

Circular Building Design for the Infill Domain

Materialisation, and Value Network study of the Niaga ECOR Panel innovation

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Circular Building Design for the Infill Domain: Materialisation, and Value Network study of the Niaga ECOR Panel innovation

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Abstract. Circular Building gained traction during the past decade in the Netherlands. Circular Building (CB) is rooted in concepts such as Circular Economy and Cradle-to-Cradle®, accentuating closing and continuing of material flows to establish sustainable resource cycles. CB implies that buildings and building components are designed to retain value, tailored for specific service lives and responsive to changing needs. This way, wasting of buildings and building components can be reduced or avoided. This paper revolves around circular materialisation and operation of building infill, such as furniture, partitions, and kitchens. The short to medium-long material cycles usually associated with those components provide potential benefits for circular resource management. The paper comprises a study into materialisation and operational performance of the Niaga ECOR Panel (NEP): an innovative cellulose board product. NEP aims to offer a healthy and circular alternative for conventional linear board products and value chains, adhering to multiple Sustainable Development Goals, notably: SDG11 (Sustainable Cities and Communities) and SDG12 (Responsible Production and Consumption). The study follows *Circ-Flex* assessment guidelines, anticipating operational performance through the supply, use, and reverse-supply chain. The findings indicate that the intrinsic properties of the NEP can enable circular infill value models, provided that networked actors remain aligned.

1. Introduction: Material Circulation

1.1 Problem Statement

According to the Global Footprint Network, in July 2019, humanity had used up nature's resource budget for the entire year 2019 [1]. There is an increasing body of evidence to support this statement: biodiversity loss, soil erosion, and climate change data indicate that we are indeed depleting our natural capital [2]. In this respect, the Sustainable Development Goals report (2019) concludes that, despite progress in policies and tools to anticipate sustainable production and consumption, the global trend is that the material footprint (MF) is ever increasing [2]. Moreover, there is no sign of decoupling between the growth of MF, on the one hand, and the growth of gross domestic product (GDP) or population, on the other, see Figure 1.



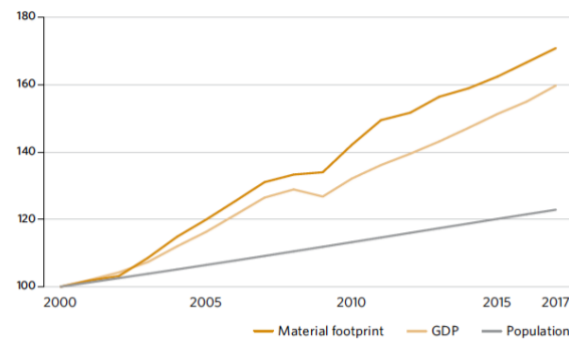


Figure 1. Lack of decoupling between Material Footprint vs GDP growth and population growth
[Source: UN]

In the Netherlands, the concepts of Cradle to Cradle® and Circular Economy receive broad attention. This attention has various origins, one of them being the growing awareness that sustainability measures, as of the 1970s, have fallen short and goals are not met [3]. Alternatives for the essentially linear and wasteful production and consumption systems the Dutch economy is built on are sought in models that aim more radically at retaining the value of resources. This implies keeping these resources in high-grade functional iterations longer, whilst extending the service lives of products or improving recycling potential and management of raw materials. Such developments, however, are in their infancy, and new guidelines and indicators are required [3,4]. Construction, being one of the most material-intensive sectors, is a priority domain in the Dutch circular strategy [3]. In the current Dutch construction sector, a persistent flaw can be distinguished, namely that dismantling, demolition, material-reutilisation, and other end-stages of a building, are not internalised in upfront cost calculations and agreements [5]. This flaw resonates in legal and regulatory frameworks as well, leading to the situation that end-stages are usually associated with additional costs rather than residual value. In turn, this greatly hampers the establishment of business cases revolving around the way existing real estate is valued, both in terms of material stock and societal meaning [6]. Such realisations make it hard to overhaul the existing paradigm. An additional complication is the fact that the Netherlands are generally regarded as an EU frontrunner in construction and demolition waste recycling strategies and practices, which may take away incentives for change in the sector [7].

