Rethinking Biowaste Supply Chain as Innovation

Case study on mycelium-based products for MUSH Materials

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Abstract

Purpose

The purpose of this thesis is to propose some possible ways on how supply chain managers can support designing a scale-up plan for a bio-waste company. The case firm chosen is MUSH Materials, a start up in the field of mycelium manufacturing. Furthermore, it is a wish of the author to give more visibility to a firm like Mush Materials and others who deal with mycelium production.

Research design and Methodology

This is an exploratory research, where the author collected qualitative data through a systematic literature review and semi-structured interviews. The approach will be that of a case study, where the role of the author will be that of the observer-as-participant studying the subjects in a set time horizon.

Findings

The analysis offers an application of Product life cycle, Four Vs and Four Ps framework to the mycelium industry and proceeds to suggest solutions in the phase of Procurement, Distribution, Capacity, Process Design and Performance Management as parts of the structure for a scale-up in the supply chain. The Conclusions are a series of recommendations to the firm and all posterity for each of the most important areas found. There are presented through short-, medium- and long-term solutions

Research limitations

The author acknowledges the limitations imposed by the researcher's bias and errors.

Academic implications

Hence, the ultimate goal of this case study is to investigating Waste Management as a Branch of Environmental Innovation Management: this is in itself a source of innovation. Plus, the use of modularity, as means of scale up through changing the architecture of product and production process. This helps studying Sustainability issues with an Operations Management perspective. This paper precisely offers an example of interlinking Operation management, Sustainability research, and a case study.

Empirical implications

A case study with context and evidence-based solutions are what business and society need, and specifically Mush Materials needs to figure out how can be impactful in its business environment. Lastly, this paper represents a "translational research", turning research results on mycelium into easy-to-use practical tools.

Future research

Future research can be surely done around future applications of mycelium. In particular, conducting a SWOT analysis in other markets can highlight new opportunities for Mush Materials.

Introduction

Businesses have a huge potential to change the way we live. Influenced by governments and consumer demands, companies have the power to shape our economies and lifestyles. It is fascinating to see how businesses are created, cooperate, compete, invest in research & development, so they can deliver the best and come up with new products and services.

However, the increasing size of a consumer's basket of goods is leading to more waste being generated, for which not enough recycling systems are put into place yet. This calls for a dramatic change in the currently less than optimal waste management systems through the promotion of positive changes and the redefinition of the *status quo*. In mathematics, the commutative property assesses: "by changing the order of the addenda the result won't change" that is precisely why to change the present status of matters we need to redefine the addenda, that is the current parameters until the result meets our expectations.

The interest in finding the right solution to this dilemma stems from a personal interest in Operational Sustainability. In fact, throughout the CBS Supply chain management master's degree, it appeared clear that all of the author's past projects had this as a common thread and most discussions with peers lead to an exchange of information on this topic. As well as a personal drive to implement the available knowledge in the field of Operational Sustainability, during her academic studies, the author became aware that, even if it is a hot topic in the Danish acolytes' community, there is still a general lack of Operational responsiveness on Sustainability. In other words, Academia and Companies all agree that there is indeed a need for filling the gap in the lacking literature, in response to the increasing demand in the market.

This paper will argument on the ideas that Waste Management should be a part of Innovation Management and that writing about handling waste should also mean proposing effective and efficient innovations of products and processes, rather than perpetuating past and present practices. In the Literature analyzed for this project, these research areas have always been studied as two separate and distinct entities, and often thought to be at the opposite ends of supply chains. Nonetheless, the purpose of this analysis will be to integrate them and fill the gap, emerging with an innovation-driven perspective on waste management issues. Attempting to create a new literature thread would take far more than

just one paper, so here, the main focus will be to explore if such a link is feasible by applying the proposed interdisciplinary approach to a practical case.

To do so, out of all the discarded materials to be studied the writer selected the laminated wood, as it is one of the most predominant contributors. Its massive use is linked to the low-cost production, the availability of various types of thickness and shapes, its property of sturdiness and impact resistance, which makes it a reliable and lightweight material, while, at the same time, guarantees chemical resistance and surface dimensional stability (Böhm et al., 2012). In conclusion, it is a material hardly beaten by any other possible alternative and substitute with similar features. Particleboard is used in the creation of many products, from pieces of furniture and internal structures to dock's and ship's building to stage and cinema props! It would be very hard to find any indoor or outdoor environment which is not made, at least in part, by this material.

Highly customizable and cheap material, while easy to buy and sell, it is also infamously known to be an omnipresent material in legal and illegal dumpsters. Final disposal of particleboard continues to be a major concern for the following reasons: 1. Its life span is can be up to 20 years, depending on the type of wood and glues applied, while its uses are typically one-time off; 2. Reuse possibilities are limited due to strength and since recycling options are often overlooked in favor of inferior alternatives, such as combustion which has some calorific value; however, the burning of particle board also releases harmful air pollutants (Böhm et al., 2012). Unfortunately, specialized arrangements required to dispose of particle boards are often not available in normal waste management structures and this is the more reason to support the use of a novel approach to Waste Management practices looking from the Innovation Management perspective.

Some might say that the quickest and easiest way to deal with the critical situation of particleboard waste would be to find better ways to dispose of it, however, a more insightful solution would be to remove it from our environment. Many people have seen the detriments of uncontrolled accumulation of laminated wood's waste and have invested in developing alternatives that are recyclable or better yet biodegradable. One of the more interesting candidates are the Mycelium based materials, which will be described in more details in the following paragraphs.

Indeed, studying the mycelium material under the Operation Management scope is extremely proficuous considering the issue of waste disposal, since this discipline's acolytes pride themselves to be experts in dealing with optimal allocation of resources. For this reason, researchers in this field may have to challenge the attitudes shown so far by tackling this problem with any method and tool available and bring to the discussion table both operations and other disciplines experts, in order to research and develop strategies and solutions in line with the modern issues.

Focusing only on the operations perspective, might turn out to be a high-risk strategy - and to some extent already has - nonetheless the impact and relevance of an innovative approach, as well as the eventual rewards, are enormous. If Operation Management (OM) continues to focus only on technical operational topics at hand, it may doom itself to become of scarce relevance: OM researchers may face what can be defined as their own discipline's sustainability. If this discipline is to continue to thrive and be prosperous, it should reinvent itself and make stronger contributions in the sustainable development area chain (Van Wassenhove, 2019). This study is aimed to be also a wake-up call and an invitation to the dance, to push the boundaries of OM discipline, by being innovative, and strongly contribute to a more sustainable and happier business world!

Furthermore, Operations Management is the best approach to study waste-related issues, since its focus on promoting efficiency, *alias* doing more with less, and its practice-oriented body of literature represents a fertile soil to foster innovative solution in terms of the end products of a supply chain (Van Wassenhove, 2019). For this reason, it can be noticed that across the literature, closed-loop supply chain research has become mainstream. It has merged with similar efforts in product recovery and concern for environmental and social footprints of supply chains, rising a broader field the author now prefers to call Sustainable Operations (Kleindorfer et al., 2005).

Ideally, it would be best to spread a more environmentally friendly culture in consumers' and entrepreneurs' minds, but a more immediate way could be approaching this issue from an operational point of view. It is the belief of the author, that however noble, the idea of changing people's cultural attitude toward waste recycling is a long-term oriented goal and such transition should be aided by the introduction of more sustainable alternatives to today's most popular materials. In other words, even if it were possible to achieve a shift in

the global mentality toward a greater awareness of produced waste, how could the ever-changing humans' needs and requests be satisfied if there are no alternatives available?

This paper aims to introduce a very promising alternative to particleboard: mycelium-based substitute. The goal of this project is to study the design of a supply chain producing particleboard that, instead of chemical glue, uses fungal (mushrooms) mycelium as collant or binding agent. The final product has similar performances and applications and can be disposed of simply by throwing into the soil: it will degrade naturally because, as will be discussed later, it is made of mushrooms and agricultural waste. This innovation has the potential to change the laminated wood industry.

This thesis case study on the Mush Materials company will be investigating their recent mycelium-based substitute for particleboard. The research question will explore how their current supply chain can be scaled up to take over, at least a part of the building industry market.

Summing up, the research question, this paper will try to understand, analyze, and answer to, is the following:

How can supply chain managers support designing a scale-up plan for a bio-waste innovation company in the processed wood industry?

The research question will be analyzed, at first, through a literature review of the most recent and relevant peer-reviewed articles. A summary of the main focal points - indicated as Statements S1, S2, S3, and S4 - will be provided and used as a guiding principle for the later analysis section. Subsequently, the case study will be introduced, along with a description of the product and of the mycelium, and finally, a series of short-, medium- and long-term recommendations will be suggested to the case's company with all the related limitations, academic and empirical implications, and suggestions for future research.

Literature Review

In this section, the paper will analyze the current development in Waste and Innovation management literature. This is a huge literature, so the paper has set some criteria to narrow down the research as explained in the Methodology section.

Traditionally, innovation came from the input of universities scholar or experts in a certain field of study. However, the present review has revealed that, much like everything else in the modern economy, innovation is driven by customers' needs. Furthermore, rather than the result of activities taking place in single firms, innovation is the result of their collaboration: the wider the span of the networks, the faster the rate of change. The rate is also influenced by how transparent supply chain managers build their work as it impacts the chance to support current partnerships and encourage future ones (Klitkou et al., 2019). Additionally, following the advent of the supply chain discipline, innovation studies have undergone significant change. As it will be shown later, besides having a clear concept of what innovation is and does, it is of paramount importance to study its evolution throughout the whole supply chain. When designing a scale-up plan, any supply chain manager should look at the customer's perspective (Galliano & Nadel, 2015; Stucki, 2019). As a result of the executed systematic literature review (SRL) 4 main themes or topics were found to be recurrent throughout the sources: Innovation for sustainability, Importance of partnerships, Focus on the wood and furniture industry, and Customer perspective on sustainable innovation.

Environmental Innovation As A Core Value

The first theme is introducing to the reader the background of innovation in the field of Sustainability, to understand how it became integrated into the new product development. It is thought that this idea was introduced at the beginning of the 21st century through the broader concepts of eco-design and the application of life-cycle assessment, as a method of eco-design support (Luiz et al., 2016a). Across the first decade, environmental New Product Development (NPD) and Eco-design were established as a united field of study and practice, and their research objectives gravitated toward finding strategic and organizational implications for further applications. The most recent phase has been characterized by the

expansion of this area of studies, with the inclusion of the social dimension, which resulted in the supply chain design for sustainability and with extrapolation of NPD, which introduced the concepts of green innovation and product maturity, models. This phase has also produced a wide variety of studies on the tools and practices applied in eco-design and the identification of the main barriers and incentives for their adoption (Luiz et al., 2016).

As a result of such evolution, academics and practitioners have coined a specific term for this particular field of study: "Environmental Innovation" (Adams et al., 2016; Klewitz & Hansen, 2014; Watson et al., 2018). This term represents the subset of sustainability-oriented innovations concerning the environmental dimension of sustainability. It is defined as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use compared to relevant alternatives" and this paper will adopt this definition. (Watson et al., 2018). Environmental Innovation is a quite complex area of study inside the wider field of Innovation Management: it challenges the firm's capabilities in terms of knowledge creation and technology development, it sets a higher degree of novelty, uncertainty, and diversity, and has to face low customers' willingness to pay for the reduction of negative externalities (Costa-Campi et al., 2014; Souto & Rodriguez, 2015).

