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INSIGHTS ON SUSTAINABILITY IN INDUSTRIALIZED CONSTRUCTION IN EUROPE AND THE UNITED STATES

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ABSTRACT

Embracing lean philosophy, which emphasizes waste reduction and resource efficiency, is a pre-condition to improving the environmental impact of a building but is not sufficient to produce a sustainable building. To increase the environmental sustainability of their products, industrialized construction (IC) companies need to understand the constraints of the location where they operate, and best practices applied by leading IC companies. To delve into constraints and best practices, we interviewed sustainability leaders of six IC companies at the forefront of sustainability practices in Europe and the United States. The purpose of each interview was to highlight the challenges and opportunities caused by external factors that companies are experiencing, and the advancements that other companies could replicate. Based on comparative analysis, our results show stricter sustainability regulations and a collaborative stakeholders' network with similar sustainability goals in Europe compared to the US. These factors seem to favor 1) a careful evaluation of tradeoffs when considering technical solutions; 2) the adoption of disassembly, adaptability, and circularity principles; 3) the development of new business models; and 4) companies developing new rating systems to capture their advanced product sustainability. Our results can inform lagging IC companies to adopt the most advanced sustainability practices.

KEYWORDS

Lean Construction, Lean and Green, Sustainability, Industrialized Construction, Off-site Construction

INTRODUCTION

Improving the efficiency of construction processes and minimizing waste, as embraced by lean philosophy, has been widely recognized for its economic benefits (Poppendieck, 2011). Beyond the economic advantages of reducing waste, some studies highlight the positive relationship between lean philosophy and environmental sustainability (Solaimani & Sedighi, 2020; Johnsen & Drevland, 2016; Galeazzo et al., 2014; Carneiro et al., 2012). Specifically, the lean philosophy holds promise in reducing the environmental impact of construction (Degani & Cardoso, 2002; Ghosh et al., 2014). In addition to following lean philosophy, the application of industrialized construction (IC) methods generates several environmental benefits over the entire building life cycle if compared to conventional construction methods (Kedir & Hall, 2021;

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Sotorrío Ortega et al., 2023). Companies that adopt industrialized construction methods design their buildings using a product-oriented approach based on predefined solutions structured in platforms, which are used project after project and are essential for continuous improvement and systematic management of knowledge. IC companies can be more efficient in material estimation and acquisition (Banawi & Bilec, 2014), can control the source of energy to power their factories and their means of transportation (Quale et al., 2012), and achieve sophisticated buildings with consistent quality that support energy-efficient solutions (Podder et al., 2020).

However, achieving the environmental sustainability of a building involves multifaceted considerations beyond applying lean principles and industrialized construction methods (Tasdemir & Gazo, 2018). These additional considerations depend on the location in which each company operates and include, for example, the possibility of innovating product design, regulatory compliance, and stakeholders' engagement to create a more environmentally sustainable building product. With new IC companies emerging in different countries around the world (Pullen et al., 2019; Wuni et al., 2022; Malmgren, 2014) and the increasing pressure to create sustainable products (Dutil et al., 2011), it becomes critical to identify how external factors differ depending on the country and what their impacts are on the sustainability of a product. The goal is to raise awareness among companies and policymakers about regulations and stakeholder's engagement that foster sustainability in different countries and highlight the best sustainability practices adopted by leading IC companies.

This work shows initial findings of the external factors relevant to the advancements of sustainability practices and the impact they have on final building products and the structure of IC companies. We hope this work enables emerging or lagging IC companies to replicate the identified sustainability approaches and new policies that will favor sustainability practices.

METHODOLOGY

In this work, we chose a multiple case study method to enable a broad understanding of the sustainability approaches taken by six different industrialized construction companies in the US and Europe. Over four months in 2023, we researched all six companies and interviewed them to collect information and data. Our data collection followed the same pattern and included the following three steps:

- Analyze the company's public stance on sustainability as expressed on the company's website.
- Conduct a 1-hour semi-structured video interview with the sustainability manager or CEO of each company.
- Review additional documents shared directly by the company (e.g., pilot study results and projects in collaboration with universities).

