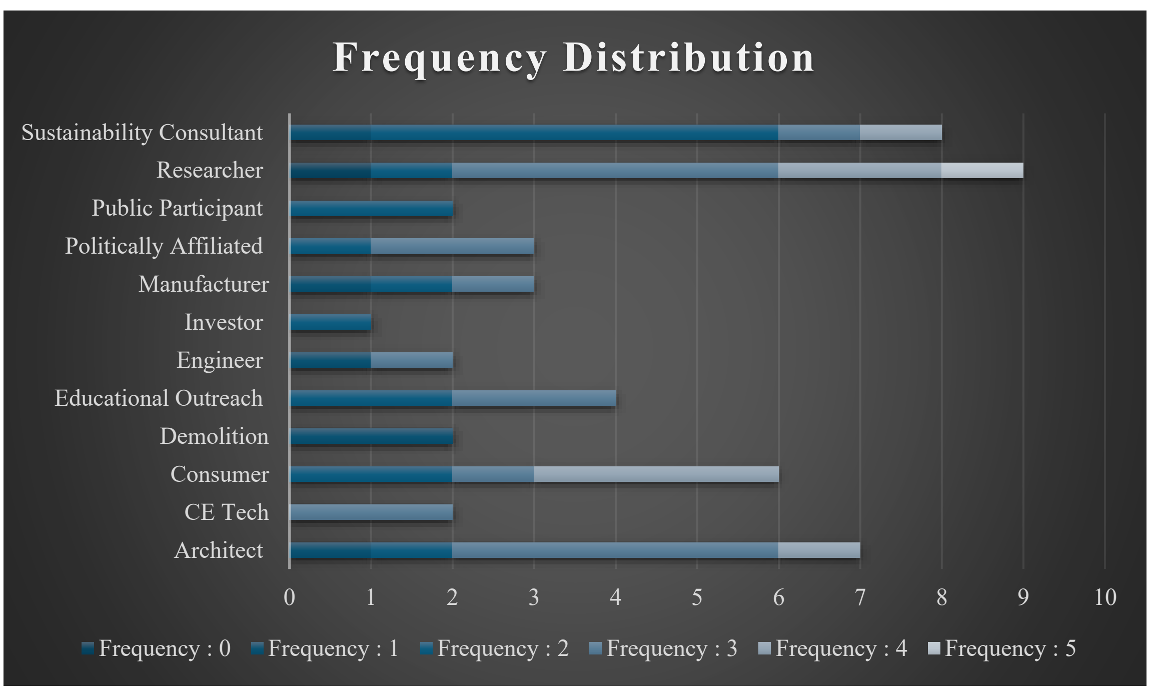

Figure 32. Frequency distribution for Social factors among stakeholder groups in Q11.

Q11. Technological Factors: consider the likelihood of external technological factors posing a risk to the use of building material waste in circular economy practices. Rate each factor on a scale of 0 (No Impact) to 5 (High Impact)

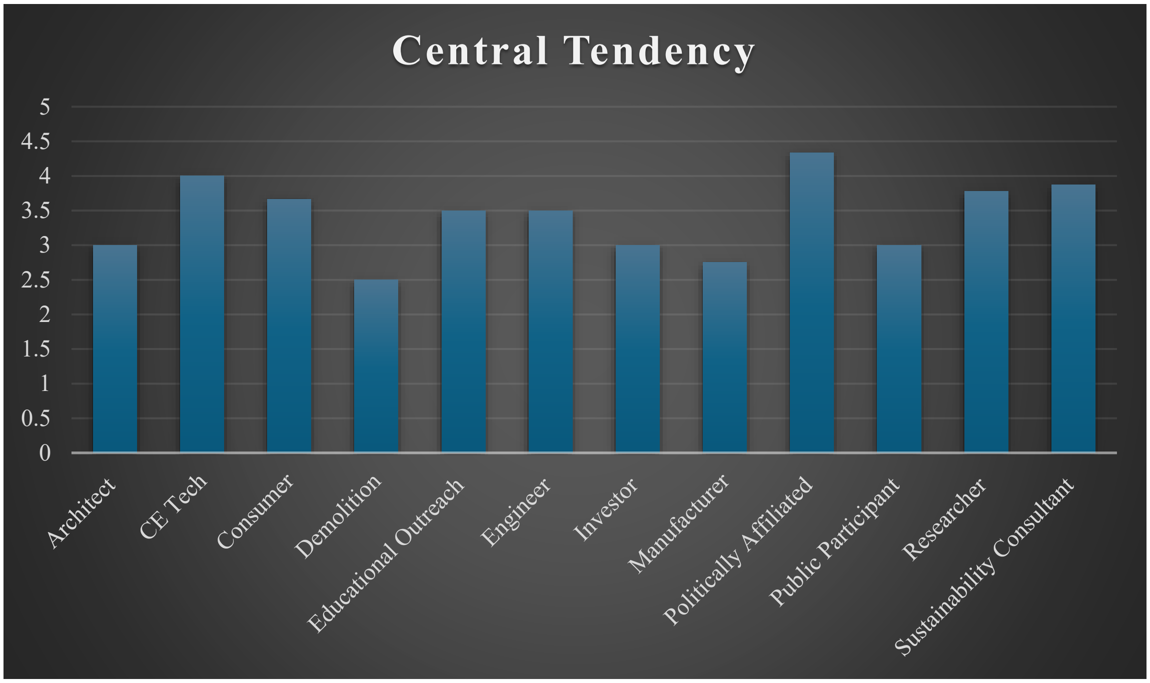

Figure 33. Central Tendency for Technological factors among stakeholder groups in Q11.