As previously anticipated, Environmental Innovation springs out of multiple stakeholders' interactions that go beyond the mere sharing of information. In this regard, recent stakeholder engagement literature shows that companies that move from informing to involving stakeholders develop internal capabilities that reduce their resource dependence uncertainty (Herremans et al., 2016) and suggests that stakeholder relationships can deliver innovative "win-win" solutions (Eccles et al., 2014). In other words, any attempt to develop innovation across different parties is a means to decrease supply uncertainty and more importantly leads the involved player to get invested with each other and implement mutually beneficial solutions.

However, other authors believe that this awareness is still latent and not acknowledged enough, referring to the bio-economy transaction (the branch of the Environmental Innovation that concerns any business relating or implying working with living and organic

matter), they counterargue that public awareness of the bio-based transition is limited (Koppejan & A, 2011; Pesch et al., 2010). Besides, some others, like Sleenhoff et al. (2015; 2016), go even further and claim that public representation of a bio-based economy can only be found on a theoretical and idealistic level and it is currently non-existent in the real world.

At the same time, a softer and a middle position is proposed by some through a modular approach (Paparoidamis et al., 2019). According to this author, there is no need to transition to a completely sustainable product, as long as producers make available sustainable add-ons to their present product portfolio. In other words, to sell it would be sufficient to replace part of a certain item with sustainable features or detachable components to gradually gain and engage consumers: "Firms should consider developing eco-innovative attributes as optional/detachable accessories because consumers are often uncertain about their new eco-friendly product purchases. It would be useful to employ experiential marketing techniques to highlight the detachability of eco-innovative attributes." Here, modularity is presented as a means to incorporate sustainable innovation like new and environmentally conscious attributes that are additional options and "is more advantageous than doing so in base products and the core locus" (Abdelkafi et al., 2018; Paparoidamis et al., 2019).

In conclusion, the underlying assumption is that all companies will be able to decrease the environmental impact of their product through the design of the overall product or part of it. Nevertheless, being able to and being efficient and gain competitiveness is not always directly correlated, and here lies the crux of the matter. This has been extensively discussed in the academic community, as always is the case when a massive innovation is changing the business environment. Isomorphism theory would suggest that only the most adaptable would survive over time englobing the smaller players (Jaja et al., 2019). On the other hand, it has been demonstrated that, mostly in Europe, only companies that have adopted the sustainable way of thinking wholeheartedly from the beginning are capable of integrating it in their procedures and gain a competitive advantage from it (Beske & Seuring, 2014; Harms, 2013; Kriechel & Ziesemer, 2009). Operational Sustainability is not a process that gives results in the short term; thus, good motivation is fundamental for the positive outcome of environmental innovation. As a result, in the words of Beske et al. (2014): "Only companies with sustainability as a core value appear to take the extra effort of transforming

their supply chain, or at least parts of it, into a sustainable supply chain and use such an “opportunity oriented” strategy for a competitive advantage"(Beske & Seuring, 2014)

In conclusion, it is possible to summarize the above-cited sources, both contrasting and agreeing sources with the following statement:

S1: “*Most authors agree on the existence of a particular branch of Innovation Management, that deals with environmental impact. At the present, the level of awareness is fairly low, and it is very context-related and business-specific. Sustainability must be a core value for a successful implementation of environmental innovation processes*”

Partnerships

When talking about recent innovation is a good practice to investigate the environment in which is fostered. Surviving and thriving in the business battlefield with an innovative product is not at all an easy task and if the size can help counterbalance the financial risks, it does not necessarily mean that big ones are going to succeed on their own. Large firms may be more exposed to various environmental pressures, either from the government or from other stakeholders (Lin & Ho, 2011). Therefore, large firms may be more likely to deploy their resources and capabilities toward the adoption of green strategies to improve their environmental performance and enhance their green image.

As the institutional theory (Hsuan et al., 2015) suggests, corporations may receive the support of smaller and highly innovative partners to manage common problems such as complying with new environmental regulations, as well as obtaining legitimacy and credibility from influential stakeholders (Hsuan et al., 2015). Moreover, from the resource-based theory point of view, partnerships may help businesses access diverse resources and capabilities not existing within a single firm, especially with the state of the art innovations (Bigliardi et al., 2012). In the specific case of sustainable products, partnerships are not only boosting performances in terms of profit and time-to-market but also create a positive environment to fuel more change and increase the innovation rate. The organizational mechanisms of cooperation between firms exceed the open innovation logics, in terms of focus on the collective creation of favorable conditions for the emergence of new industrial

ecosystems, such as the ones built on biological materials, like the mycelium- based ones (Hooge & Le Du, 2016).

In this regard, partnerships are the fertile soil in which innovation can grow its roots and several articles highlight the importance of collaboration between firms and university born start-ups to accelerate the upgrading process (Klitkou et al., 2019). Such partnerships are both operational support and of knowledge sharing nature: these combined are utterly important to keep the innovation rate high and implement the learning and knowhow acquisition process. Both formal and informal knowledge transfer is needed for partnerships to work out and produce a solid innovative product/process (Grimpe & Hussinger, 2013). Formal knowledge is collected and transferred according to a common code, e.g. procedure, a licensed patent; whereas the informal one is the tacit knowledge surrounding a specific technology and the experience gathered during its implementation. In order to transfer a full knowledge of a component is pivotal also without the related competence to operate with it. Therefore firms, which are interested in setting up a relationship with a university to transfer knowledge and technology, should be well aware that the full potential of these relationships can only be realized if both the transfer channels are used (Grimpe & Hussinger, 2013)

In this sense, establishing permanent relationships with universities, with varying degrees of formality or informality, seems to be key in enhancing the development of expertise also outside the same universities.

During the Systematic Literature Review (SLR), was found that interaction with universities has an additional value. When exploring the functioning of the new bioeconomy, to which mycelium manufacturers belong, it is best to take an interdisciplinary approach. Such a method is mainly applied in academic settings, where people are encouraged to think on a theoretical level and then extract cross-functional results that can be applied to a variety of fields. Many recent articles strongly suggest that a multidisciplinary approach is key to new bio-economy companies, given their lack or scarcity of academic and environment-specific knowledge and competencies, that can be translated and successfully applied to different areas (Bigliardi et al., 2012; Borge & Bröring, 2017; Dingler & Enkel, 2016). In this new light, interdisciplinarity is seen as a concept that

brings together different disciplines or areas of research and practice to work together on a specific problem, such as a case study (Szostak, 2016).

On the other hand, not all authors endorse this logic. An often-remarked counterargument states that is it utterly unrealistic trying to implement Operational Sustainability based on collaborations. The topics and contents of a partnership are, in fact, heavily reliant on the stakeholders and competitors involved, as well as by the context in which they operate; so It is really hard to draw generalizable conclusions from this premise (Balasubramanian & Shukla, 2017). This is especially true in the case of the particleboard industry, where the number of players and competitors is high since this component has been a well-known and popular material for a long time. Moreover, this sector is also characterized by one-off contracts and by repeated failures to develop longer-term and stable relationships between stakeholders (Dainty et al., 2001; Dubois & Gadde, 2000). Henceforth, the construction supply chain has a reputation for low-trust and adversarial trading relations between supply chain stakeholders (Trigkas et al., 2012). For these reasons, many believe that the introduction of new material is essential to promote an actual positive change in the industry and its established practices.

Lastly, after the analysis of the current and contrasting views, the following can be said:

S2: "*Environmentally sustainable innovations thrive when solid partnerships are established, and universities are involved. However, they can't be long-lived if not supported by the introduction of new materials and designs that replace old ones with a better environmental performanc*e"

Wood Waste In The Furniture Industry

In the context of Innovation Management as previously stated it is of fundamental importance a good understanding of the various stakeholders involved and their interactions to study any phenomenon taking place in such area. During the literature review conducted, a third recurring motif concerned the topic of innovations in the field of waste management.

The most important and quoted conclusion, given by several study analyses conducted in the wood and furniture industry, is that this market is characterized by a profound need for "going green" since the modern tools and techniques have been granting a cost-efficient but certainly not sustainable output. Most notably, the study presented by Trigkas (Trigkas et al., 2012) underlines the importance of clean innovation in the industry under exam and denounces an utter lack of competitiveness when small and medium businesses trying to implement operational sustainability. Stated differently, the absence of a strategy concerning innovation and utilization of the relative expenditures in the wood and furniture sectors is preventing incumbent companies to evolve their portfolio in this direction.

According to many authors (Klitkou et al., 2019) and this same paper's introduction, it has been postulated a shift in the source of innovation for modern business.

This point of view is also supported by Trigkas et al. (2012). Namely, "A characteristic of the innovation system in the wood and furniture sector in the EU region is that the majority of the enterprises are developing co-operations with innovation organizations of different types." (Trigkas et al., 2012)

However, some authors argue that this might not to be true the industry selected, the laminated wood sector, is heavily reliant on internal and suppliers based R&D rather than on universities or other institutions, due to the general lack of acknowledgment among the sector's players of the central role that specialized institutions could play (Arantes et al., 2015; Trigkas et al., 2012).

Furthermore, the design and management of a supply chain in the construction industry is a complex task. The first reason is linked to the interactions between different actors who are often indirect, articulated, and highly influenced by imbalanced power dynamics, e.g. contractors and subcontractors, contractors and suppliers, suppliers, and customers, who are subcontracting as well. The second being that contractors and subcontractors may change roles from project-to-project and the role of an individual company can vary greatly also within the same project (Arantes et al., 2015). Given such multiplicity, all parties are generally unaware of their potential as combined supply chain partners to each other.

To understand the internal mechanism, some contextualization is necessary. The case study is revolving around mycelium and organic (meaning once-living) waste; therefore, it

seems fitting to take a supply chain approach and track the steps back to their main raw material's industry.

An informative example of this approach is given by Ata's study (Ata et al., 2012), which presents some data from the agricultural experience. In this context, farmers who produce agricultural waste and textile industries who produce cotton waste are customers as well. At the same time, the waste-to-output transforming firm serves and collects revenue from two types of customers: waste generators who pay for waste disposal service and final consumers who buy the end output (Ata et al., 2012).

Similarly, a supply chain for the mycelium-based product would need to incorporate these kinds of actors, as well as those already involved in the complex wood and furniture chain.

On a positive note, some authors have proven that mycelium-based products can benefit from a unique set of attributes that could still make it a successful investment. Being grown into shape according to the recipient on which is laid, mycelium materials have an incredibly flexible and modular nature. More specifically, since their main compound is made of spores plus organic material and each organic material confers different chemical and physical properties to the final product, from wood chips to cotton fibers (Interview to Dan, CEO). Since it is made by a completely compostable material, any of this product modular upgrades will not increase the environmental impact, as it happens, instead, for other material products mostly due the more and more frequent introduction and replacement of their modular upgrades leading to accelerated obsolescence (Agrawal & Ülkü, 2013; Demeester et al., 2013; Van Wassenhove, 2019).