COMPANY SELECTION

We chose six companies based on the following four primary criteria:

- Categorized as working with industrialized construction methods according to Lessing's framework for industrialized construction (Lessing, 2015).
- Produce wood based modular residential buildings.
- Companies are based in different countries, including Europe and the US, and at different maturity stages, including well-established and recently started companies.
- Companies are at the forefront of sustainability practices in their country.

We selected six IC companies: four in Europe, specifically two in Sweden, one based both in Denmark and the Netherlands, one in Switzerland, and two in the US, one in Pennsylvania and one in California. Among the companies selected in Europe, two were newly established startups (Group A), and the other two were well-established Swedish IC companies (Group B). The two companies selected in the US (Group C) were established about ten years ago. Each company is briefly described in the following section, and all companies' names have been anonymized.

Group A: European IC Startups

Company A1 is a non-traditional real estate startup established in 2021 with operations in Denmark and the Netherlands and a team of about 25 people. Their main goal is developing urban communities that are inclusive, livable, and sustainable. They recently partnered with a construction company to build their first residential project, which has a minimal carbon footprint. They are using modular timber construction, have developed material passports, and are applying circular economy principles.

Company A2 is a Swiss startup established in 2021 that designs and develops reusable and re-adaptable buildings for real estate owners and investors and has a team of about 10 people. The company aims to help cities become more dynamic and fulfill changing users' needs through their future-proof circular building products. Their products are manufactured as a standardized modular kit of components and designed to maintain value over multiple life cycles since they can be quickly readapted or relocated to minimize their environmental impact.

Group B: Swedish Family-owned IC Companies

Company B1 is a well-established family-owned Swedish wood company with over 2,000 employees. They act as suppliers of wood materials and components but also as manufacturers and developers of wood volumetric modular multifamily houses. Environmental consciousness is one of their core values. They source raw materials from forests and replace the trees removed with new trees. They build climate-smart and energy-efficient homes with the goal of creating sustainable communities.

Company B2 is a well-established family-owned Swedish company with about 150 employees that builds wood volumetric modular multi-story dwellings. About 70% of their production is offered to external customers, whereas the remaining 30% is used by their own real estate company. They consider sustainability from an ecological, social, and economic perspective, looking at the entire life cycle, and have the goal of developing long-lasting communities.

Group C: United States IC Companies

Company C1 is a vertically integrated wood volumetric modular construction company established nearly ten years ago with factories in Pennsylvania and California and about 300 employees. It is focused on providing multifamily affordable housing that is resilient and environmentally friendly and invests in sustainability on many fronts, from using clean energy to power factories to reusing and recycling materials.

Company C2 is a California-based company that produces wood panelized components that can be assembled into volumetric modules. Launched in 2016, the company has about 100 employees. Their goal is addressing the housing shortage in California while supporting people and the planet. They have had carbon-neutral operations since 2020 and are working to further reduce emissions throughout their value chain, reducing waste, and selecting sustainable materials.

Data Collection and Execution

We developed interview questions about sustainability to better understand the company's motivation, technical advancements, challenges, future vision and whether they use Whole Building Life Cycle Assessment (WBLCA) on their products, track their direct and indirect environmental impact, and collaborate with their stakeholders to improve the product sustainability. We also asked additional questions about circularity, e.g., whether they apply circular principles in their product development or plan to include them in the future. The interviews were 1-hour long, semi-structured, and via video with the sustainability manager or CEO of each company. They were conducted by the same interviewer who asked open-ended questions that encouraged a conversation. Once the information was collected, our analysis followed a qualitative approach using qualitative coding to systematically categorize the excerpts to find themes and patterns and qualitative synthesis to pool data and draw conclusions. The study revealed similarities and differences between the six companies, which are reported in the next section.