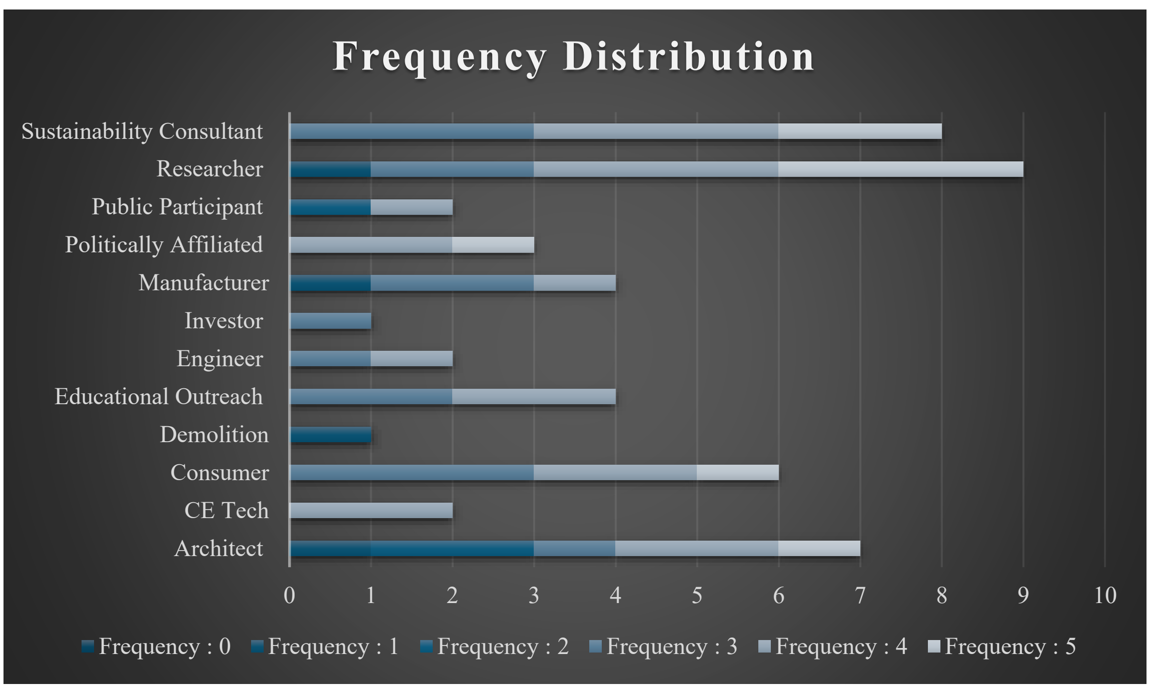

Figure 34. Frequency distribution for Technological factors among stakeholder groups in Q11.

Q11. Environmental Factors: consider the likelihood of external environmental factors posing a risk to the use of building material waste in circular economy practices. Rate each factor on a scale of 0 (No Impact) to 5 (High Impact)

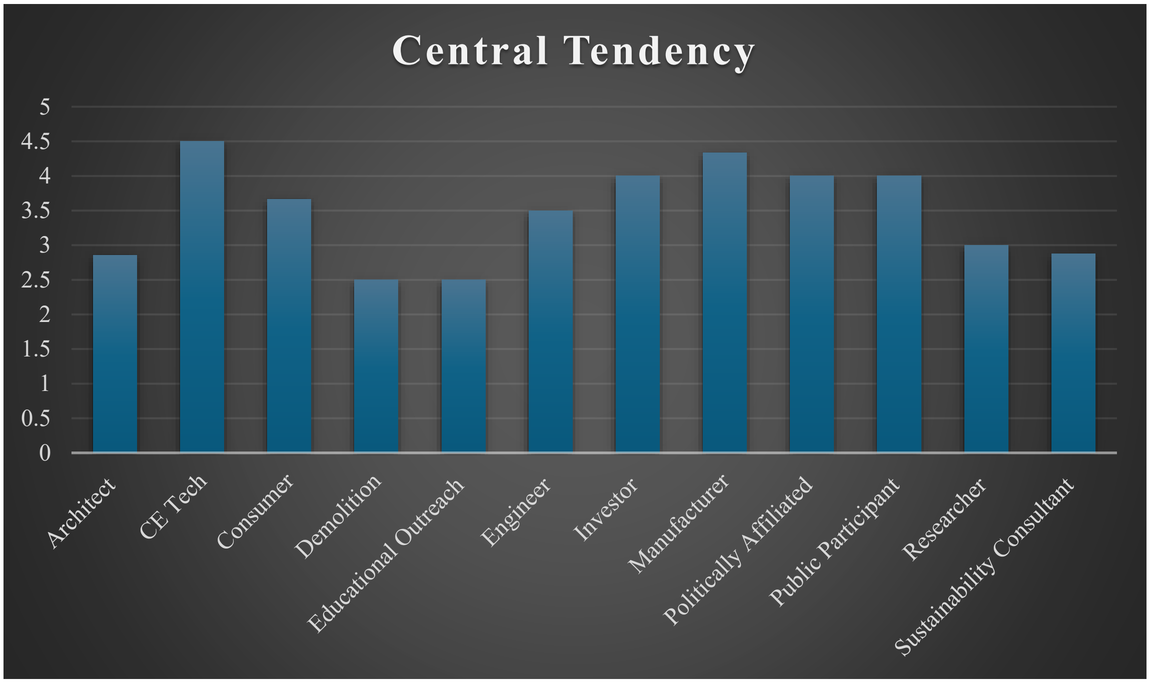

Figure 35. Central Tendency for Environmental factors among stakeholder groups in Q11.

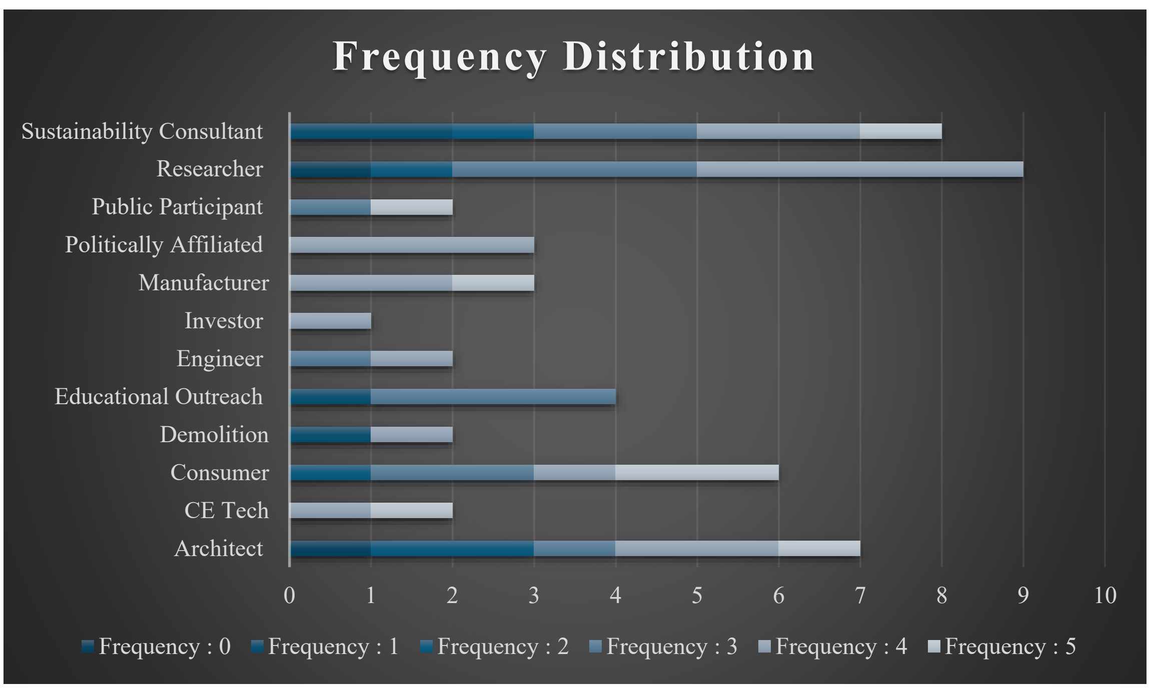

Figure 36. Frequency distribution for Environmental factors among stakeholder groups in Q11.