On the other hand, a counterargument was made by others regarding the actual net benefit that could be gain by advancing and financing any waste-related industry: what if businesses were encouraged to produce more waste to keep up with scaled-up supply chains?

For instance, Leal Filho et al. (2020)'s study shows how a firm can generate and capture value by converting its waste stream (through further processing) into a useful and saleable by-product, and how this practice can potentially benefit the environment. The conversion of a waste stream into a by-product is commonly referred to as "by-product synergy" (BPS), a term that it will be used throughout this paper (Leal Filho et al., 2020). Since the waste

stream is productively used in a BPS operation, counter-intuitively it could be said that the more the waste, the better. The authors also describe the conditions under which the firm should strategically "overproduce" or increase the quantity of the original product beyond the business's usual quantity, to leverage the cost advantage. Another interesting implication of valuable waste is that the firm could increase profit by generating more waste per unit of the original product. Whereas the strategic increase in the production of the original product generates more waste proportionally, this study hypothesizes that it could be even more profitable for the firm to generate an overplus of waste, essentially being more wasteful than strictly needed. This is the opposite strategy to the "cost minimization through waste reduction" prescription, generally followed by manufacturing managers. Therefore, it is not farfetched to think that potentially this innovation could lead wood transforming facilities to increase the waste generated. Such an increment would still be leaving to the mycelium based industry the need to periodically switch from one supplier to another, because of the under or overproduction of raw material (Lee, 2012).

Lastly, to gather the main insights offered by the literature presented in this section, the paper will provide the reader with the following conclusion:

S3: "*Laminated wood industry is highly saturated and in need of modernization process toward more environmentally conscious disposal of waste. The business context is characterized by a general lack of awareness and communication along the supply chain. Future innovation may take place by first approaching the market with modular upgrades of current products.*"

Customer Role: Performance Vs Design

After exploring the concepts of operational sustainability and partnership for green innovation from the point of view of the selected industry, which is the laminated wood one, the thesis will switch perspective and look at mycelium based materials and products with the customers' eyes. This section of the literature review will allow the reader to get to know more about the customer's role in the supply chain.

Most authors recognize that customers can play different roles according to their level of participation in the final product design. According to Paton et al. (2011), there are 3

different possible roles that customers can assume, depending on their involvement in the product design process: customers as a resource, as co-creators, or as regular users. The closest relationship between customers and the firm sees *clients as a resource,* that is essential to complete the blueprint of any object. This requires a series of refined characteristics, such as appropriateness of customers to become a source of innovation, need for varied customer incentives, infrastructure, and channels for capturing customer knowledge and the differential role of existing and potential customers (Nambisan, 2002). Mycelium based industry is mainly oriented toward the Business to Business (B2B) (Interview Dan, CEO and to Kristian, CTO) and this is very valuable to a firm, as new ideas and surprising insights are invariably critical for the development of new products and distinctive features plus to stimulate learning useful also for future projects (Mahr et al., 2014). However, it is advisable not to rely too much on final users' inventiveness: in a batch production system, storage and types of machinery can be adjusted and amortized only to a certain extent to accommodate customers' needs. This leads often to the choice of setting up clients either as regular users and/or as co-creators.

In the former setting, it is established a regular relationship with the client that is seen as *a user*. In this case, the firm would only be concerned with executing time-based activities, ensuring customer diversity plus product support, and implement activities and infrastructures to enforce customer-to-customer positive interaction.

In the latter, *customers as co-creator,* become part of the creation process and therefore are involved in a wide range of design and tools' development. The nature of the project is still going to be industrial, since the customers will be allowed to take over/participate in the design decisions but only after placing a large volume order. This collaboration will require a well-working and highly adaptive research and development team to be able not only to face project uncertainty but also to enhance and acquire the customers' product/technology knowledge. (Mahr et al., 2014)

On this point, the literature offers divided opinions. Some authors consider the role of customers as co-creators as pivotal for gaining competitive advantage. "Customer co-creation of relevant knowledge has a positive impact on any successful outcome. Through interaction, firms obtain project-relevant knowledge on customers' needs or feedback on prototypes" (Mahr et al., 2014).

Opposite to those, some others advise against such a closer partnership as, per the "Green Supply Chain Management"(GSCM) paradox, the closer the end customer the less the performance gain for the firm (Schmidt et al., 2017). Therefore, the client's as co-creators could substantially damage the competitive advantage. In other words, a designer could find a negative moderation effect of Supply Chain Partners (SCP), such as the customers, on the "GSCM practice–performance link"(Schmidt et al., 2017).

While the results of this article suggest that all firms can benefit from GSCM practices, they also suggest that the performance effect decreases as the end consumer proximity to the focal firm increases.

In light of this, it can be stated that sustainability should be the core value of a company's business model, for the product to be an order qualifier, as per H2 above, even if this is unfortunately not enough for it to be an order winner.

It has been several years since sustainability has become a hot topic in the business environment and still, users prefer a product with high performance over one with higher sustainability features unless a minimum threshold of functional performance is achieved (Chitturi et al., 2007; Luchs et al., 2012; Schmidt et al., 2017). So, these studies point out the importance of showcasing not only the sustainability of a product but also, at the same time, as its superior performance levels.

However, at the moment is still not the norm that of a new sustainable product performing similarly to its traditional counterpart, so there is a lot of different and not conclusive hypothesis on how to manage such tradeoff.

Nonetheless, there are some authors, such as Paparoidamis et al. (2019), that offer a different possible approach proposing that it is not necessary to produce an entirely sustainable product. In fact, replacing parts of it with sustainable features or detachable components would be sufficient to sell it without affecting its performance levels. De facto, modularity could be a way to integrate sustainability in existing designs, offering not only a solution for a future product but also for current items on the market, whose performance, or better its perception by the users, would not change. The success potential of this solution is corroborated by research showing that in a trade-off between sustainability and performance, consumers tend to choose the morally inferior alternative, in this case, a

higher performant product over a more sustainable one, unless, a satisfactory or similar threshold of functional performance is achieved. (Chitturi et al., 2007)

All the more reason, for a company to focus on developing eco-innovative attributes as optional or add on "because consumers are often uncertain about their new eco-friendly product purchases. Including really new and highly eco-friendly features in new product designs in the peripheral and optional locus is more advantageous than doing so in base products and the core locus."(Abdelkafi et al., 2018; Paparoidamis et al., 2019; Raz et al., 2013)

From the above review, it is possible to summarize the opinions presented in the literature with the following statement:

S4: "*Customers in a green innovation context are likely to be more involved but should be at the level of co-creators to preserve the functionality of a company. Modularity could be a way to resolve the performance- sustainability trade-off perceived by clients*."

Here is a summary of the 4 main takeaways from the literature review, with the respective sources:

Takeaway	Related Sources
S1: "*Most authors agree on the existence of a particular branch of Innovation Management, that deals with environmental impact. At the present, the level of awareness is fairly low, and it is very context-related and business-specific. Sustainability must be a core value for a successful implementation of environmental innovation processes*"	(Abdelkafi et al., 2018; Adams et al., 2016; Beske & Seuring, 2014; Costa-Campi et al., 2014; Eccles et al., 2014; Harms, 2013; Herremans et al., 2016; Jaja et al., 2019; Klewitz & Hansen, 2014; Koppejan & A, 2011; Kriechel & Ziesemer, 2009; Luiz et al., 2016b, 2016a; Paparoidamis et al., 2019; Pesch et al., 2010; Sleenhoff et al., 2015; Sleenhoff & Osseweijer, 2016; Souto & Rodriguez, 2015; Watson et al., 2018)
S2: "*Environmentally sustainable innovations thrive when solid partnerships are established, and universities are involved. However, they can't be long-lived if not supported by the introduction of new materials and designs that replace old ones with a better environmental performanc*e"	(Balasubramanian & Shukla, 2017; Bigliardi et al., 2012; Borge & Bröring, 2017; Dainty et al., 2001; Dingler & Enkel, 2016; Dubois & Gadde, 2000; Grimpe & Hussinger, 2013; Hooge & Le Du, 2016; Hsuan et al., 2015; Klitkou et al., 2019; Lin & Ho, 2011; Paparoidamis et al., 2019; Szostak, 2016; Trigkas et al., 2012)

S3: "*Laminated processed wood industry is highly saturated and in need of modernization process toward more environmentally conscious disposal of waste. The business context is characterized by a general lack of awareness and communication along the supply chain. Future innovation may take place by first approaching the market with modular upgrades of current products.*"	(Agrawal & Ülkü, 2013; Arantes et al., 2015; Ata et al., 2012; Demeester et al., 2013; Klitkou et al., 2019; Leal Filho et al., 2020; Lee, 2012; Savaskan et al., 2004; Trigkas et al., 2012; Van Wassenhove, 2019)
S4: "*Customers in a green innovation context are likely to be more involved but should be at the level of co-creators to preserve the functionality of a company. Modularity could be a way to resolve the performance- sustainability trade-off perceived by clients.*"	*(Abdelkafi et al., 2018; Ata et al., 2012; Chitturi et al., 2007; Luchs et al., 2012; Mahr et al., 2014; Nambisan, 2002; Paparoidamis et al., 2019; Paton et al., 2011; Raz et al., 2013; Schmidt et al., 2017)*

Table 1: Summary of guiding principles and related sources

Mycelium background and Mush Materials case study

Having previously introduced and exhaustively explained what will be the guiding principles when evaluating any Environmental Innovation in the field of laminated wood, the author will now illustrate the characteristics that make the mycelium such a fascinating and high potential material and the reasons why it has been chosen. In this section, the author will explore in more detail the process behind the mycelium materials manufacturing and its properties as well as present the company Mush Materials and the case study they assigned.

Mycelium background

In response to this alarming rate of waste generation, research efforts have been made to provide alternative renewable technologies that can convert the present liability of waste into an ultimate sustainable resource for the future (Joshi et al., 2020) .

Intense research efforts are focusing on “the development of polymeric materials from a wide range of natural sources, such as cellulose, eggshell membrane, lignin, etc. Such natural alternatives offer a varied and unique combination of properties and are all sustainable, biocompatible, and biodegradable” (Islam et al., 2017).

The development of such materials needs usually difficult and complicated methods of processing that can be costly, time-consuming and with low production yield. Therefore, although they could resolve various environmental problems, these materials are hard to bring to the market (Haneef et al., 2017). A strategy to overcome these problems could be the development of composite biomaterials with properties controlled and tunable during their growth, like mycelium-based products.

The mycelium is the vegetative part and the root system of fungi, it is constituted by a network of branching elongated cells or tubular filaments, which fungi develop in order to expand underground or onto organic substrates and soil to acquire nutrients (Antinori et al., 2020). In other words, the mycelium penetrates into the feeding substrates by physical pressure and enzymatic secretion, it grows due to its symbiotic relationship with the materials that feed it, and acts as a natural binding agent to the substrate.

The mechanics of the mycelium network are largely controlled by the nutritional and environmental conditions: temperature, CO_2, humidity, light, and airflow. These influence the growth of tissue, resulting in varied predictable structural and mechanical properties of these fabricated materials: some features of the mycelium-based material produced are their excellent thermal stability, hydrophobic properties, and mechanical strength (Joshi et al., 2020, Interview Dan, CEO).