A two-level approach to construction and renovation or transformation can contribute to the implementation of circular building models [8]. This approach distinguishes two separate levels of decision-making, as already put forward in the 1960s by John Habraken, concerning: a) the collective domain, for example a multi-family building's support structure, and b) the individual domain, for example kitchens, bathrooms, and non-bearing partitions in housing units [9]. This opens up new material-circulation-models tailored to the differentiated service lives and flow profiles of infill components, while the superstructure remains uncompromised. As such, construction and demolition waste (CDW) associated with both levels, can be prevented. Presently, however, there are very few examples of building infill materials and business propositions rooted in a systems perspective, that is, propositions that substantially take account of the various subsystems or domains it touches, think of: raw material sourcing, product manufacturing, real estate facility management, secondary waste logistics, and so on. Even in the furniture sector, which is more familiar with aforementioned product-market mechanisms, such systemic scopes are rare, which is underscored by the fact that associated waste mainly ends up in incinerators or landfills [10]. New innovations, research initiatives, and marketing efforts around circular models for infill products face persistent barriers, both of a technical and an organisational nature. For example, Geldermans et al. (2019) identified multiple obstacles for a 'best practice' partitioning product to perform appropriately in a circular value model, notably with regard to applied chemicals, irreversibility of connections, and reutilisation logistics [11]. More radical system innovations are thus required, including business and value models that entice the industry.

1.2 Delineation, and Objective

In order to explore key enablers for the implementation of systemic circular value models for building infill, we narrow down the scope to a material that is ubiquitously used in the infill domain, from furniture to kitchen cabinets and partition walls, namely: board material. Geldermans et al. (2019) singled out several innovations that could disrupt the status-quo in this respect, specifically concerning natural fibre panels based on renewable raw materials and reversible connections [11]. Based on challenges identified in relation to conventional board materials, enablers for circular value-models are found, above all, in: raw material sourcing, manufacturing processes, reutilisation logistics, and data-sharing [11]. This article focuses on those enablers with regard to one pioneering technology: the Niaga ECOR Panel (NEP). The NEP is a joined product of circular design & materials company DSM-Niaga and manufacturer/technology company ECOR. DSM-Niaga and ECOR developed a laminated panel that can be brought back to its separate parts - natural fibres and synthetic polymers. Two innovations are combined here: 1) an additive free fibre board and platform technology that can use virtually any clean cellulose-based fibre material, and 2) a reversible adhesive technology. Underlying study revolves around the objective to pinpoint enablers for the NEP innovation to perform optimally in a systemic, circular value model.

2. Methodology

A quick-scan study of the NEP is conducted following *Circ-Flex* assessment guidelines (Circ-Flex). Circ-Flex provides a framework within which the performance of the NEP can be assessed from an integrated perspective, addressing characteristics that concern material health, material and product reutilisation potential, and operational context. Below, the guidelines are introduced in more detail.

2.1 Circ-Flex assessment guidelines

Geldermans et al. (2019) developed a set of criteria and guidelines based on three existing assessment schemes that focus on health, well-being, and/or circularity in the built environment, namely: Cradle to Cradle Certified™, WELL Certified™, and Pre Returnable Procurement® [11]. Main objective of synthesising those three schemes was to establish stronger bonds between circular material and product performance over time in relation to the health & well-being of residents, explicitly including whole operational iterations and flexibility relating ever changing user requirements [11]. The original set comprises eight categories and eighteen criteria, which also opened up towards embedded impacts of material and product use, particularly ‘Embodied energy’ and ‘Social fairness’ through the supply, use, and reverse supply trajectory (the ‘value network’). For this study, the focus is on four categories of these Circ-Flex assessment guidelines: Material Health & Transparency, Material Reutilisation, Health & Well-being Awareness, and Integrative Design.