RESULTS AND DISCUSSION

All the IC companies in this study see lean principles and industrialized construction methods as advantageous to achieving a more sustainable building product. In this section, we show how, in the last decade, the IC companies interviewed similarly developed buildings that can support energy-efficient solutions and are now shifting towards lowering the embodied carbon emissions of their building products. We also illustrate that finding sustainable technical solutions is not their main challenge. Conversely, cost, industry resistance to change, and regulation play a greater role in hindering their ability to make their final product more sustainable. These factors are common in both Europe and US based companies though in some countries in Europe, the establishment of a network of stakeholders interested in improving sustainability and stricter building regulations that promote sustainability seem to have accelerated the continuous improvement of more sustainable products. Indeed, only the European companies interviewed evaluate tradeoffs between operational and embodied carbon impact; consider products’ disassembly, adaptability, and circularity while developing their technical solutions; and look beyond typically adopted business models and rating systems.

SUSTAINABLE TECHNICAL SYSTEMS

All companies interviewed have focused on achieving energy efficiency for both their factories and the final products they offer. All companies’ factories are partially or totally powered by solar energy, reducing the environmental impact of the production and assembly phases of the building life cycle. In the last decade, all the companies put substantial effort into reducing operational carbon and developing an energy-efficient building product. They offer buildings powered by electricity generated by solar energy or geothermal energy, heat pumps, and wastewater recycling systems to treat and reuse water. These options are available to customers and could be easily implemented in the final building product. After focusing on energy efficiency and achieving products that generate low operational carbon during their lives, all the IC companies interviewed are now switching their interests towards reducing the embodied carbon of their products. These companies are now experimenting and testing new bio-based materials to substitute materials commonly used in construction and lower the initial carbon footprint of their building product. For example, company B1 is trying to replace mineral wool with cellulose to insulate buildings and company C1 is testing bamboo as a replacement for lumber. Given the high embodied carbon of traditional concrete foundations, companies are exploring alternatives such as using cross laminated timber (CLT) or steel for the foundations and bedframes of their buildings. This work of lowering embodied carbon emissions is quite challenging since the companies must triangulate their sustainability goals with financial constraints and current regulations.

BARRIERS AND CHALLENGES TO IMPROVING SUSTAINABILITY

Although innovating technical systems can present challenges, none of the interviewed companies explicitly mentioned technical issues among the main barriers and challenges they face while improving the sustainability of their products. Conversely, all the interviewed companies identified financial issues, their industry's resistance to change, and regulation and compliance requirements among the challenges preventing the wide adoption of the most sustainable solutions, as summarized below.

High Initial Cost

The IC companies interviewed shared that the most sustainable option, on average, is not yet cost effective and that bio-based choices on the market are more expensive. This represents a barrier for them to improving the sustainability of the baseline product. Although they see a growing interest in sustainability, only a few customers choose the most sustainable option available since they need to pay a premium for it. In addition, progress in building sustainability requires increasing investment by IC companies. However, it is hard for them to prioritize sustainability when the building sector is struggling, and they find it challenging to be profitable and guarantee fast product delivery.

Resistance to Change

The IC companies interviewed note a general resistance to change from their stakeholders. For example, suppliers would need to change how they produce materials and use cleaner energy instead, customers would need to change their approach and consider the entire building life cycle and opt for the most sustainable option. The adoption of sustainable options is still quite limited and to expand it, we need a change of mindset that prioritizes sustainability as a factor that matters when evaluating a final product.

Regulation

The IC companies interviewed believe regulatory infrastructure is quite fixed and difficult to change. It is often challenging for them to bring new sustainable products into the market because of compliance issues. It is difficult to meet fire, acoustic, and structural requirements with new sustainable products. Doing so would require them to do more testing and larger investments of money and time in mockups. In the US, building codes are fragmented because it is a large country with different needs (seismic, hurricane, etc.). Therefore, it is difficult to broadly adopt certain technologies and methodologies.