In conclusion, mycelium, it is a natural polymeric composite fibrous material. All these benefits come with small environmental cost: the process of growing mycelium results in limited waste (mostly compostable) and requires minimal energy consumption. Indeed, “agricultural waste/residues can serve as excellent substrates for biomaterial/biodegradable

material production as it is a good source of lignocellulosic content to provide sufficient nutrients for growth" (Joshi et al., 2020).

The research on possible applications of the cultivation of *Mycelia* started in 1958 with a patent on how to grow mycelium from mushroom and continued throughout the last 70 years (Szuecs, 1958). Mycelium-based biomaterials such as mycelium leather, mycelium packaging material, building material, and mycelium acoustic panels have been recently developed and patented (Joshi et al., 2020). For example, some studies have focused on constructing acoustic absorbers from agricultural waste products such as switch grass, rice straw, and hemp (Pelletier et al., 2013); while others have developed mycelium-based bio foams using sawdust for the replacement of expanded polystyrene, which is widely used in packaging and building insulation (Audia Bruscato et al., 2019)

The company object of the case, Mush Materials (Interview with Dan, CEO and Kristian, CTO), gravitates toward the use of wood and cotton waste as the main substrate, due to the unique characteristics that they give to the final product. Therefore, the case study will focus on the scale-up plan for mycelium-based boards, as a natural and compostable alternative to particleboard.

The manufacturing process starts with agricultural waste, which is easy to source locally and very cost-effective. This represents a huge competitive advantage since wherever the production site is placed, the sourcing operation can be adjusted to the local availability. As a first step, the waste is brought to a high temperature in a convective oven, sterilized, and moisturized. Finally, after a phase of preliminary growth, it is poured into a mold of the desired shape. Over the course of 4 to 5 days, the mycelium will keep growing forming a filamented network that englobes the substrate by expanding and binding the mixture into the final shape(Interview Dan, CEO). When the growth rate slows down and the desired shape has been developed, the compound will be heated in order to kill the living cells and harden the structure of the material obtaining the final biodegradable product. The resulting product is a durable, lightweight, fire-resistant, water repellent, and 100% biodegradable product.

There is a lot of ongoing research on the manufacturing process: as dealing with a living organism, there are many variables to take in account for the success and reproducibility of the final product, as the level of moisture, the outside temperature, the material of the mold,

the way of transport, etc. Since a plethora of factors in the manufacturing process, that can be finely tuned, will affect the characteristics of the final material obtained, many believe that the mycelium-based products will slowly, but steadily replace the non-compostable ones widely used today in many fields. (Interview to Dan, CEO).

As previously mentioned, research and knowledge about this material have been around for more than half-century, however, it was only in recent times, with the new sensitivity to environmental issues, that businesses have been urged to be more aware of their emissions and to conform to the latest regulations, implementing more operational practices. According to the literature review presented, a major driver pushing companies to innovate, are regulations' changes that require factories to produce fewer emissions and/or to cut down on the usage of certain materials. Switching to mycelium based materials is a perfect decision to lower the level of pollution while giving the exhaust product a remarkable end of life purpose as a natural fertilizer (Boffey, 2018; Cainelli et al., 2012; Jaja et al., 2019).

Furthermore, using mycelium materials into production also satisfies the need to differentiate and propose a more impactful image: a company can show itself as forward-thinking and fully capable of exploiting the most innovative technologies to improve its operational and environmental performance (Horbach et al., 2013).

As an innovation, the mycelium use is "a new idea, which may be the recombination of old ideas, a scheme that challenges the present order, a formula, or a unique approach which is perceived as new by the individuals" (Van De Ven, 1986).

Moreover, it is a particularly appropriate idea to bring innovative products into the laminated wood market according to Trigkas (2012): "The majority of wood and construction enterprises adopts and improves already existing methods of production and products' distribution followed by enterprises that innovate through the improvement of already existing products and new products production. Relatively few are the firms that develop new methods of production and products' distribution" (Trigkas et al., 2012). Therefore, the need for new and more environmentally conscious material is really strong in this sector and often goes unsatisfied.

Mush Materials: An Introduction

Mush Materials was founded in 2018 by two Master Students Kristian Ullum Kristensen and Dan Skovgaard Jensen. They first met at a common course for master studies in Design and Innovation with a focus on Sustainability and Eco-design, at the Technical University of Denmark. As founding partners, they provided the company with valuable and complementary skills: Kristian had already technical experience with prototyping and model-making respectively as a student assistant at Novo Nordisk, while Dan had obtained commercial and technical experience by twenty years of work in the construction industry, in various functions, as a craftsman, supervisor, and construction manager. The mix of their academic and practical background turned out to be a solid background to build and develop their business idea.

Mush Materials' business's goal is to grow biodegradable materials for the construction industry. Mycelium based products have an almost infinite range of possibilities: they did already come up with more than 20 different applications, from sports board to isolation panels, from disposable cutlery to drink's coasters. Furthermore, since mycelium materials are compostable, all their products are environmentally friendly substitutes for their classical counterparts. In the specific case of the construction industry building materials, such as particleboards, medium-density fiberboards and particleboard can be substitute with components that are fully c compostable and grown on industrial waste, collected from different sources, such as the textile, agriculture, and construction industry, that are mixed with a natural binding agent: the mycelium. The manufacturing process is fairly simple as described previously.

This production process requires minimum energy consumption since the growth of the mushrooms requires only a water-based solution to keep the environment moist and electricity to refrigerate the spores. Furthermore, it leads to less waste in all sorts of industry cutting away waste management and disposal cost for their customers.

The founders' vision is aimed to revolutionize the construction industry and enable everyone to build and live in completely sustainable houses, by launching affordable and compostable alternatives to conventional building materials. The company guarantees that all materials are compliant with building regulations and EU directives as customers' safety is paramount especially when promoting an innovation so radical.

Case study

Mush Materials reached out to the author as a young player in an unknown and untapped market. The main issue they are facing is the lack of knowledge and general know-how in this field, given the predominantly technical education of the founders. The initial idea proposed for a case study was to map their supply chain in order to highlight the competitive advantages of the firm and leverage it against the incumbents to established themselves as major players in the market.

However, after a preliminary investigation to assess the presence of potential competitors in the European market, it became clear that the mycelium business is at a fairly initial stage and in particular in the particleboard and construction products field there aren't any real competitors, since there's not much knowledge about the material itself. Therefore, the initial proposal turned out to be of limited usefulness and not worthy of being pursued.

After, presenting the preliminary results, the author together with the commissioning business, considered the idea of designing a supply scale-up plan. Two were the main driving reasons behind the new proposal: 1) The company had already found product-specific recipes ready to be implemented and 2) The author already had a certain experience in researching Mycelium as an alternative product thanks to a previous university project.

From that moment the partnership was oriented to look for the most suitable market that would fit the company's mission and its assets. First, the packaging industry was considered: this proposal was fairly promising for the many different applications that could have been implemented and the strong market push toward any plastic alternative, however, the significant number of competing players significantly decreased profitability prospects. The second idea was to look into the children's toy industry: it was a very original and innovative one and could have been executed with a short time to market, on the other hand, it would need strong storytelling and involvement from the management of the sector, which in reality did not show an adequate level of passion or commitment toward the project.

Finally, the choice made was the laminated wood industry, in particular following the supply chain structure required to produce a particleboard substitute. This sector is

characterized by a strong stagnation in environmental innovations and it would be the most interesting to explore for new options to modernize the industry. Furthermore, the disposal of the byproduct of current production methods has been investigated for quite some time without delivering significant results, so that new places and storages have been constantly swamped with construction residue, waiting for better solutions in future times.

The time has come for a radical innovation that could solve the problem at the root by eliminating the material from the world's landfills while still satisfying the growing need of customers: introducing compostable material like mycelium-based boards.

Methodology

Systematic Literature Review

Following the format of the systematic literature review (SLR) given by (Henry & Foss, 2015) a multiple-step investigation will be reproduced.

First, a series of keywords are established "sustainability entrepreneurship", "bio innovation", "Biowaste supply chain", "Waste management", "innovation management", "bio-waste challenges", "mycelium products", "processed wood industry" with their synonyms and semantic affiliates are used when selecting the articles on which the discussion will be built in scope for this research for a total of a dozen keywords.

Second, the journal search was finalized. After thorough consideration, it was decided that peer-reviewed articles over the past 10 years (2010-2020) which is the most prolific period for publications around bio waste and innovation management, given the recently discovered area of study. Aside from the literature review, more journals, types of sources, and years are considered for 2 main reasons: 1. In case they help build up the case of the main argument; and 2. If their relevance is modern and relevant enough. For these reasons, the following articles are included:

Szuecs, J. (1958). Method of growing mushroom mycelium and the resulting products. *US Patent 2,850,841*. https://www.google.com/patents/US2850841

Van De Ven, A. H. (1986). Central problems in the management of innovation. *Management Science*, *32*(5), 590–607. https://doi.org/10.1287/mnsc.32.5.590

Dubois, A., & Gadde, L. E. (2000). Supply strategy and network effects - Purchasing behavior in the construction industry. *European Journal of Purchasing and Supply Management*, *6*(3–4), 207–215. https://doi.org/10.1016/S0969-7012(00)00016-2

Dainty, A. R. J., Briscoe, G. H., & Millett, S. J. (2001). New perspectives on construction supply chain integration. In *Supply Chain Management* (Vol. 6, Issue 4, pp. 163–173). https://doi.org/10.1108/13598540110402700

Nambisan, S. (2002). Designing virtual customer environments for new product development: Toward a theory. In *Academy of Management Review* (Vol. 27, Issue 3, pp. 392–413). Academy of Management. https://doi.org/10.5465/AMR.2002.7389914

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. In the *British Journal of Management* (Vol. 14, Issue 3, pp. 207–222). https://doi.org/10.1111/1467-8551.00375

Kleindorfer, P. R., Singhal, K., & Van Wassenhove, L. N. (2005). Sustainable operations management. In *Production and Operations Management* (Vol. 14, Issue 4, pp. 482–492). Florida International University. https://doi.org/10.1111/j.1937-5956.2005.tb00235.x

Alves, J., Marques, M. J., Saur, I., & Marques, P. (2007). Creativity and Innovation through Multidisciplinary and Multisectoral Cooperation. *Creativity and Innovation Management*, *16*(1), 27–34. https://doi.org/10.1111/j.1467-8691.2007.00417.x

Chitturi, R., Raghunathan, R., & Mahajan, V. (2007). Form versus function: How the intensities of specific emotions evoked in functional versus hedonic trade-offs mediate product preferences. *Journal of Marketing Research*, *44*(4), 702–714. https://doi.org/10.1509/jmkr.44.4.702

Kriechel, B., & Ziesemer, T. (2009). The environmental Porter hypothesis: Theory, evidence, and a model of the timing of adoption. *Economics of Innovation and New Technology*, *18*(3), 267–294. https://doi.org/10.1080/10438590801943235

Subsequently, to guarantee the academic quality, only journals that were deemed to be recognized leading journals in the fields of higher education were consulted. In particular, following the directive given by (Harzing, 2020) who compares over 20 different sources of peer-to-peer review and provides different ranks on each journal. Subsequently, it was decided to consider papers in the areas of “Innovation”, “Operation management” and “Management”. Besides, it was decided that the paper with a minimum rank of 2 by the Danish ministry peer-review document (2017) would be prioritized. According to said

criteria, 32 journals were selected as a source of academic data behind the literature review, however, due to some of them were not relevant to the topic: out of the total sample, only 15 were considered because they focused on the areas related to Operational Sustainability and the affiliated semantic.