Q11. Legal Factors: consider the likelihood of external legal factors posing a risk to the use of building material waste in circular economy practices. Rate each factor on a scale of 0 (No Impact) to 5 (High Impact)

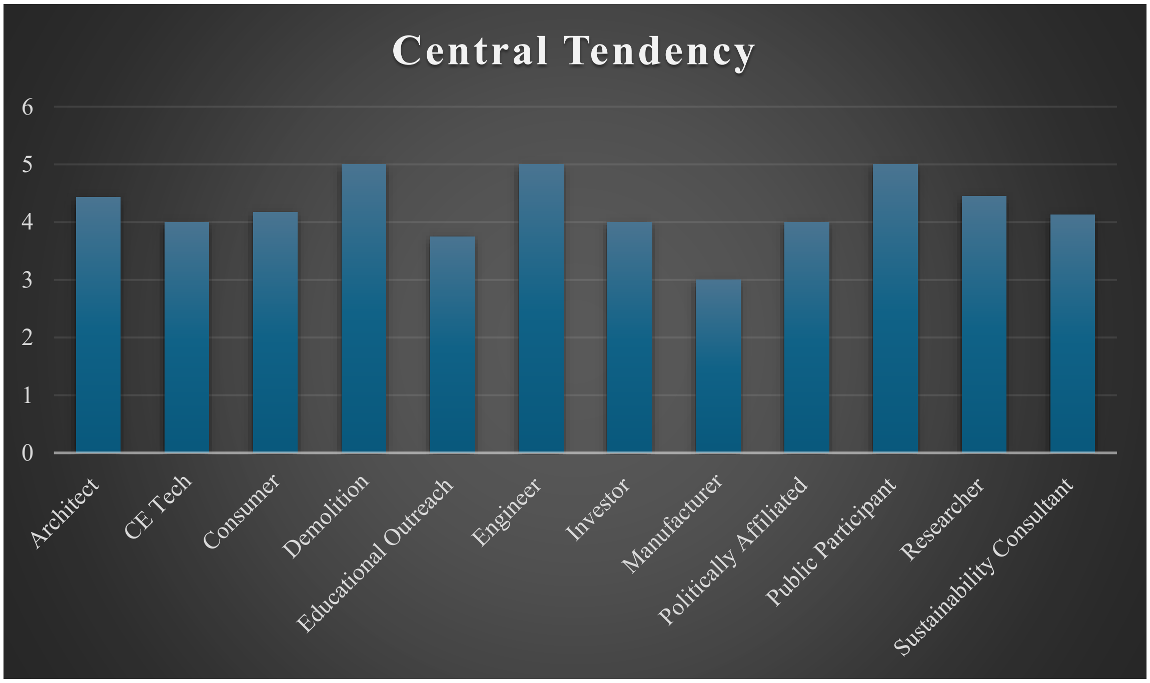

Figure 37. Central Tendency for Legal factors among stakeholder groups in Q11.

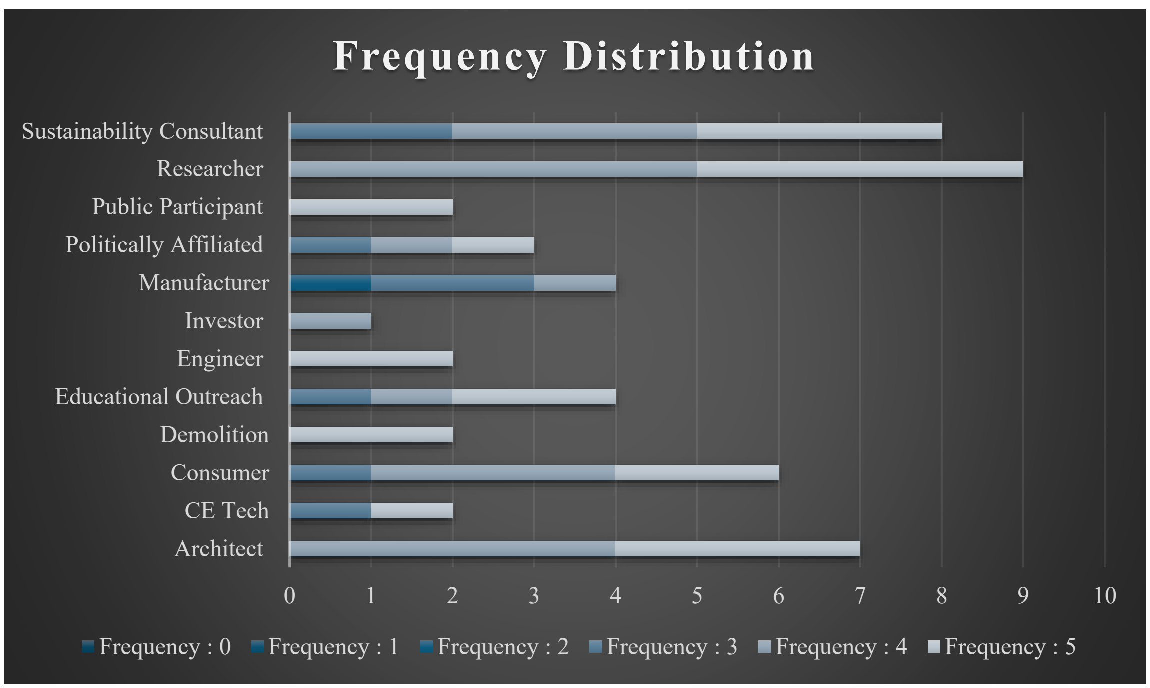

Figure 38. Frequency distribution for Legal factors among stakeholder groups in Q11.

Q12. Political Factors: consider how much uncertainty surrounds its potential impact. Based on this, how much does the level of uncertainty affect the use of building material waste in circular economy practices?