The first category - Material Health - dwells on the “x-listing” of Cradle to Cradle Certified™ (C2C), banning any potentially damaging substances, whilst adhering to the most ambitious level within this certification scheme i.e. ‘Platinum’ [12]. X-listed materials and chemicals are also represented in WELL Certified™ (WELL), albeit distributed over multiple preconditions and optimisations, and in reference to external standards and guidelines [13]. As for Pre Returnable Procurement® (PRP): this scheme is based on provable preserved resources throughout the whole value chain, from resource to resource, realised in accordance with international human rights and relative to ‘absolute circularity’ [14]. The second category - Material Reutilisation - is based on C2C and PRP with regard to design and manufacturing specifications that accommodate material circulation in biological or technical cycles. Furthermore, it includes recovery strategies to secure that circulation can indeed take place. Category 3 - Health & Well-being awareness - is adapted from WELL, focusing on the importance - and current lack - of health literacy for end-users of buildings, as well as for other stakeholders throughout the value network. This concerns the degree to which individuals can obtain, process, and understand basic health information associated with the infill component in question. Lastly, Category 4 - Integrative Design -

is rooted in the notion that feedback loops for product & service development and performance result from - and inform - co-creative processes. Only a collaborative design process ensures that construction and upkeep of a space, as well as reutilisation of parts, follows the intended expectations and goals [13]. Table 1 lists a selection of Circ-Flex assessment guidelines with a brief explanation and potential assessment means. Data sourcing can be performed on various levels, depending on availability, accessibility, transferability and confidentiality of data. A thorough, comprehensive assessment is estimated to take a substantial amount of time and commitment from data-owners. A quick-scan assessment, however, can already provide valuable insights, and pave the way for a more advanced elaboration.

Table 1: Selection and summary of Circ-Flex assessment guidelines

Category	Explanation	Assessment
<i>Material Health & Transparency</i>	Identification of applied materials, up to the raw material level, in product, manufacturing process, and product operation. As well as potential emissions on short and long term.	Bill of Materials (BoM); Test results; Appropriate certifications; Supplier declarations
<i>Material Reutilisation</i>	Anticipation of specific cycle - biological or technical - in (reversible) design and operation.	Designated reutilisation pathways, for example as part of the Bill of Materials; Reutilisation score concerning recycled and recyclable content, for instance adhering to the Material Circularity Indicator (MCI) [15]; Management strategy for parts and ingredients; Collection and reutilisation programs; Actual collection and reutilisation data; Test results
<i>Health & Wellbeing Awareness</i>	Provision of information and guidelines throughout the whole value network, including building end-users.	Documentation and professional narrative concerning components and handling; Educational materials; Accessible databases/libraries
<i>Integrative Design</i>	Facilitation of co-creative processes towards continuous improvement of value chains.	Thorough and transparent agreements and feedback mechanisms throughout stakeholder network

3. Case-study description: material innovation and value network

As stated in section 1.3, ECOR joined forces with DSM-Niaga to develop a board panel that can be combined, separated and reutilised over and over again. This product is called the Niaga ECOR Panel (NEP). Envisioned markets are, for example, furniture, partitions, kitchen cabinets, event and stand building products, and retail displays. The NEP is manufactured from pure cellulose fibres and synthetic polymers. The fibres come from residual flows, such as agricultural and horticultural by-products, paper and cardboard industry leftovers, woody construction & demolition waste, and textile remains. The polymers are widely used in the industrial and coating resins industries. Raw ECOR panels of 2.5 mm thickness (called FlatCOR) can be reversibly laminated together with Niaga® adhesive under specific

conditions: temperature, humidity, and pressure. Alternatively, a honeycomb core can be applied to reduce weight while adding thickness, and the raw product can also be finished with decorative top-layers.¹ The NEP has a Technology Readiness Level (TRL) of 6-7, which means it is currently being tested in operational settings. After an initial service life, a NEP can be reused directly or through a refurbishing step, to the extent its technical lifespan allows. Ultimately, NEP can be recycled following a technical pathway (synthetic polymers and natural fibres) and a biological pathway (natural fibres). The diagram of Figure 2 represents the NEP innovation. Figure 3 shows raw materials (in this case beer brewery grains), raw FlatCOR boards, reversible adhesive pellets, and various NEP products.