Here is a list of the journal considered:

0963-1690	Creativity and Innovation Management
1460-1060	European Journal of Innovation Management
1366-2716	Industry and Innovation Management
0267-5730	International Journal of Technology Management
0737-6782	Journal of Product Innovation Management
0963-6625	Public Understanding of Science
0162-2439	Science, Technology and Human Value
0144-3577	International Journal of Operations & Production Management
0272-6963	Journal of Operations Management
1523-2409	Journal of Supply Chain Management
0160-5682	Journal of the Operational Research Society
1523-4614	Manufacturing and Service Operations Management
0030-364X	Operations Research
1059-1478	Production and Operations Management
1359-8546	Supply Chain Management: An International Journal

This led to a total of 9000 articles, this is an average based on the following computation (15 journals x 20 years x 5 Issues x 6 articles). Since not all the issues from the selected journal were focused on the topics related to the research question, the third stage of the process involved scanning and selecting articles for inclusion. This was done by reading the introduction of identified issues to determine their relevance in answering the research question. The author understands the global nature of the issue addressed, however, given

the empirical nature of the presented study it was decided to focus primarily on English written papers based on European based studies, to obtain as close and real information as possible: the author wanted to study the European environment to understand the context-specific challenges posed by the external factor to this paper's business case study: this reduced the sample to around 3600 articles (15 journals x 20 years x 2 Issues x 6 articles)

This led to step 4 which involved data extraction. Each of the articles was read thoroughly and reviewed according to a standardized set proforma (Tranfield et al., 2003) then they were first put in either the Innovation management art of the review or the Waste management related part. This made the author realize that among all the selected issues only a small percentage of articles contributed toward finding an answer to the research question: so the analysis was conducted on c.a. 1800 (15 journals x 20 years x 2 Issues x 3 articles). Subsequently, they were analyzed and information was noted down on author(s) name(s), year of publication of the paper, a summary on how it contributed to solving the research question, the direct quote from the paper to support the previous column statement and finally the section of this paper where it should be cited: Appendix 1 provides a visual example with three sample entries. This proforma template formed a raw data repository to be utilized in stage 5. Also, some specific papers, books, international observations, and official websites were cited to second the ever-changing and newly discovered area of research, to incorporate the author's knowledge gathered throughout the course of study, and to prevent the loss of relevant information due to the source lacking one or more of the previously illustrated criteria. Bringing the total number of references consulted to c.a. 82 which were included in the dissertation. All of them have been consulted and physically found through the use of suitable online science databases like Scopus, Eco host, and Mendeley, as well as Google Scholar and Academia.edu.

At the end of the Literature section, the data obtained through this research from the selected article were analyzed to identify, compare, and contrast recurring themes and future agenda, which set the base for the paper analysis section.

Data Collection Methods

The research question at the center of this paper is: How can supply chain managers support designing a scale-up plan for a bio-waste innovation company in the processed wood industry?

Like the research question implies, the nature of this investigation is exploratory which is aimed to clarify the understanding of an issue. In fact, the principal goal of this paper is to gain further insights into how the contributions from the different kinds of literature sources and basic research will aid and improve the development of innovative sustainable products. It is a piece of common knowledge that in exploratory studies, the researcher is to collect data through interviews, leading the investigator to work with qualitative, more than quantitative data; also this paper will follow this approach and it will show how information is collected through semi-structured interviews.

Semi-structured interviews provide the opportunity to probe answers, where it is needed that people explain and build on their responses or preexistent convictions or the author (Saunders & Lewis, 2016). Interviewees may use words or ideas in a particular way, and the opportunity to test these interpretations adds significance and depth to the data collected. Looking retrospectively, this approach helps the interviewee as well to contribute to the solution of the case study because it allows them to think aloud about previously overlooked possibilities. At the same time, the researcher needs to be aware that such closeness with the participants may lead to bias being generated, as it will be elaborated on later in this section.

The participants initially chosen for the interviews were people who were qualified by their competence in the Innovation or Waste management field and experts in the chosen industry of processed wood. Unfortunately, in the end, it was not possible to reach out to general experts due to the highly specific nature of this innovation and the general lack of knowledge and interest in the mycelium-based product in the business world. Therefore, it was decided by the author and the business to collect exclusively internal opinions on the company's processes, sacrificing the general character of this thesis in favor of a more operational and consultancy approach. While it could sound unconventional, the author believes this contributes to the actual implementation of the models proposed more than another theoretical publication that looks for abstract meanings.

In particular, it was decided to reach out to the Chief Executive Officer (CEO) of Mush Materials Dan Skovgaard, to get his insight on the functionalities of the mycelium based material production, a source of and the strategic approach that Mush Materials is pursuing; and to the Chief Technology Officer (CTO) Kristian Ullum to sound the feasibility of the supply chain configurations suggested.

HOW DATA ARE USED IN THE PAPER?

The content of the interviews was used to build up the supply chain. The process implied:

- Reasoning over the different tools presented (Four Ps, Four Vs, and Polar diagram). The response of the interviewers helped highlight the strengths and weaknesses of mycelium boards compared to particle one
- Introduce the mycelium definitions and functioning, to elaborate fitting solutions
- Test the result of the Systematic Literature review, to gain empirical and academic relevance.
- Increase awareness of the limitations and barrier to consider when setting up improvements in the scale-up plan

HOW WAS THE DATA COLLECTED DURING THE INTERVIEWS?

The interviews were performed online with in-person in-depth individual talks. The choice of a live and real-time interview is particularly well suited to the exploratory nature of the data collected in this study since it allows the interviewer to adjust the questions and tune the conversation toward the most relevant themes that come up in the conversation. At the same time, to guarantee the homogeneity and comparability of the data, that will be subsequently pooled and analyzed, a common framework for all the interviews must be established, hence the choice of their semi-structured character. Here is the list of the question asked:

1. Please, introduce yourself and the company
2. Can you tell us about the functions of mycelium manufacturing?
3. What is the issue in your case study?
4. What is the industry where you would want to study your scale-up?
5. Could you tell us something about the particleboard industry?
6. Who do you think your customer will be?

7. Now, I am going to present to you 4 Statements drawn from the literature analyzed around Innovation for bio-waste companies. I will read them one by one and you will have the chance to ask for clarification and be allowed 5 minutes to think about them.

S1:

Most authors agree on the existence of a particular branch of Innovation Management, that deals with environmental impact. At present, the level of awareness is fairly low, and it is very context-related and business-specific. Sustainability must be a core value for a successful implementation of environmental innovation processes

S2:

"Environmentally sustainable innovations thrive when solid partnerships are established, and universities are involved. However, they can't be long-lived if not supported by the introduction of new materials and designs that replace old ones with a better environmental performance"

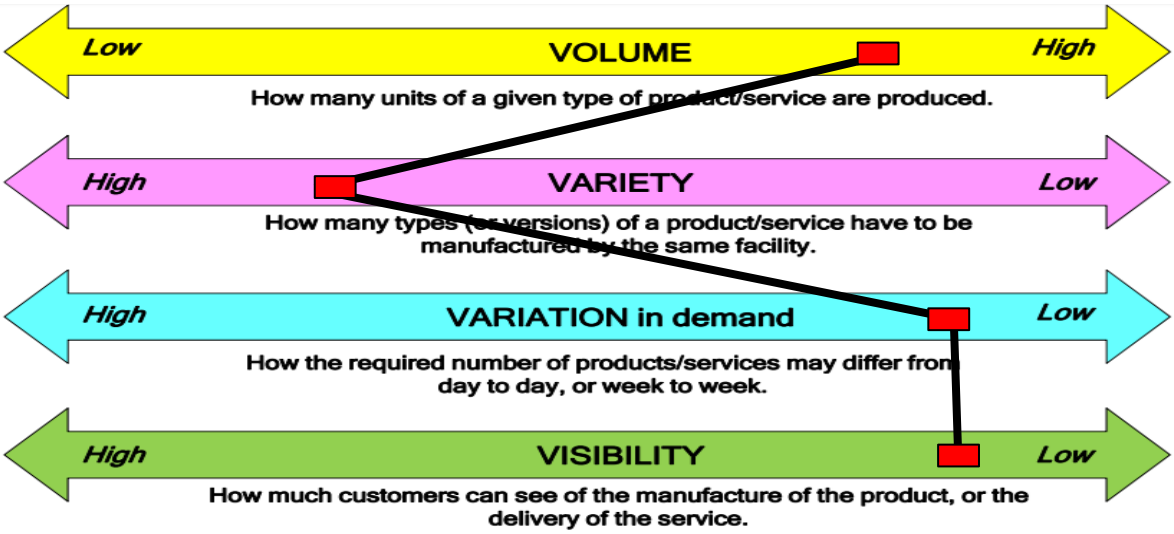
S3:

"Laminated wood industry is highly saturated and in need of modernization process toward more environmentally conscious disposal of waste. The business context is characterized by a general lack of awareness and communication along the supply chain. Future innovation may take place by first approaching the market with modular upgrades of current products."

S4:

"Customers in a green innovation context are likely to be more involved but should be at the level of co-creators to preserve the functionality of a company. Modularity could be a way to resolve the performance- sustainability trade-off perceived by clients."

8. To what extent would you disagree or agree with the following mycelium positioning in the "Four Vs" diagram?



9. Can you please, briefly describe your firm business model?

10. What is the main mechanism in the furniture/processed industry that you can see Mycelium struggling with?

11. Would you like to provide any further comments or contributions?

Given the digital communication means used, the interviewer did not have access to the non-verbal signs of the interviewee posing a risk for information to get lost in communication or misunderstanding of either the question or the answer to happen. For this reason, the questions are structured to be open and relatively short to allow for a more personal and natural response, the questions are read out loud and explanations are provided over technical contents to level the knowledge gap between the parties and ensure a more proficuous verbal exchange. Finally, confirmation of correctness is asked at the end of each answer to make sure that the right interpretation of the data as passed through.

Building on this, the lack of standardization in a semi-structured interview can lead to concerns about the reliability and dependability of the result conclusions drawn. Now, it has been often looked at the Observer bias and similarly, there's the interviewer bias, where informal comments, tone, or non-verbal cues can alter the way the interviewee answers the questions (Saunders & Lewis, 2016). The risk for semi-structured interviews is often to propose leading questions that encourage the interviewee to reply in a certain way, therefore

tampering with the result of the investigation. However, the author being an observer-as-participant is already contributing to such predicament making herself, her role, and study clear to the subject of the study. At the same time, in this way, it is possible to achieve tailored results for the specific firm, and opening the subject at ease given their young age will be more willing to answer freely and stimulating the innovative nature of the study. This process is also known as habituation, it is used to inspire trust in the subject of a study so that the presence of the researcher becomes normal and they scarcely notice the observation being made. The habituation process is also used to counteract the interviewee or response bias, where the subject is willing to participate but during the exchange, their reluctant and might seclude information, for instance, because the credibility of the interviewer is compromised or their asked sensitive questions.