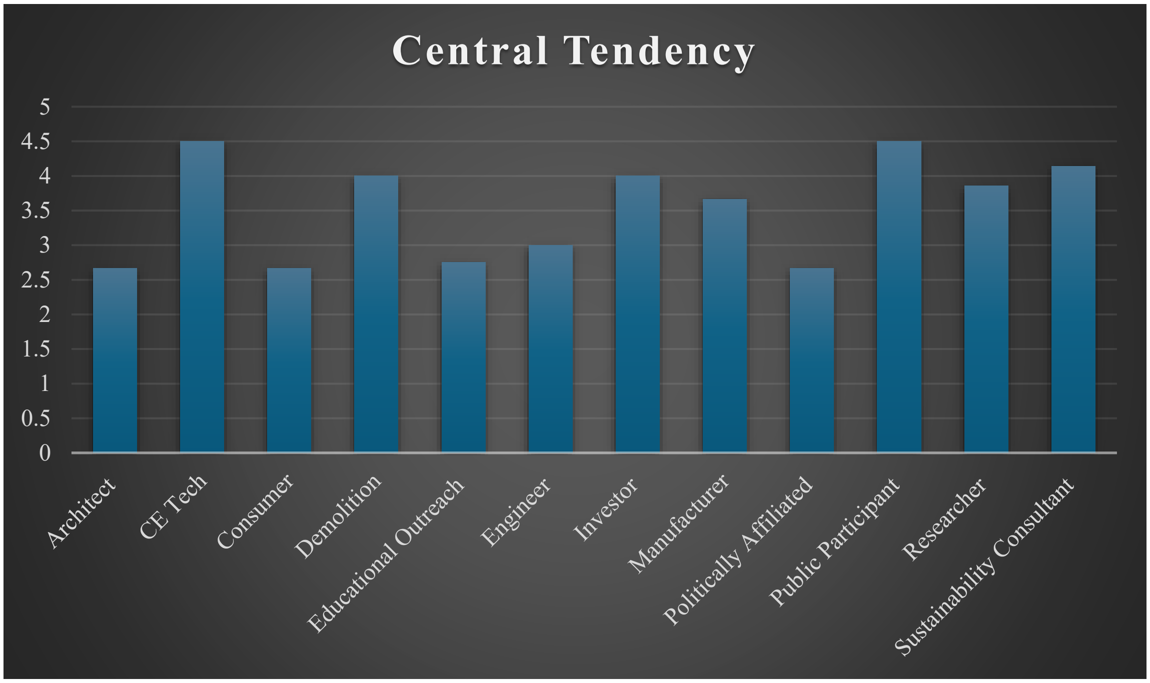

Figure 39. Central Tendency for Political factors among stakeholder groups in Q12.

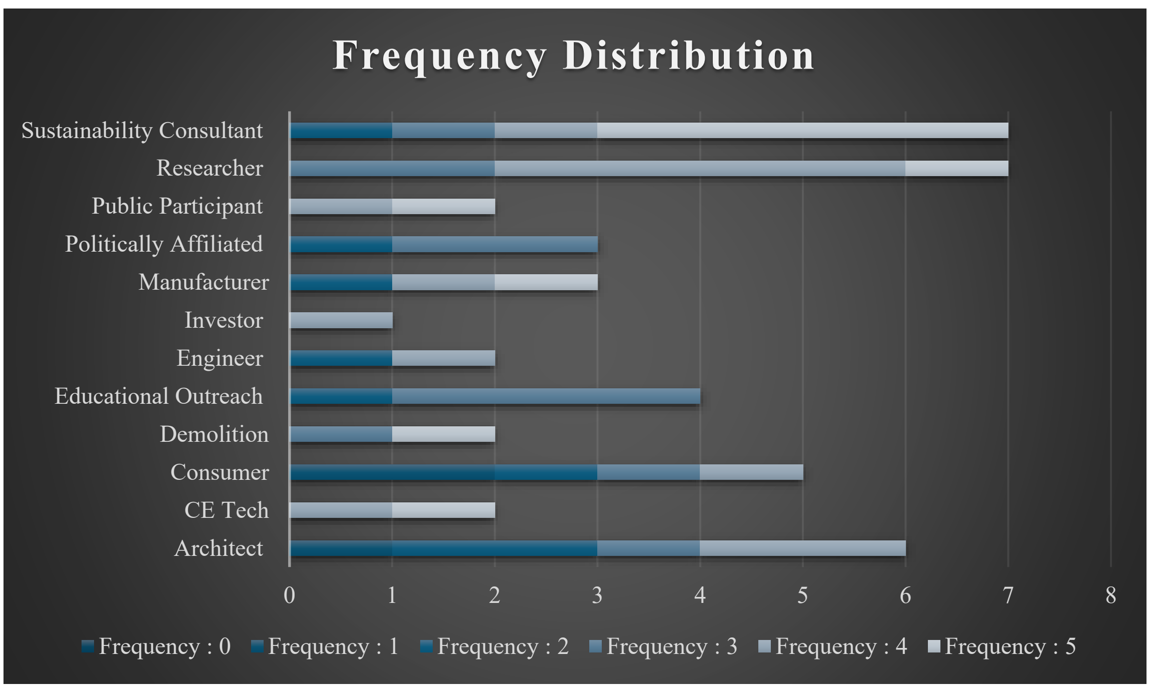

Figure 40. Frequency distribution for Political factors among stakeholder groups in Q12.

Q12. Economic Factors: For economic external factors, consider how much uncertainty surrounds its potential impact. Based on this, how much does the level of uncertainty affect the use of building material waste in circular economy practices?