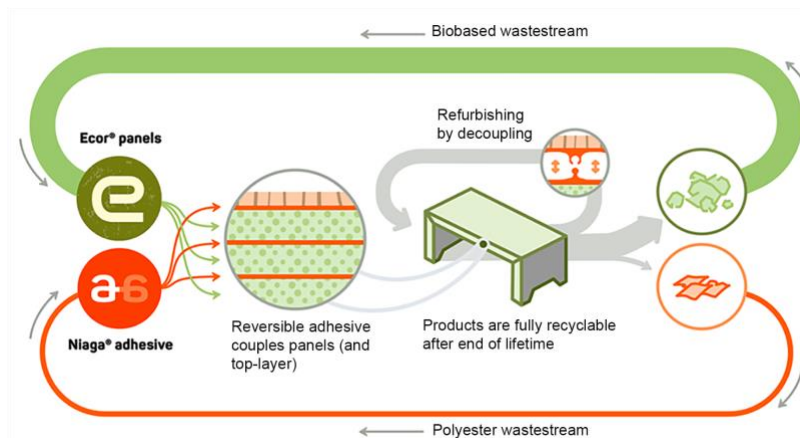


Figure 2. Visualisation of Niaga Ecor Panel innovation [Adapted from source: Niaga Ecor]



Figure 3. FlatCOR panels (left), Niaga pellets (centre), and Niaga Ecor Panel products (right) [Source: Ecor]

Applying the NEP in circular configurations means it needs to be examined concerning appropriate supply, operation, and reverse supply pathways. To that avail, Ecor focuses on locally sourced secondary raw materials and partnerships based on operational excellence, whilst exploring the options for take-back systems. Locally sourced materials may comprise any cellulose fibrous material currently wasted or applied in low-value processes. Most applicable clean - post-industrial - rejects can be used by Ecor in value-adding process steps. With regard to transport distances, the basic rule is that raw materials are sourced within a range of 250 km. Operational excellence refers to the notion that the quality - and *circularity potential* - of board materials is retained over time, thus including future interventions and relocations. This implies, for example, clear agreements concerning the use of surface or insulating layers, and reuse iterations. Envisioned value-cases revolve around Ecor retaining ownership of the product or ownership is outsourced (to the client). In both cases, the product-narrative dictates that intrinsic health and circularity potential disappear when the product becomes degraded. For

¹ For the sake of simplicity, only the raw panel and the Niaga adhesive are considered in this study. Top-layers and potential additives are left out of the equation, even if these may be part of specific requirements, for example with respect to fire-safety: different rules may apply for different product categories or geographical areas.

example, due to contaminations with unfit paints or other decorative or protective surface coatings. At this moment, ECOR works largely in direct contact with the client, in order to keep prices low, feedback loops short, and take-back opportunities intact. However, in the future, other value networks are imaginable.

Figure 4 is an example of a traditional linear supply chain around board products in the Netherlands. Displayed are five different activity categories that currently play a key role in the associated value chain: raw material production; manufacturing; wholesale & retail; on-site construction, use, and maintenance; waste treatment (in Dutch context for example shredding and incineration with energy recovery). Figure 5 shows an envisioned circular variant with validity for the NEP. Traditional waste management steps are left out of the equation in this model, and a logistical epicentre is added with regard to alignment of supply and demand that goes beyond the initial actors. Many different flows are imaginable in a circular configuration: board parts can move between nearly all of the networked actors two-directionally, depending on the quality-status of the product at the time of intervention or relocation, and depending on market mechanisms and maturity of the value network. With regard to the NEP, specific value networks are in preparation, see also Sections 4 and 5.



Figure 4. Common linear value chain associated with board materials [Source: Geldermans et al. 2019]

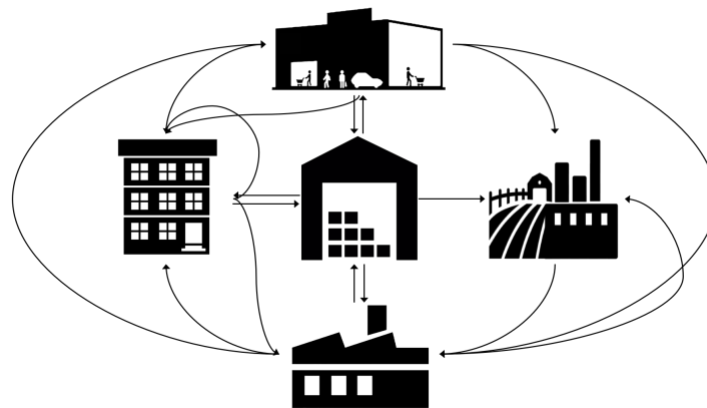


Figure 5. Elaboration of a NEP value network [Source: Geldermans et al. 2019]