A counterargument offered when the reliability of semi-structured interviews is discussed, is that not all studies are meant to be repeated. It is important to outline a research methodology for the coherence of the study, but this doesn't mean that given the chance another researcher will follow the same methods. In other words, during a case study, a problem is raised by the company and a method is defined to look for the answer: if following these methods the problem is solved there's no need to repeat the investigation, at the same time if the same problem arises again in a different circumstance, even if applied literally, the same method might not work again (Saunders & Lewis, 2016). As previously mentioned, this study is quite a context and time-specific and this characteristic alone prevents the replicability of the results in other contexts. "Therefore, an attempt to ensure that qualitative, non-standardized research could be replicated by other researchers would not be realistic or feasible without undermining the strengths of this type of research" (Saunders & Lewis, 2016, pg. 399).

The role and perspective presented throughout all the interactions with the firm will be that of the observer-as-participant: authors will be collaborating closely with the case study's subjects, who will know the main purpose of the study and partially be influenced in their future activities and behaviors through the formulation of a scale-up strategy. As an observer-as-participant, the identity of the researcher is known to the subjects and has the main advantage of being able to focus on the research role, concentrate on the discussion with the informants and simultaneously jot down insights as they come to mind. On the

other side, the paper loses emotional impartiality and as a result, the risk of bias is increasing.

Other risks related to findings with ecological validity could be observer bias, observer errors, and observer effect (Monahan & Fisher, 2010)

1. Observer bias is faced when the researcher does not allow themselves time to develop a deep understanding, required to objectively review the data collected. Much like this case, where a time-limited case study is assigned this limitation is bound to happen. Therefore, the researcher is set to assume their subjective view to interpret the events. In this case, this was partially avoided by setting a research question around the role that the research plays in the study. In other words, the author acts and implemented their idea as a supply chain manager because the research question asks her to look through those lenses.

Furthermore, being on overt observer the researcher throughout the interviews was able to validate her understanding with the subject of the study. In this way, achieving both reliability of the interpretation and verification of the informant/interviewees.

2. Observer error is linked to the lack of understanding or over-familiarity with the setting in which the study is conducted. Due to this, minor yet relevant detail may slip the attention of the researcher as the moment of the interpretation and collection of the data alternate seamlessly. Actually, interpretation should stem from the comprehension of the settings and the insights collect and not before. If the opposite happens, the researcher should stop the process, collect their observations, and look at them in the same light to guarantee consistency in the interpretation.

3. The observer effect is referred to as the influence the researcher exercises by simply being present. Saunders et al suggest that a solution to this would be for the observer to have as minimal interaction to the subject as possible. This was achieved by having digital non-video calls, so the presentation was not heavily perceived, and sending the interview questions was sent to the interviewees 1-2 days before the meeting. Upon receiving them, it was asked to them to note down some first reaction responses. This choice resulted to be both time-efficient for the company because the employees already formed an opinion around the questions and minimized the observer effect since the interviewer was not there. Simultaneously, the interviews were conducted in separate weeks and the participant was

not informed of each other participation. This coupled with the short forewarning around the question contributed to internally uninfluenced and not staged answers.

Besides, this paper will follow the case study strategy through an exhaustive search into the topic of interest within a real-life setting (Hollweck, 2016). For this purpose, this thesis includes a section dedicated to introducing the case study, the company involved Mush Materials, and the relatively new industry of mycelium materials and product to introduce the reader to the necessary information to understand this specific business environment. The point of view adopted in this study will be those of both supply chain managers and academic entrepreneurs in the processed wood industry. The dualistic perspective will greatly help to investigate the dynamics in a reality-based context reaching a double goal: 1) Avoid any excess noise in the data gathering process given by information that doesn't apply to this paper's case, thanks to the practical and issue-related approach of supply chain manager and; 2) Counterbalance the lack of general information, establishing boundaries and limitation that allows for energy and efforts to be channeled towards collecting more relevant data and drawing more reliable conclusions.

Differently from other kinds of research strategies, like experimental and survey ones, the explorative case study strategy assumes that certain variables have predetermined values but do not consider them completely fixed or leaving space for changes due to unforeseen insights and findings (Hollweck, 2016). In other words, the investigator while setting clear limits and ranges, at the same time leaves them dynamic or flexible, fully aware that knowing the context and its variations is crucial for a case study paper.

In the context of this study, the exploratory approach has the additional advantage that it allows us to capture insights from outside the box perspectives that are particularly relevant when investigating a topic outside of the commonly established procedures.

The criticism that can be raised to this kind of strategy the limited extent to which any conclusion can be generalized and applied to other contexts (Flyvbjerg, 2011; Ostrom, 2012). A counterargument is that the topic considered in this thesis hasn't been studying long enough and as a consequence, there's poor and low-quality information available plus the number of reported cases of such operational sustainability is quite low and hard to find. In other words, attempting to draw a generally valid conclusion on a fairly new conceptual connection between different academic areas, like waste management and environmentally

sustainable innovation management, is premature when there is still a scarcity of documented trail of proofs.

Hence, the ultimate goal of this case study is to provide a stimulus to encourage academic and operational professionals to divert their attention toward Waste-Innovation management interactions by portraying an example of what kind of value it can bring to the business world.

On this note, it is fundamental that the chosen case and company are a perfect fit and that is why Mush Materials was chosen as subject entity in this thesis. This young and local start-up represents a small entrepreneurial reality, born out of the academic world while implementing a traditional for-profit business model and simultaneously selling innovative products from agricultural waste. It adheres to a business philosophy that is very close to the author's one and pertinent to the context highlighted by the research question.

On one side, if the size of this company allows for deep comprehension of the internal mechanism and easy access to information, on the other its recent creation implies that they will have little experience in this field, even if this is a common limitation when working with innovative start-ups. Interestingly, this downside can still be turned into a competitive advantage, because in this kind of environment there is also more cooperativeness and willingness to try new and different scenarios compared to more established companies that already know what works for them and what doesn't. In conclusion, the case company is vibrant with the overall outside the box approach that characterizes this paper.

Having defined the general structure of this argumentation, the author will now describe in more detail the applied research methods. The research approach pursued is the linear analytic process in a cross-sectional time horizon (Hollweck, 2016): arguments are studied with a deductive approach by which a conceptual framework is developed to test data gathered in a given time and location. The position of the writer will be that of an external impartial researcher as Mush Materials has freely accepted to collaborate and no funding is going to be exchanged for the findings of this paper.

As for the research design, this paper will present substantive research as it is restricted to a particular time, space, group, or in this case a particular company. While the overall applied philosophy applied will be Pragmatism. According to Kelemen & Rumens, (2012),

a pragmatist shows interest in acting and see the research process as a tool to change existence. Hence, the feeling that acolytes have a moral responsibility in presenting knowledge that is applicable and has consequences for future developments. In other words, the effort spent in studying a phenomenon should be made toward making a positive difference and implement the status quo with new and better elements. This philosophy has been chosen because it reflects the attitude of the author toward the research process and it acts as a solid bridge between academic knowledge and operational practices. To realize this view, this paper adopts the logic deductive structure which comprises a series of 8 sections to be more pertinent to the flow of topics introduced. Therefore, the overall amount of section is 6, namely: Introduction, Literature review, Case Study introduction, Methodology, Analysis, Conclusion, and Final recommendations. Starting with the literature review, this dissertation will conduct a systematic literature review using a comprehensive pre-planned strategy for locating, critically assessing, analyzing, and synthesizing existing research that is pertinent to a formulated research question to allow conclusions to be reached about what is known. This type of literature review was chosen as the pool of academic information is quite shallow and this method can help the author find and group the current knowledge. This brings 2 benefit: first, it sets up a bade for future study on the current information available on the topic; and second, it allows the paper to make more meaningful and fruitful academic and empirical contribution by highlighting the gaps in the literature that need to be filled.

Additionally, some might argue that this thesis would be a good example of what has been coined “Responsible Research,” and that it includes additional ethical dimensions (Brown, 2012; Kourany, 2013; Tsui, 2019; Wang et al., 2016). It is not within the scope of this study to engage in this discussion, but this paper opinions align with those of Responsible Research.

Lastly, during the data collection, the author pledges to have acted with integrity and objectivity when conducting the research, to have respect for participants, to have made clear of the voluntary and free nature of their contribution and, lastly, to have asked permission before recording any of the material presented in the interviews (Appendix 2). The subjects have also been informed of the purpose of data collection and grant anonymity where this will be asked and overall ensuring an appropriate and scientific approach throughout the research process.

Analysis

As seen in the literature review, the main topic can be summarized in 4 different statements. These refer to the main points to be addressed and configured when dealing with an environmental innovation based on waste, like mycelium-based products. In this Analysis part, these statements are going to be the starting point to build up the investigation on the best configuration for a supply chain in this context. The Statements will not be used in the same order as presented in the literature review, as they were not listed according to their importance rank or sequentiality of their derivation. These statements are, in fact, linked to each other and equally contribute to defining the current picture: the order in which they are going to be used in this section is rather due to the multi-stage approach taken when describing the supply chain.

In this Analysis paragraph, the presentation of the process will begin by framing mycelium also as a business reality not only as a great innovation. Therefore, a double-sided point of view will be adopted: on one side the demand related aspects will be looked into with the tool of "Product life cycle", which is helpful to understand what does the market currently think and expect of mycelium as a particle boards alternative; on the other, the supply side aspect will be described through the "Four Ps" and "Four Vs" framework, as described by Professor Hsuan and Professor Paton (2018; 2011). The analysis presented strongly relies on and has been influenced by both the Statements S2, on the importance of partnership, and S4, on the use of modularity, plus the two interviews with the founders.

Subsequently, the core of the study on the proposed configurations to scale up Mush Materials supply chain phases will begin. The paper will focus, at first, on the fundamental factors that are necessary for the production of mycelium materials and products: agricultural waste and fungi spores. Here, ordering and storage costs are presented along with the procurement and inventory targeted suggestions and limitations. This part is based on the conclusions drawn in the Statement S3, on the wooden industry as well as insights gathered from the interviews.

After, the study will move on to formulate different distribution scenarios to implement when Mush Materials will be ready to scale up its operations and in need of allocating resources to ensure smooth supply to its customers. The main contributing ideas to this

paragraph have been the ones outlined in the Statements S2 on partnership and S4 on customers and modularity.

Thirdly, the expected running and maximum capacity of the supply chain will be calculated based on the assumption of a standard item being produced, which is a mycelium block of 40x40x2 cm, since this is currently Mush Materials most popular product. Here, the Statements S2 on partnerships and S3 on the wooden industry have been greatly taken into consideration.

Lastly, having configured how the supply chain design should look like, the dissertation will provide some basic Key Performance Indicators (KPI) to track, to determine the successful implementation of the operations and the eventual critical points to correct.

Business framing: double-sided view

Product Life Cycle

When studying any innovation, it is paramount to look at the item‘s frame and position both in comparison with other equivalent and on its own. This paper will offer a double-sided analysis: a demand-side, illustrated with the product life cycle model, comparing the maturity stage of mycelium and particle boards, which will give an overview of the market’s perception; and a supply side, explained through the “Four Ps” and “Four Vs” analysis, that will give a representation of the frame in which to allocate its production.