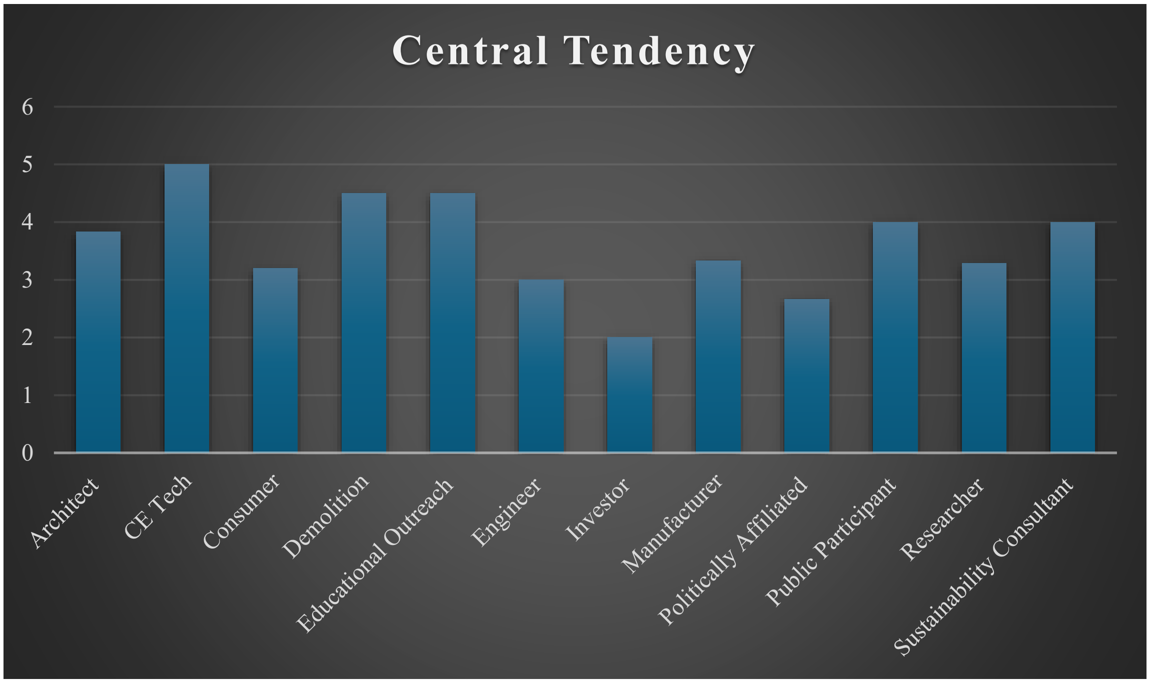

Figure 41. Central Tendency for Economic factors among stakeholder groups in Q12.

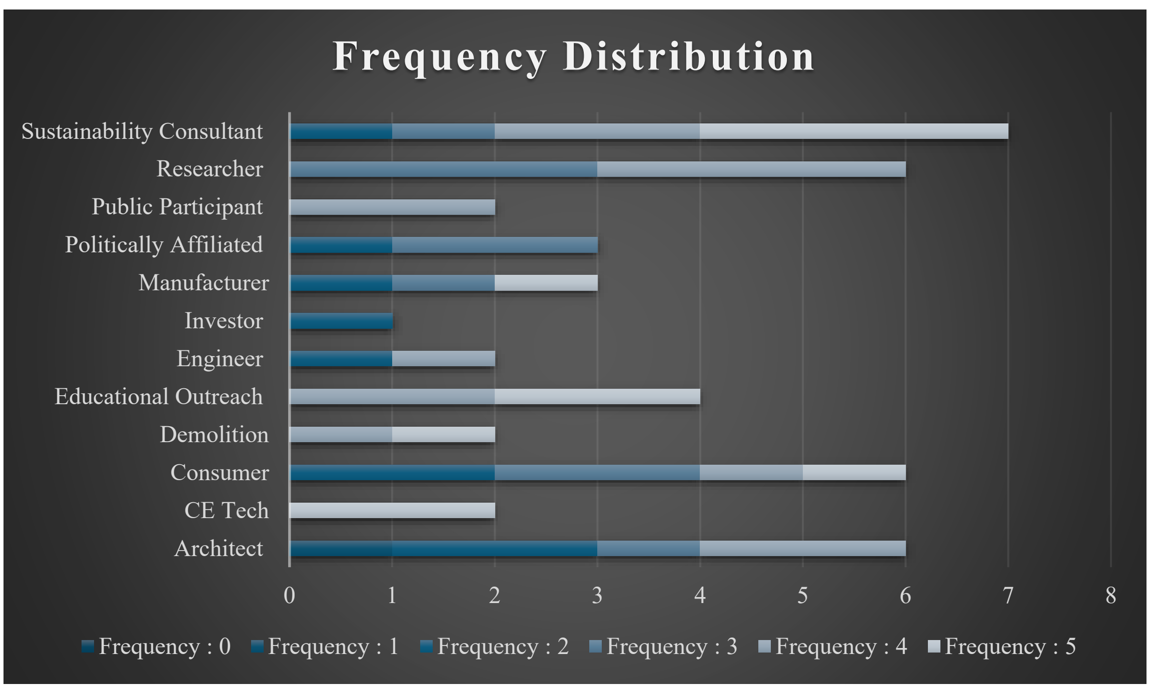

Figure 42. Frequency distribution for Economic factors among stakeholder groups in Q12.

Q12. Social Factors: For social external factors, consider how much uncertainty surrounds its potential impact. Based on this, how much does the level of uncertainty affect the use of building material waste in circular economy practices?

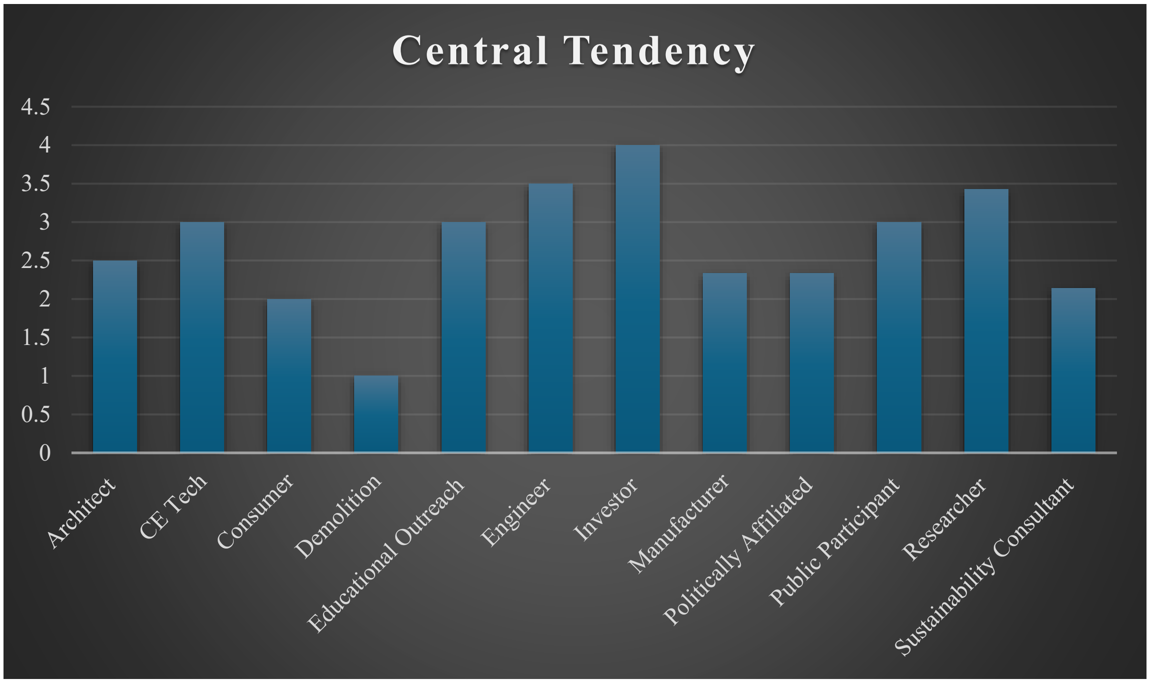

Figure 43. Central Tendency for Social factors among stakeholder groups in Q12.