Geographical scale levels, which the NEP may cross in value-adding iterations, are depicted in Figure 6. The core circle concerns a collective urban spatial typology where multiple households and workspaces are united, this could be a neighbourhood as well as a large building block. This ‘block’ is located in a town or city environment, which is part of a city region, province, and so on and so forth, all the way up to the global scale, if applicable for the supply of product ingredients. Figure 6 is based on the assumption that the fibrous ingredients can be sourced locally, with limited transport miles. In this case, that means: regions in the Netherlands or just over the border, taking account of the current production-facility (Venlo, The Netherlands, near Germany).² Generally, there is a large potential of -

² At this moment, FlatCOR production takes place in Serbia. Future production locations can be anticipated in relation to product manufacturers and projects, such as large scale urban developments including residential and commercial typologies.

secondary - raw material supply for the NEP fibres to tap in to, which is currently channelled to low-end waste management steps [11,16]. For the polymer ingredients, at this moment the NEP depends on transboundary supply. The reversible adhesive concerns a synthetic polymer based on regular chemical feedstocks. The polymer is produced in Germany, raw materials may come from a variety of origins in Europe and beyond. In relative terms, primary feedstock will diminish over time, as the polymers are recycled.

Wholesale and retail facilities may play a role in future value networks around the NEP. Such facilities are expected to be located relatively close to the block/neighbourhood in question, that is, within the city region. Furthermore, logistics and storage facilities are envisioned to connect flows between the various activities on supply and demand side. In an elaborate circular model, such facilities can be imagined as part of a network, connecting dots throughout the Netherlands.

Figure 6 thus distinguishes the five activity groups of Figure 5: ‘Construction, Use, and Maintenance’ activities on Block or Neighbourhood level, ‘Wholesale and Retail’ activities on the regional level, ‘Logistics and Storage’ activities on regional and national levels, ‘(Re-)Manufacturing’ on the national level, and ‘Raw Material Production’ on regional and national for the fibres. Chemical feedstock for the polymers currently follows a global market, hence the dotted line in Figure 6.

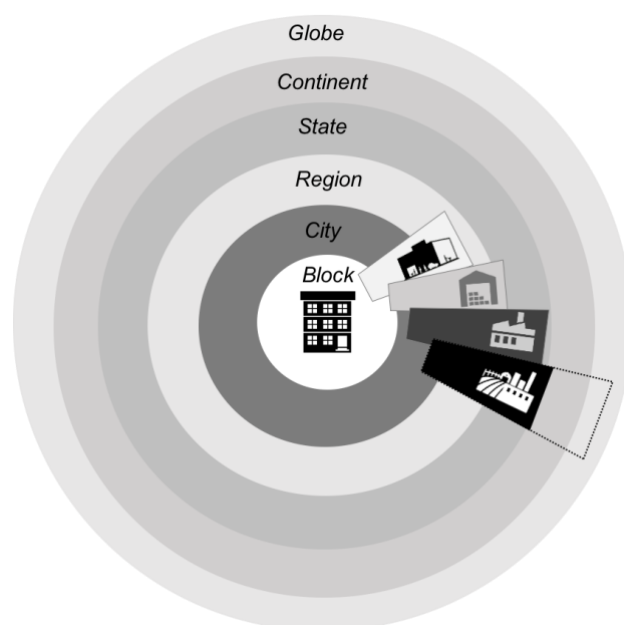


Figure 6. Geographical scale levels associated with the Niaga Ecor Panel

4. Circ-Flex Assessment of the Niaga-Ecor Panel

Table 2 lists the results from a quick-scan Circ-Flex assessment of the NEP product, based on the case-study description in section 3 and discussions with stakeholders from Ecor and DSM-Niaga. It is shown that, although required levels of detail are often not readily achievable, important assessment parameters can be pinpointed, particularly concerning stepping stones on the roadmap towards an envisioned goal. This is a challenge with regard to a comprehensive Circ-Flex assessment, but sufficient for a quick-scan analysis (see 2.1). A decisive factor at play in the case of NEP, is the Technology Readiness Level (TRL). Which is estimated to be 6-7. At this stage, multiple tests – in labs and co-creation settings – are done and results are still underway. Furthermore, allocation of budgets is aligned with the TRL level, and certification trajectories have been initiated. Last but not least, operational excellence and commercial scale-up is in preparation, but has not yet had the chance to build up further evidence. In the discussion section, multiple aspects of Table 2 will come back.