Regarding the demand, the Product Life Cycle theory (Vernon, 1966) states that a product goes through a different life cycle characterized by 4 stages: Introduction, Growth, Maturity stage, and Decline. These are defined by the annual sales volume of a product in the function of time. In case, its life cycle as shown in the graph of Fig.1. In the case of mycelium boards - indicated in the Fig. 1 graph by the green square symbol - it can be shown that they are currently in its Stage 2, otherwise known as Growth. This stage is characterized by rising order volume levels, which have as consequence the fact that availability and quality of the products are ordered winning features and the preferred users in the market are called “Early adopters” (Paton et al., 2011). Particleboards, instead, are currently in their Stage 3, or Maturity, indicated by the red square symbol in Fig.1. In this stage high volumes of the

products are available, and customers are attracted by its cost efficiency and dependability. However, in this phase, there is also a high likelihood that the product will be replaced by an alternative or a completely new one since the market is almost saturated. The current status of the two types of the product drastically increases the chances that mycelium boards take over the market (Trigkas et al., 2012).

More importantly, given the pluripotential nature of this product, users are notably involved and play a critical role in its future developments. They will be able to contribute with their ideas, requests, and specific needs and to work along with R&D to the development of a variety of products for the best customer experience. This will ensure a wider market segment and hence a higher annual sales volume in the Maturity stage. According to Paton et al. (2011), this type of client is called "Lead users" - people who help in the development of the product. Their presence among end customers is vital to explore the many features and applications of this material and challenge the production process to be both cost-efficient and innovative.

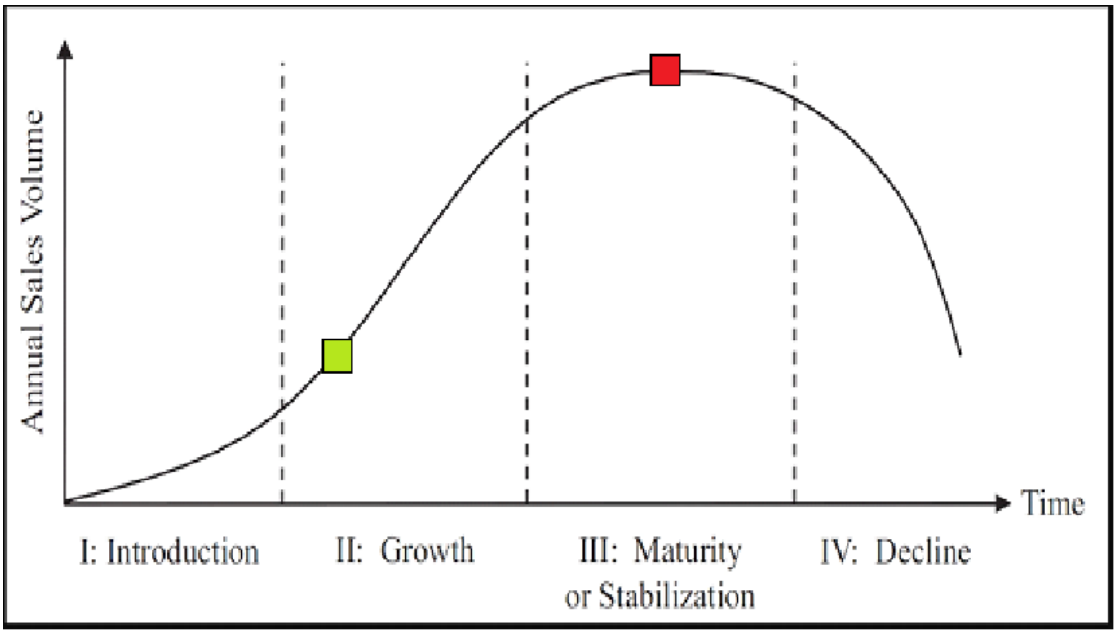


Figure 1 Product life cycle model adapted to Mycelium and Particle boards material maturity stage

Four Ps Analysis

From a supply point of view, mycelium can be classified as an innovation of outcome. In the Innovation Management theory, an innovation of outcome can be distinguished in incremental and radical innovation: the first ones are dedicated to modifying an existing object by adding attributes or features to it, while the latter is aimed to introduce completely new and unknown products. These two types often end up being complementary, working in synergy, and enhancing each other performances: for this reason, it is pivotal to explain the different types of innovation and understand how do they interact with each other to exploit them in the most beneficial way (Doran, 2012). In particular, this paper will utilize the "Four Ps" analysis to better understand how the different sides of innovation characterize the mycelium product under consideration:

- Product Innovation: This might be the less innovative aspect of the "Four Ps" since mycelium is replacing existing objects, although with compostable material. Therefore, it can be certainly described as incremental innovation, rather than a radical one, in fact, it does not revolutionize any concept, but manages to improve an already existing one.

- Process Innovation: Dealing with a living organism as raw material is going to represent a challenge for production facilities since they will have to keep under control more variables in the manufacturing environment to ensure the proper growth of the fungi's mycelium, that was not an issue with the processed wood equivalent (Interview to Dan, CEO). Moreover, such circumstances necessarily lead to an upgrade in the production processes, which have now to take account factors like the growing period of the fungi (4-6 days), the temperature and humidity of the production facilities, the oven setting and performance in which it is cooked and the storage conditions other similar parameters. In other words, given the substantial difference in the raw material, new production processes are required, so concerning Process innovation mycelium products surely represent a radical innovation.

- Paradigm Innovation: Until now, particle boards were mostly purchased for the main purpose of building structures in a short amount of time, with the requirement of few resources and capability to adapt to multiple needs and designs. However, with a mycelium-based line of products, companies, while offering a product that has similar features and performances, will also get the chance to make a statement to the public about their

environmental responsibility and to save indirect costs linked to negative externalities. In this context, this can be considered a radical innovation in the Paradigm.

- Position Innovation: Once fully set up in the processed wood industry, mycelium boards will be suitable to adapt to a wider variety of contexts compared to particle boards. This will determine a shift in the way the products and related services are targeted. However, at the present, it is not yet suitable for new positioning other than particle boards already have. In this regard, it can be considered a mild incremental innovation.

Four Vs Tool

According to (Slack et al., 2010) all across different sectors' operations processes are similar but differ on several dimensions, four of which, are known as the 4 Vs: Volume, Variety, Variation in Demand, Visibility.

In order to continue the double-sided analysis, this paper will now adopt the supplier's point of view and analyzes the mycelium potential as a product through the "Four Vs" Analysis, as described by professor Hsuan (2018) and schematized in Fig.2.

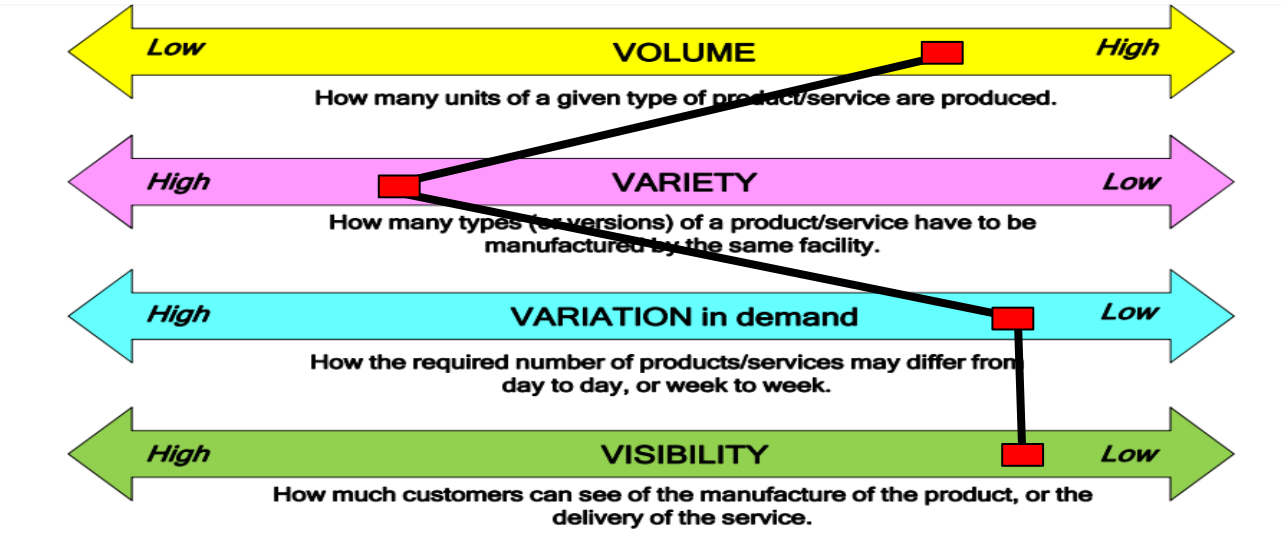


Figure 2 Model adapted from Hsuan Professor (2018) *based on info from interviews*

- Volume: This parameter defines how many units of a given product are produced in each manufacturing cycle. Once the mycelium-based boards will be a well-known and established product, Mush Materials company will plausibly receive multiple high-volume

orders, and to satisfy this kind of demand the best option appears to be the batch production system. The general outcome of such a system is assumed to be at least 100 batches per year. So, the "Volume" for the Mycelium based boards will be high. (Interview to Kristian, CTO)

- Variety: This parameter refers to the number of different types of product/service are going to be manufactured by the same facility. Boards can be created to fit the shape of each product, manufactured at a facility, most of which will have regular shapes. However, adopting the customer-oriented development process, as suggested after the Product life cycle analysis, will implicate that the measures of these shapes might often change, varying from just a few centimeters difference to a completely new outline. The ductility of mycelium boards production will allow the company to accommodate such variations and the creation of different kinds of shapes with little to none burden, or change required for the production infrastructure. Hence the "Variety" of mycelium boards will also be high.

- Variation in demand: This parameter describes how the number of products/services required may vary in time, day by day, or week by week. Being mycelium boards basic components in construction, it can be inferred that they will not be sensitive to seasonality, although the demand may experience some fluctuation over some specific time range, such as back to school period or construction intense period due to exceptional circumstances e.g. building renovation, green incentives, new constructions, etc... So, the "Variation in Demand" of mycelium boards will be Low.

- Visibility: This parameter describes how much the customers/public can see or be aware of the background processes related to product/service manufacturing. Understandably, the supply chain will not be completely publicized, since many customers will be selling a mushroom-based product to users in the construction or furniture industries, notoriously affected by mold issues. So, they might prefer not to advertise it, in order not to create an unfounded diffidence toward the product (Interview to Dan, CEO).

In addition to that, the processing of multiple batches and multiple products at the same time poses another challenge to the "visibility of the mycelium boards, due to the large number of goods manufactured at the same time. In any case, a sort of recognition mark, like a logo on the package could represent a way to inform and remind the final user about the firm, increasing its visibility. Taken all into consideration it is possible to estimate that the "Visibility" of mycelium boards will be Low.