DIFFERENCES: EUROPE VS UNITED STATES

All European and American IC companies face similar challenges and barriers to achieving a more sustainable product. However, different regulations and business norms create differences in how European and American companies address these challenges and barriers. In this section, we will present two external factors that favor sustainability advancements in Europe: the presence of stricter regulation and a stronger network of stakeholders to collaborate with. We highlight factors that are indicative of the progress of the European IC companies interviewed that can be taken as models of how to achieve further sustainability: evaluating tradeoffs between operational and embodied carbon emissions when choosing a technical solution; considering disassembly, adaptability, and circularity of the final product; and developing new business models and sustainability rating systems.

Regulations and Life Cycle Assessment Requirements

External factors that exist in Europe and not in the United States yet are regulations that mandate reporting the environmental impact of a company (Directive 2022/2464) and a maximum carbon footprint for projects (One Click LCA, 2022). In the European Union (EU), in addition to reporting Scope 1 emissions, which are direct emissions that occur from sources controlled or owned by a company, and Scope 2 emissions, which are indirect emissions from the generation of purchased electricity consumed by the company, companies must report Scope 3 emissions, which are indirect emissions from upstream and downstream activities in the value chain (Bhatia & Ranganathan, 2004). As of 2024, large companies are reporting Scope 1, 2, and 3 emissions, whereas small and medium-sized companies will start in 2026 (Directive 2022/2464). This also means that IC companies in the EU will soon need to report the environmental impact of purchased materials; upstream and downstream transportation and distribution; waste generated; processing, use, and end-of-life treatment of their sold products (in this case buildings); employee commuting and business travels; etc. In the US, only public companies need to disclose greenhouse gas emissions. Starting in 2026 (Scope 1 and 2) and 2027 (Scope 3), the State of California (S.B. 253, 2023) will mandate disclosure of GHG emissions to public and private companies, but only if operating with over 1$ billion in revenue.

Besides the mandated reporting of companies' environmental impact, in recent years, several North European countries such as Denmark, Finland, France, Netherlands, and Sweden, put in place mandatory regulations for Life Cycle Assessments (LCA) of all newly constructed buildings including residential, whereas in the UK, Germany, and Switzerland, similar requirements exist for public buildings only (One Click LCA, 2022). Regulations setting limit values for the carbon footprint of buildings will be further revised in the upcoming years to progressively reduce the environmental impact of new buildings. The European IC companies interviewed are in the countries with the most advanced mandatory legislation to lower the carbon footprint of new buildings. The life cycle stages and building components and systems required to be included in the calculation of the LCA differ depending on the regulations in each country, and details are reported in Table 1 (One Click LCA, 2022). In the United States, no requirements around the carbon footprint of buildings are yet enforced, although there are programs to support green buildings and initial work to require embodied carbon considerations in new construction and major renovation projects. With CALGreen, starting in July 2024, the State of California will require LCA calculation for certain projects, but this does not apply to residential buildings (California Building Standards Commission, 2010).

Table 1: Mandatory regulations for the LCA of newly constructed buildings in each of the country where the companies interviewed are based (One Click LCA, 2022).

Country	Buildings	Year	Limit value	Future plan	Stage LCA	Components required for LCA
Denmark	All new buildings >1000m^2	2023	Yes	All new buildings in 2025	A1 to A5, B4, B6, C3, C4, D	All except for MEP, furniture, and appliances.
Netherlands	Offices >100m^2 and residential	2018	Yes	To be determined	All except for B6 and B7	All except for external work, furniture, and appliances.
Sweden	All new buildings >100m^2	2022	Not yet	Mandatory limit value in 2025	A1 to A5	All except for floor and wall finishes, external work, MEP, furniture, and appliances.
United States (California)	Office and schools	2024	Not yet	To be determined	To be determined	To be determined

Although limit values enforced today are not yet strict, the European IC companies interviewed envision their path ahead and the need to become more sustainable year after year to comply with more stringent rules in the future. They have already started the journey to lower the carbon footprint of their final product. On the other side, the American IC companies interviewed are still in an experimental phase, since their initiatives to lower the carbon footprint of their product are taken on a voluntary basis and not because of pressing regulations or the belief that rules will be stricter in the years to come. They have assessed the building life cycle environmental impact only on specific projects or when the client asks for it, whereas the European IC companies interviewed do it routinely because of regulations that enforce it.