Table 2. Circ-Flex quick-scan assessment Niaga ECOR Panel

Category	Niaga Ecor Panel: raw panel	Niaga Ecor Panel: reversible adhesive
<i>Material Health & Transparency</i>	<ul style="list-style-type: none"> • Appropriate certification (C2C Certified™ [12]) which includes <ul style="list-style-type: none"> ▪ Bill of Materials ▪ Supplier declarations regarding composition of raw materials ▪ Test results EOX & AOX emissions ▪ Test results particles: Cadmium, Hexavalent Chromium, Lead, Mercury, Arsenic, and Halogenated hydrocarbons (bromine, chlorine and fluorine containing compounds) • Material ID: FlatCOR Panels part of Circular-IQ registration system³, including declarations on material health in line with C2C® and the European Chemicals Agency registration system (REACH) 	<ul style="list-style-type: none"> • Material ID: Niaga® adhesive is registered at Circular-IQ, including declarations on material health in line with C2C® and the European Chemicals Agency registration system (REACH)
<i>Material Reutilisation</i>	<ul style="list-style-type: none"> • Appropriate certification (C2C Certified™) • Reutilisation score part of Circular-IQ report • Use of top-layers to safeguard panel quality • Preferred finishers such as natural oils, Graphenstone paints and varnish • Designated pathways: differentiated technical and biological flows • Management strategy for material reutilisation in place • Return and reutilisation program 	<ul style="list-style-type: none"> • Designated pathways: refurbishing and recycling of Niaga ECOR Panels, enabled by Niaga® adhesive • Management strategy for material reutilisation in place
<i>Health & Wellbeing Awareness</i>	<ul style="list-style-type: none"> • Storytelling: prominent professional narrative with regard to, amongst others, health and circularity. • Set-up of Circular Economy Materials Excellence Centre (CEMEX) targeted at a diversity of stakeholders, not yet including building end-users. • Guest Lecturers at business schools, 	<ul style="list-style-type: none"> • Storytelling: prominent professional narrative with regard to, amongst others, health and circularity supported by DSM's Niaga® brand, endorsed by other product categories, notably: carpets and mattresses

³ Circular-IQ is a Dutch initiative, set up to streamline the digitisation of existing data hidden in documents as well as the collection of new data, including the information coming from supply chains. Circular-IQ – closely linked to the Cradle to Cradle Certified™ measure – enables collaboration of internal and external teams including suppliers and their suppliers [17].

	universities, local and global learning programmes <ul style="list-style-type: none"> • Databases filled, maintained and governed by ECOR R&D B.V. 	
<i>Integrative Design</i>	<ul style="list-style-type: none"> • Feedback mechanisms throughout stakeholder network. At this stage, not yet including residential end-users • Experimental stages with a diverse group of NEP stakeholders • Product co-creation with community of designers and craftsmen 	<ul style="list-style-type: none"> • Circular design according to Niaga® design philosophy: 1) Keep it simple; 2) Clean materials only; 3) Use reversible connections [18] • Product co-creation with community of designers and craftsmen

5. Discussion

In this discussion section, we reflect on the research through the lens of circularity as a systems innovation, focusing specifically on four interrelated stages in Circ-Flex partitioning configurations: raw material sourcing; manufacturing; use; and reutilisation. Only when those stages are well integrated into circular value propositions, SDGs can be anticipated appropriately. Particularly relevant in this respect are SDG11 (Sustainable Cities and Communities) and SDG12 (Responsible Production and Consumption), but links also exist with SDG3 (Good Health & Well-being), SDG9 (Industry Innovation and Infrastructure) and SDG13 (Climate Action). Although all these stages are acknowledged by ECOR and Niaga, some are more thoroughly anticipated than others at this moment in time. This also resonates in the adherence to certification systems, notably C2C Certified™ and Circular-IQ, of which the former has a more developed and well-documented track-record.