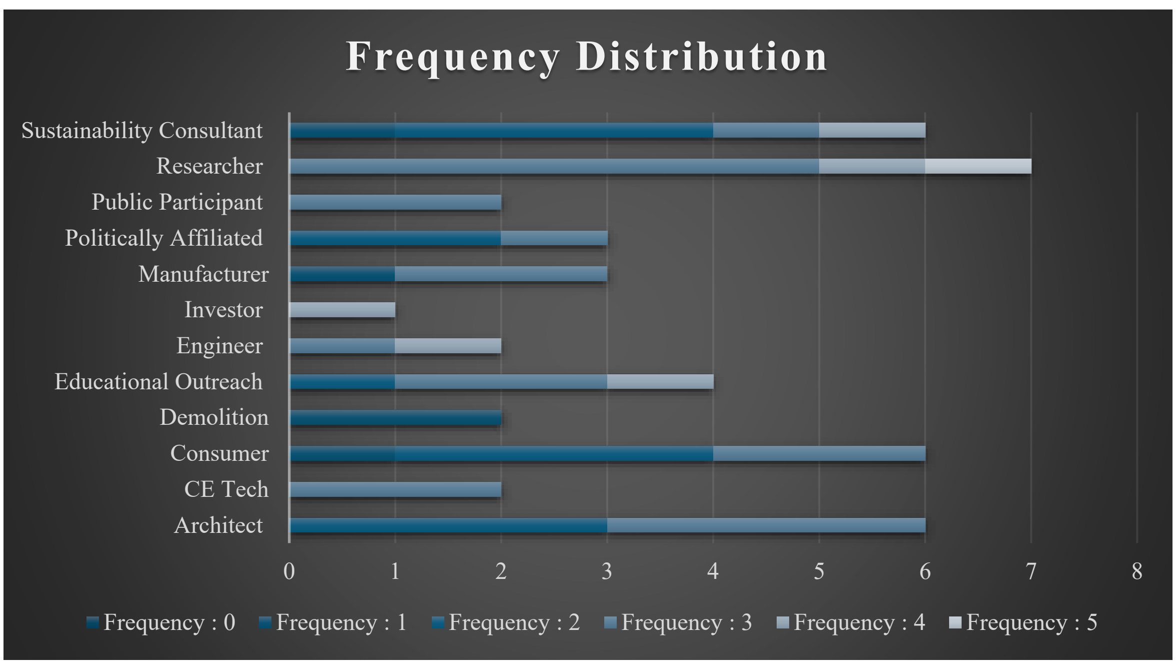

Figure 44. Frequency distribution for Social factors among stakeholder groups in Q12.

Q12. Technological Factors: For technological external factors, consider how much uncertainty surrounds its potential impact. Based on this, how much does the level of uncertainty affect the use of building material waste in circular economy practices?

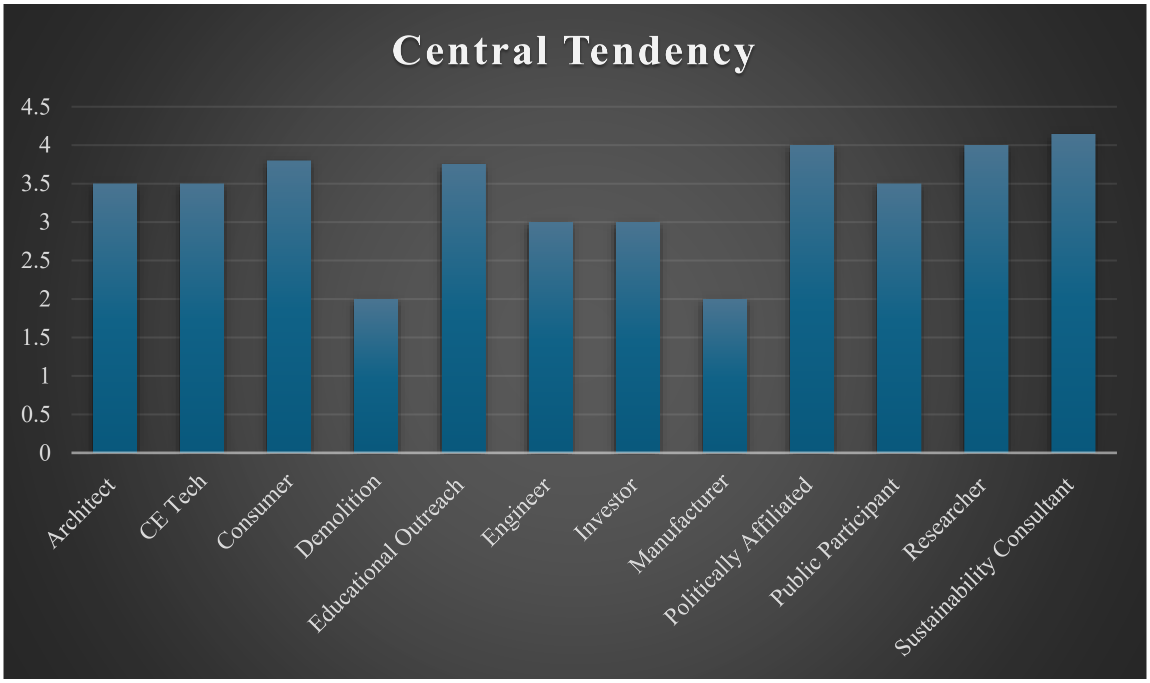

Figure 45. Central Tendency for Technological factors among stakeholder groups in Q12.