Network of Stakeholders with Similar Sustainability Goals

Besides the presence of a different regulatory infrastructure, we found that the network around IC companies in Europe is more supportive of and interested in sustainability than the network present in the United States. Swedish IC companies collaborate with stakeholders on sustainability throughout the entire product value chain (Fig. 1). Customers, municipalities, architects and engineers, facility managers, construction companies, suppliers, subcontractors, and waste management companies share their perspectives and tackle sustainability from different angles, enriching the discussion and proposing solutions to technical and commercial issues. In addition, academia is involved in the discussions within this large network of stakeholders and acts as an independent and impartial entity. Even financial institutions and insurance companies are part of this large network. The former offers advantageous loans to customers that invest in a more sustainable project, creating a virtuous loop; the latter is working to provide insurance for buildings made of reused materials, increasing the expansion opportunities of this nascent market.

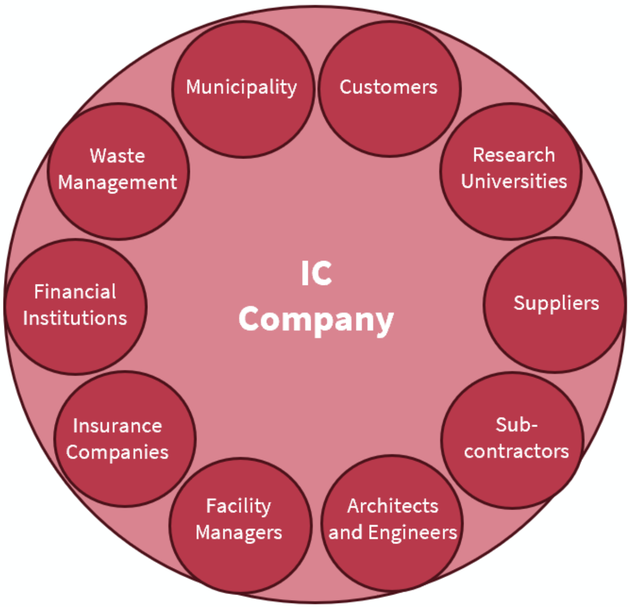

Figure 1: Network of stakeholders in Europe supporting sustainability efforts throughout the product value chain.

Like Swedish companies, company A1 based in the Netherlands and Denmark has created an online platform to engage the entire industry in the sustainability and circularity journey. This platform offers a place to connect many stakeholders but also serves educational purposes. European IC companies interviewed have a collaborative approach and work on advanced topics related to the sustainability of their product even with direct competitors, understanding that the journey towards achieving sustainability cannot be undertaken alone.

Although willing to cooperate with stakeholders, the companies interviewed in the US find challenges on the supplier and developer sides. For example, company C1 aspires to have a consortium of all stakeholders in the market with a third party, whether academia or government, to get more attention from all the players in the construction market on sustainability topics and foster the circularity of their final product. Unfortunately, such a consortium has not yet been established, and today it is rare for individual suppliers to be willing to address IC companies' concerns around embodied carbon emissions and modify or adapt their production to satisfy the request of only one IC company. Startups offering more sustainable materials are emerging, but often can't satisfy the large demands required to complete a building project. For example, company C2 identified a potential supplier of an innovative sustainable material that could be used in buildings. However, the supplier did not have the capacity to supply enough material for their entire building project. In addition, developers typically flip the project after a short period of time, which results, with rare exceptions, in no investment in durable materials and no consideration of the usage and end-of-life stages of the project. Moreover, customers generally don't choose the most sustainable option among the many available on the market because of the high initial cost of the most sustainable option and the lack of financial incentives.