5.1 Raw material sourcing

The currently produced ECOR Fiber Alloys® are produced using - mixes of - old corrugated cardboard, paper fibres, and paper industry rejects. The selection of ECOR panels over other available fibre boards have been based on the compatibility of circularity and health standards that both the Niaga Adhesive as the ECOR panels hold. Tailoring ECOR panels for optimal product and production performance has not been investigated in depth to date, but can become a decisive factor in the choice of ECOR Fiber Alloys®. Consequently, this will have an impact on the choice of raw material input. For the production of Niaga® adhesives, raw materials are selected out of readily available polymer building blocks for Polyesters applied in industrial and coating resins. In general, oil-based polymer building blocks are used today, while a growing range of recycled and bio-based polymer building blocks become available as well. As yet, it is unknown how exactly this will evolve.

5.2 Manufacturing

Responsible production of ECOR panels is independently being assessed as part of the C2C certification process. These panels are relatively straightforward laminated into NEP panels or NEP furniture panels which include non-ECOR finishing layers such as HPL or veneers, whilst fulfilling customisation and protective functions. Manufacturing processes associated with such top-layers thus require separate assessments in relation to Circ-Flex performance. To the best of the authors awareness, there are currently no HPL products that comply with the Circ-Flex criteria, due to inherent production specifications. For veneer products, in theory, Circ-Flex compliance would be less complicated. However, this is beyond the scope of this paper and requires further research. Furthermore, running tests

in labs and operational settings will further inform the manufacturing process, as well as their impact on the Circ-Flex performance.

5.3 Use

As the circular economy aims to keep its elements in the highest value possible, the use-phase of the NEP now becomes essential for its recovery potential and the related residual value. Currently, ownership of NEP is transferred in every step of the value chain. It puts an incentive with every owner of a NEP panel to educate and document downstream supply chain in order to preserve its value. This is now done by implementation of a radical transparency strategy. It covers testing and documentation of panel use as well as applied finishers through a material ID - or passport - system. Take back for recovery will only be offered when optional finishing takes place with approved products, monitored and documented over the product's service life. By leaving the ownership at the customer level, a business model can be based on transforming customer (waste) material into NEP by recycling, refurbishing, and re-attaching (decorative) finish layers. This gives the customer freedom of choice regarding selection of input materials, and thus sustainability and health performance.

An alternative business proposition could be based on keeping ownership with the supplier, opening up to pay-per use, buy-back and deposit models. This offers the potential to increase recovery rates of products. However, it also increases complexity, as every individual panel needs to be assessed with regard to contamination and - guaranteed - health performance. When rejected, costly cleaning and separation processes need to be put in place, potentially undermining the viability of such models. Moreover, those models touch upon the topic of 'ownership as a human right', which is differently perceived globally, and which may be a threat to operating and scaling these business models [19]. Aforementioned considerations underscore the complexity of engaging the residential end-user as an active participant in the value-network. Personalisation through top-layers, as referred to in subsection 5.3, will impact the level to which such end-users become empowered, and hence further define the NEP value model development.

5.4 Reutilisation

When scaling NEP production globally, the selection of panels could become a critical variable for production and reutilisation performance. Choosing a uniform ECOR panel, tailored for optimal NEP and production performance, potentially limits fibre availability and/or could increase origin of source fibres beyond regional scale. Eventually even a choice for virgin fibres could become a viable possibility to safeguard future regeneration in a circular economy. However, sourcing panels out of regionally developed ECOR panels using various locally existing waste streams could potentially influence production, and even product metrics, and therefore pricing and performance.

Lastly, to reduce contamination risks, communities of like-minded designers and manufacturers are being built. In the development of new material product combinations, they jointly search for the best available solutions that preserve the NEP panels' integrity, so reutilisation cycles could be operationalised appropriately after a product's service-life.

6. Conclusion

Results from tests in labs and operational settings are still underway and will impact further development pathways of the Niaga ECOR Panel (NEP). Nonetheless, the findings indicate that NEP enables circular infill configurations, with regard to intrinsic material characteristics as well as reutilisation strategies. Furthermore, knowledge dissemination and co-creation are an integrated part of the NEP value model. Bringing the innovation to scale will put more emphasis on alignment of stakeholders, not least with respect to ownership, take-back, and end-user involvement. The outcomes are deemed relevant for multiple infill components, such as partition walls and kitchen cabinets, but also side-sheeting in energy renovations.

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