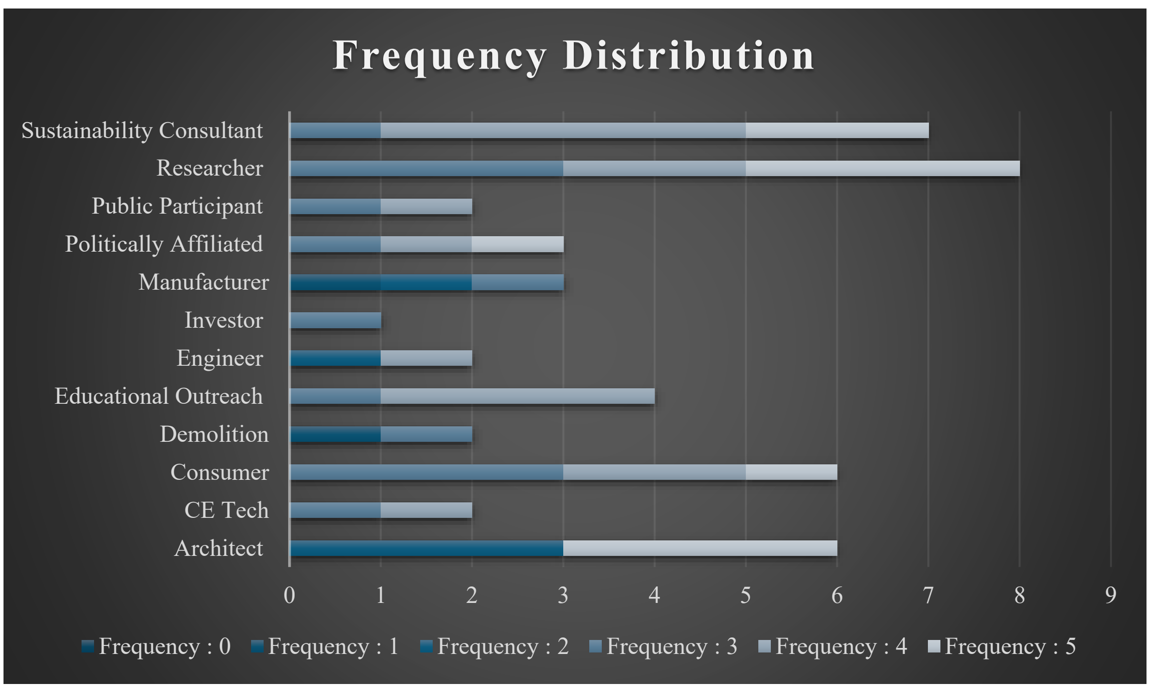

Figure 46. Frequency distribution for Technological factors among stakeholder groups in Q12.

Q12. Environmental Factors: For environmental external factors, consider how much uncertainty surrounds its potential impact. Based on this, how much does the level of uncertainty affect the use of building material waste in circular economy practices?

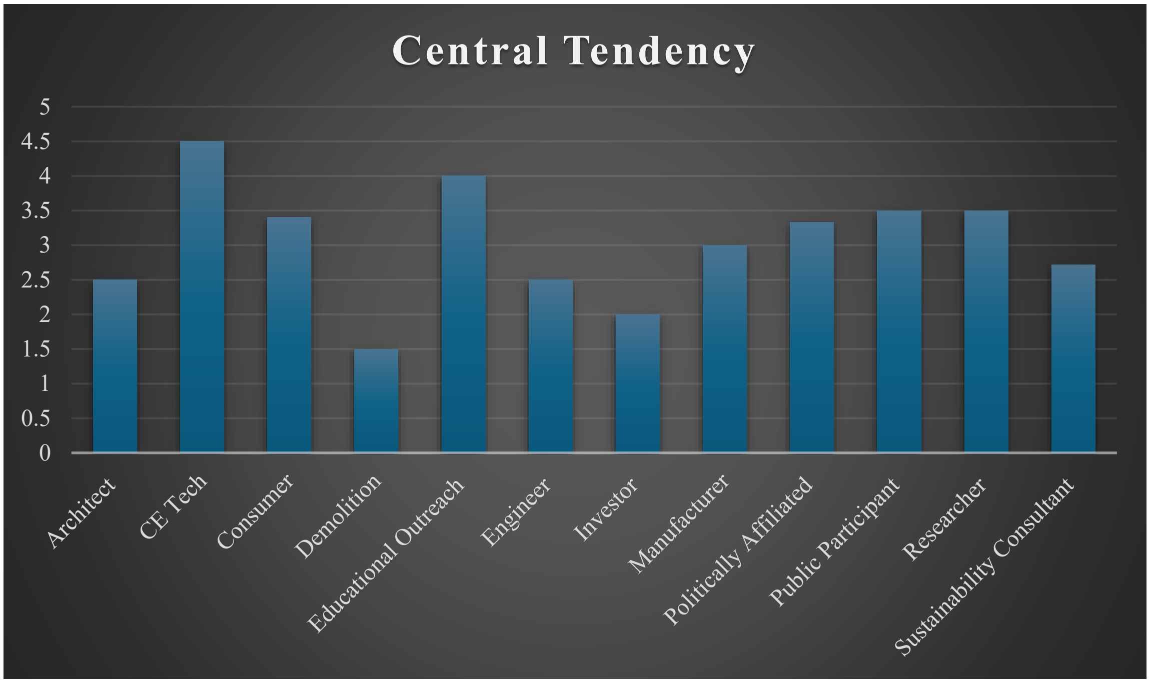

Figure 47. Central Tendency for Environmental factors among stakeholder groups in Q12.