Evaluation of Tradeoffs of Technical Solutions

From the interviews conducted, a factor that is indicative of the advancements in European IC companies is the evaluation of tradeoffs when opting for one technical solution or another, including variables such as embodied carbon, operational carbon, the source of energy for building operations, cost, and estimated building life in the decision-making process. Our analysis indicates that two practices enable evaluation tradeoffs: the habit of analyzing the entire life cycle of a building, partially due to the new regulations in force, and the developer's interest in keeping the building in their portfolio for a long time instead of flipping the project soon after construction. We report some examples that companies shared with us below.

1. **Wall Thickness**

   About 15 years ago, Swedish company B1 developed a new wall system that was much thicker than the typical one with the belief that it could be a more sustainable solution in the future and reduce operational carbon emissions. However, this solution was expensive and could not reduce the energy consumption enough to balance the high cost and higher carbon footprint generated by the extra layers. Therefore, the company did not adopt the thicker wall and concluded that increasing the thickness of the wall to achieve better performance during building use does not always represent the best sustainable option when we also account for the embodied carbon and the life cycle costs.

2. **Envelope Material**

   Swedish company B1 offers multi-story residential buildings with wood-cladding façades. This type of façade needs to be repainted every 12-15 years for maintenance. Company B1's clients prefer a brick or glass façade to reduce maintenance costs and time. However, a brick or glass façade would cost much more than a wood façade and have a higher carbon footprint. Repainting the wood façade every 12-15 years is cheaper and results in a lower carbon footprint for the envelope. Although offering the option of a brick or glass façade, company B1 recommends clients to choose a wood-cladding façade if sustainability is among their priorities.

3. **Triple Glazing**

   Company A1 explored to what extent they need to insulate a building. The building code forced them to use triple glazing to have a better insulated building and decrease the operational energy use. However, after carrying out an analysis, the company discovered that the production of the glass for the extra panel would require more energy than the energy saved by having triple glazing in the building. Therefore, the savings in operational carbon would not balance the higher embodied carbon of the extra glass panel and the company recognized triple glazing is counterproductive in the project examined.

These examples reveal that a company needs to make decisions looking beyond the initial cost, and considering the entire building life cycle with a clear understanding of all the factors that play a role in the decision. The most sustainable option sometimes is not the most obvious or the one desired by other stakeholders.

Consideration of Disassembly, Adaptability, and Circularity

Another difference that emerges when comparing companies, not only between Europe and the United States but also considering their maturity stage, is the attention to disassembly, adaptability, and circularity.

European IC startups (Group A) are placing these future-proof concepts at the core of their business. For example, company A1 offers adaptable buildings with large apartment units that can be subdivided into smaller units in the future, if necessary, as the trend indicates that families are decreasing in size on average. They also design their buildings for disassembly and embed circularity into the product from the beginning with the idea of reusing their buildings at the highest possible value once they reach their end of life. Similarly, company A2 designs its products to be reusable, embedding specific technical characteristics that make the building circular, enabling disassembly and re-assembly an infinite number of times. Their buildings are also adaptable and flexible: the floor area or number of floors can be increased, and elevator shafts can be added.

Although companies B1 and B2 are well established and much more mature than companies A1 and A2, they are considering future-proof concepts as well, evaluating how to modify their products step by step to increase the disassembly, adaptability, and circularity potential. In collaboration with a Swedish university, company B2 performed a WBLCA on one of their projects to understand whether and how a more flexible and adaptable product could reduce their life cycle environmental impact. During a workshop organized by the same university, Group B companies developed their disassembly instruction manuals as a first step towards increasing the disassembly potential of their buildings. They recognize the challenges of disassembly in practice, as the guidelines would only apply if the assembly was carried out following precise instructions, i.e., without adding additional nails or not-tracked elements to the product during construction. The wood volumetric modules can be disassembled because each module is attached to another through dry connections only. Conversely, disassembling the module itself would be challenging, especially because the mechanical, electrical, and plumping (MEP) system is not designed to be easily disassembled and glue and adhesive are used within each module. Moreover, the market value of an assembled module would be higher than the total value of each detached single component within the module. For now, companies B1 and B2 have difficulties imagining how to solve the commercial aspects of disassembly and reuse, but both foresee the importance of circularity in the future.

Group C companies do not have disassembly, adaptability, and circularity on their roadmap or among their priorities. However, company C1 considers product sustainability during design, using a scorecard system to assess the end-of-life treatment of the materials chosen: whether they are reusable, recyclable, intended for landfill, or hazardous. Company C2 is focused on increasing the quality of assembly to be able to easily replace components in the future.

Beyond Commonly Used Business Models

IC companies have different business models than traditional construction companies (Lessing & Brege, 2018). These business models are structured based on continuity and are more suitable to improving the sustainability of their product and achieving full product circularity (Berglund-Brown et al., 2022). Startups that design their business models based on industrialized construction principles have beneficial conditions to fully embrace circularity principles and translate them into practice. For instance, company A1 invested a lot of time in developing its business model. As developers, they intend to keep each building in their portfolio throughout their life to maximize the benefits of including disassembly, adaptability, and circularity. They have developed material passports since they see their buildings as a temporary deposit of materials. In this way, materials will have a retained value and investing in the sustainability and circularity of the product becomes much more attractive from an economic standpoint. Although a company changing their business model requires much effort and risk taking, especially by well-established companies, mature companies in Europe are starting to think about new business models to enable circularity. For example, company B2 envisions keeping material ownership of their buildings during their lives as a good opportunity to better control the end-of-life phase of the building and reuse its components and materials.

Beyond Commonly Used Sustainability Rating Systems

In recent years, many rating systems to assess the environmental impact of buildings have been established (Bernardi et al., 2017). Commonly available rating systems, such as the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) and the Leadership in Energy and Environmental Design (LEED), provide a framework with precise criteria for assessing different categories of a building's environmental impact, such as materials, water efficiency, and indoor environmental quality. The IC companies interviewed use these systems to benchmark their products and gain certification, which they use to market their products to customers. However, the different companies had different opinions of the commonly used sustainability rating systems and how useful they are, mostly depending on the level of maturity of the company. Group A startups criticized the commonly available rating systems because they find them too limited to capture the entire value of their innovative product. Company A1 shared that companies using these systems can achieve very good ratings with traditional approaches and materials without necessarily rethinking their methods and without creating a truly more sustainable and circular building. As an example, company A1 shared that a project with 11 $kgCO_2/m^2$/year, which is not a difficult target to achieve, can earn a good rating such as a gold certification using DGNB, whereas they are already offering their first product at 5.3 $kgCO_2/m^2$/year, but can't reference a commonly used sustainability rating system that fully captures the additional value of substantially reducing the environmental impact of their product. Therefore, company A1 started to explore methods to capture this additional value, by developing their own tracking and rating system. Company A2 made similar criticisms of the commonly available rating systems, explaining that they also developed their own tool to capture the benefits of their product spanning multiple building life cycles and show the environmental impacts and costs since there were none available. Conversely, Group B and Group C companies still measure the sustainability of their product relying on commonly used rating systems, showing that their product can reach good ratings such as Gold certification with DGNB and LEED and find that currently sufficient.

CONCLUSION

Our goal was to raise awareness among companies and policymakers by analyzing the context and the best sustainability practices adopted by leading IC companies in the US and Europe. Based on our analysis of six IC companies at the forefront of sustainability practices, we conclude that the presence of strict regulations that enforce sustainability and the collaborative approach of stakeholders play important roles in developing an environmentally sustainable final product, as demonstrated by the European IC companies analyzed. They show more advancements in sustainability than US companies because they tend to 1) evaluate tradeoffs when considering technical solutions; 2) consider disassembly, adaptability, and circularity principles; 3) adopt new business models; and 4) develop new sustainability rating systems.

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