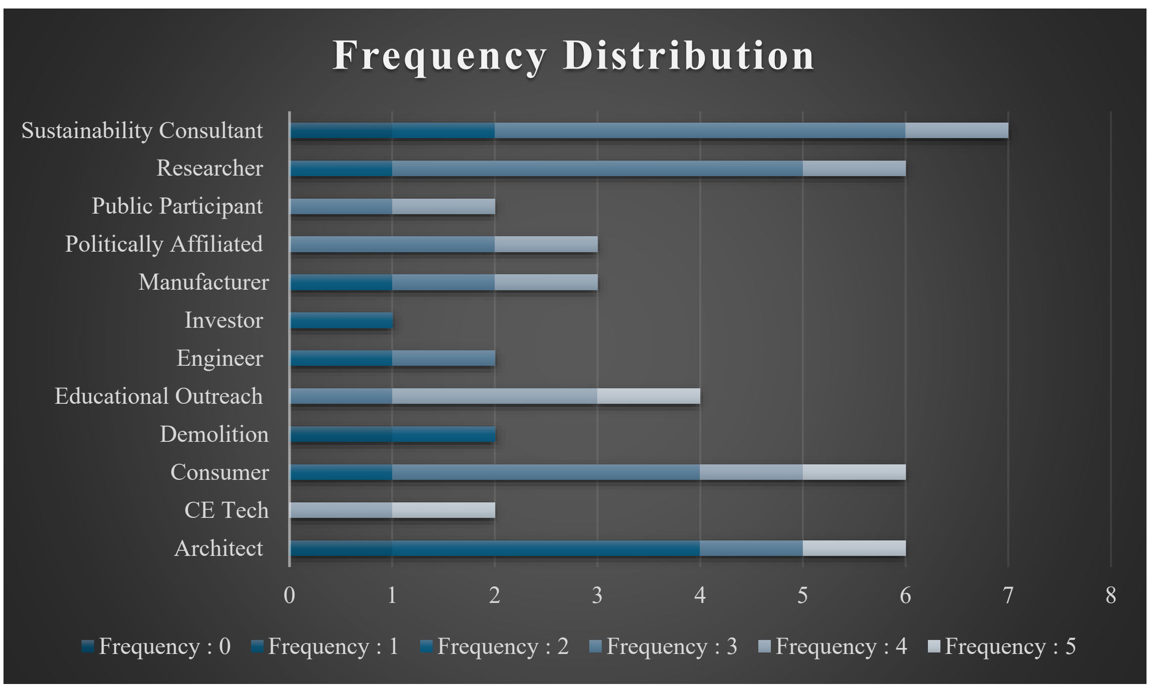

Figure 48. Frequency distribution for Environmental factors among stakeholder groups in Q12.

Q12. Legal Factors: For Legal external factors, consider how much uncertainty surrounds its potential impact. Based on this, how much does the level of uncertainty affect the use of building material waste in circular economy practices?

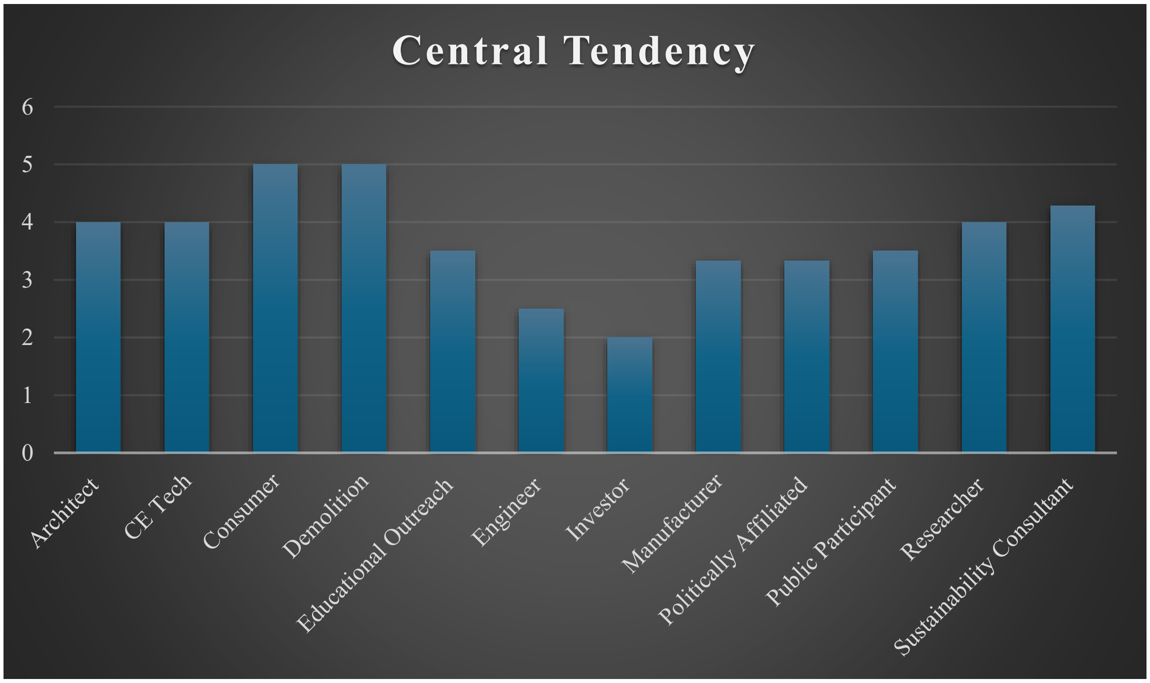

Figure 49. Central Tendency for Legal factors among stakeholder groups in Q12.

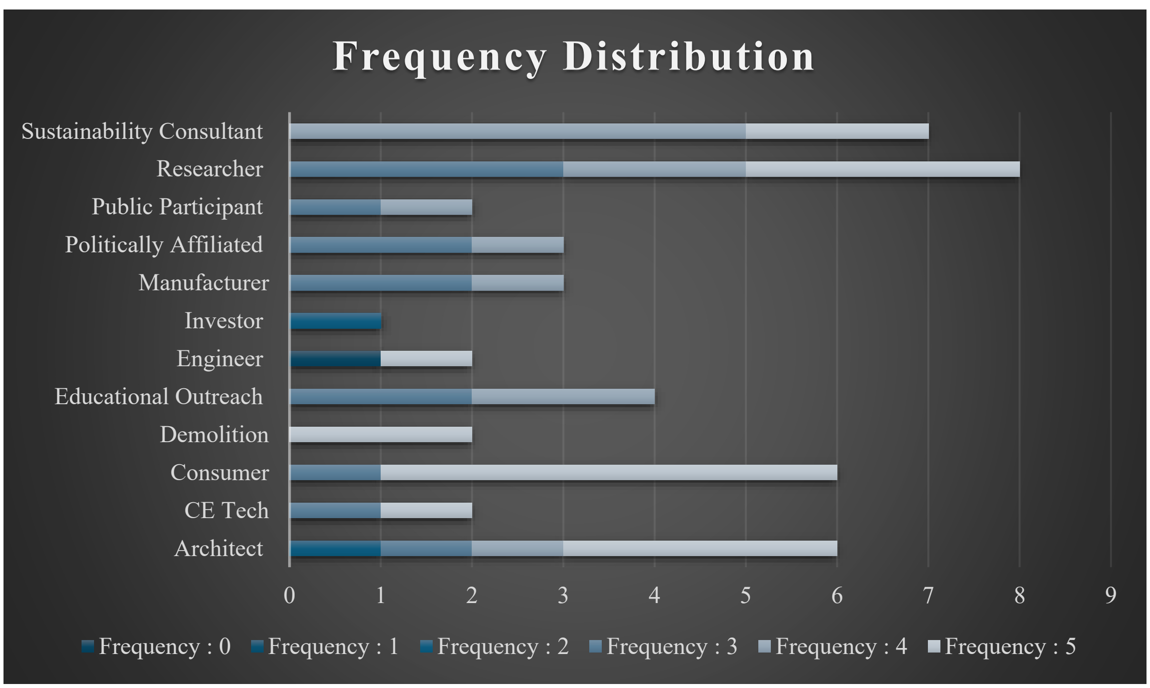

Figure 50. Frequency distribution for Legal factors among stakeholder groups in Q12.