The relative definition between among the four of them has implications on the costs of creating a product or service. In other words, a pattern with high volume, low variety, low variation, and low visibility help to keep processing costs down. Opposite to this, “low volume, high variety, high variation, and high visibility generally carry some sort of penalty for the operations” (Slack et al., 2010). Such cost is not to be intended as something to avoid overall, since it could mean an advantage in other areas or might be due to investments to amortize over time.

Anyway, as per the above analysis, we can see a discrepancy in this trend for the item here analyzed: the mycelium scales up plan this paper is configuring brings the manager to solve a trade-off between Volume and Variety. This information needs to be considered and resolved through some specific tools like modularization as the paper will show later in the “Process Design” section.

Designing the scale-up of the Supply Chain

The previous section outlined the innovation framework of the mycelium boards and placed a solid base to construct and explore in detail the case firm’s core activities. This paragraph will now give a general overview of the suggested configurations of the supply chain for a successful scale-up, shortly describing its main phases.

The underlying concept of the supply chain is simple: “a sequence of operations organized around the flow of materials from a source of supply to the final distribution as a finished product to the end-users”(Hsuan et al., 2015). Traditionally, it includes the procurement of material and human resources and the organization of different firms that a product “touches” finalized to bringing the product to the end-users. It also involves coordination supporting enterprises, that indirectly come in contact with the process like providing transport, communications, and other specialized functions. Together, they create a synergy that a supply planner has to highlight and exploit while also consider the constraints linked to capacity, storage, forecasting, and cross-firms process. If the supply management is successful, they become a single coordinated entity that transcends organizational boundaries and reacts as a wholesome being.

Following this approach, when defining the scale-up a supply chain there should be certain linearity of choices. Starting from the procurement stage, this paper will define the best practices to adopt in terms of inventory strategies. Subsequently, 3 main distribution scenarios will be presented ensuring a different way of how to reach customers.

After, overall design of the main functions the paper will show the capacity issues for which Mush Materials needs to be prepared when scaling up, while the process management section will help them ensure a smooth and efficient allocation of responsibilities across the organization.

Finally, tools to monitor and define areas of improvement in the firm will be illustrated in the performance management section to provide Mush Materials with a dashboard through which testing their performance at any given time.

Procurement

One of the earliest phases that need to be configured to initiate production is Procurement. The essential materials that are going to be gathered for the production of mycelium boards are a) organic materials, that represent the growth substrate - in this case, it will be an agricultural waste - and b) mycelium, or better the fungi spores from which the mycelium will grow. This phase set up entails two steps for each material: the design of a supplying system and one of storage and inventory.

In order to ensure a sufficient and constant flow for those materials, a fine-tuning of the procurement plan is needed, and its key factor will be communication between suppliers and the manufacturing facility.

Agricultural waste supplying system

Agricultural waste will be supplied by local farms. Multiple sourcing for agricultural waste procurement is going to be used, because this will enable the firm to switch sources easily in case of failures in the supplying phase, like natural disasters, spoiled batches, and issues with transportation that can harm the production time and outcome.

Moreover, in multisource procurement systems, communications can sometimes be difficult and turn out to be a critical factor; the coordination and fine-tuning of information on availability and delivery times of raw materials and ordering from multiple sources at the same time are pivotal to ensure the proper flow and rate of production. This is the reason why a great effort will be dedicated to the procurement phase for agricultural waste (in order to maintain the chain's sustainability)

Inventory for Agricultural Waste

The inventory costs are made up of ordering costs and stock-holding costs. The ordering cost is low: the cost of the waste itself is almost tending to zero since for the sellers it represents leftovers from farms and agricultural production units, that weighs on their inventory and handling cost without generating value (Interview to Kristian, CTO). The expenses that must be taken into consideration are those related to transportation and handling from suppliers to the Mush Materials facility.

The solution that the author recommends is to minimize the transportation cost following the center of gravity method, that is a "method used to calculate the ideal position for warehousing and distributing facilities based on minimizing transportation costs"(Oxford Dictionaries, 2009). This method states that all locations can be scored and assigned a number that is the sum of all the expenses for transportation to and from that location. Naturally, the best location is the one that minimizes the costs (Paton et al., 2011).

So, first, the coordinates are determined and plotted on a grid. Then, an estimation of the volume delivered to each location is done. After, the coordinates of the optimum location are calculated as follows:

$$x = \frac{\sum x_i V_i}{\Sigma V_i}$$

$$y = \frac{\sum y_i V_i}{\sum V_i}$$

Where x_i is the x coordinate of the source i, y_i is the y coordinate of the source i, and V_i is the volume to be transferred from source i. For example, if we have the following Farms with (x,y) coordinates Farm A (1,2), Farm B (5,3), Farm C (5,1), Farm D (9,4). Plus, the respective volumes: V_A = 5 boards, V_B= 10 boards, V_C= 15 boards, V_D= 20 boards. This will translate into the below graph in Fig. 3

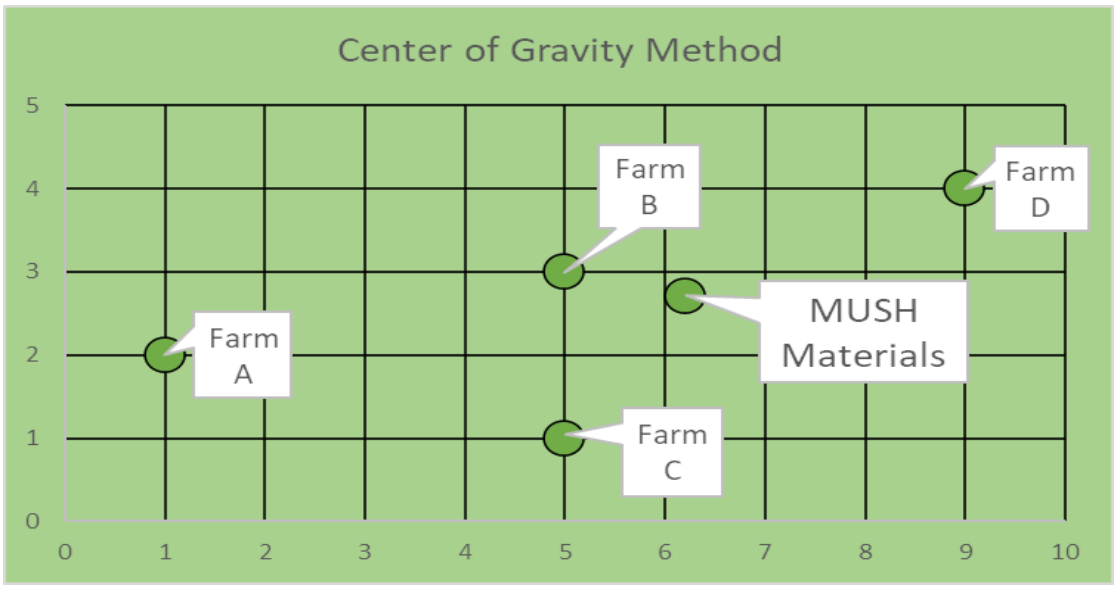


Figure 3 Center of gravity model for MUSH Materials

The solution proposed for this scale-up plan is to position the main facility near the supplying farms. This will help minimize cost while boosting efficiency and have the ulterior advantage that can be easily recalculated each time a new facility is opened.

Furthermore, since using multiple sourcing this solution will greatly increase the efficiency of the process of switching sources when needed and also help the flow of communications with the suppliers.

The stock-holding cost is on the contrary a high expense because agricultural waste requires a lot of space to be stored and specific conditions to preserve its status, like temperature, humidity, etc. Given that, the author recommends a cyclical price fixed review system as an inventory system for waste. This method, based on the assumption that local farms operate steadily and cyclically, will keep Mush Materials production aligned with the provisioners, ensuring its steady and sustainable flow.

Fungi Spore supplying system

The fusion of the Fungi spores determines the initialization of the mycelium growth and hence are one of the main components of the board's production. Opposite to the agricultural waste, that has a relatively low asset-specificity, mycelium is still an innovative product and currently under study, therefore it is not intuitive or well known yet how many different suppliers are needed in relation to a high production rate.

Such a decision is mostly affected by the number of different types of consistency that a firm would produce. Each mycelium-based material is produced by a certain combination of a particular species of fungi and the specific organic substrate. This pairing is based on observations in nature and empirical researches to find the best possible combination between the substrate and the fungi species and the optimal environmental conditions (humidity, CO2 levels, light exposure, etc.…) to achieve the best, in this case, thickest, growth density:

"Other that you start to basically to just all 5 parameters are like 1. humidity when you grow the surface 2. The amount of sugar in the substrate 3. the time that you grow it together 4. how much you sterilize it: that means how much CO2 you bring into the bags 5. and then how much light and bring into the bags depending on where you place your bags as basically some of the parameters that you can judge (and adjust).

Just like with plants the more you optimize these parameters the stronger the material gets because the roots of the mushroom simply just grow faster and stronger. Therefore, the faster and stronger the root grows the stronger the material will be at the end of the process." (Interview with Dan, CEO)

In order to ensure the reproducibility of the process, single sourcing is going to be used to provide high-quality materials, ensuring operations' success, and boosting the overall business competitiveness.

Another reason for preferring a single source approach for the procurement of the fungi spores is that the supplier is also destined to have a lot of research knowledge on the fungi and expertise in their cultivation techniques; representing the ideal partner for the exchange of R&D information. The transfer of such formal knowledge is one of the cornerstones to

upgrade current products and develop new ones (Grimpe & Hussinger, 2011). In fact, it is a well-known paradigm that a functioning supply chain has, amongst its goals, to develop trust and communication with its actors and to conduct joint improvement activities. So, scaling up the mycelium procurement operations to a top-level goes through enhancing the relationships with the supplier and eventually lead strategic allegiances, forming virtual enterprises, and possible future partnerships for new product development.

Inventory for Fungi Spores

As previously seen, for the fungi spores inventory, there are two types of costs: ordering cost, which is relatively high since they are living organisms and therefore need special treatment, and stock-holding cost, that is low due to fungi spores' long shelf life and the limited amount of physical storage that they require.

The author's recommendation for managing the fungi spores' inventory of Mush Materials is to implement a Quantity Fixed reorder level system. This kind of reordering system will help them monitor the material levels accurately, being more responsive to demand fluctuations. Furthermore, due to low stockholding cost the organization will be allowed to keep a relatively high safety stock, keeping the production in line.

Distribution

After setting up the procurement and inventory strategy, following the production phase, a distribution system needs to be designed. The mycelium board distribution is indeed customer-driven, therefore well suits the implementation of a pull system based on a Make-To-Order (MTO) manufacturing structure. Hence, a fast and responsive system must be designed to counterbalance the rather long manufacturing lead time and maintain competitiveness in the market. For this purpose, three different distribution scenarios have been developed and analyzed for production to be prompt in manufacturing almost every demanded volume:

1. Place multiple development points around the country

The first distribution scenario is to create a few development points around the country to shorten the distance between production and the final customer, as shown in Fig. 4. These

development points will be warehouses with limited equipment; they will be supplied by the main manufacturing unit of both the raw materials, fungi spores and substrate, and the molds for the growth and will be able of producing few batches at a time of mycelium boards. When the order comes in, it will be executed and produced in the unit which is closest to the customer. In case that the closest to the customer development point is incapable of fully producing, for example for a lack of materials or because already maxed out on capacity, the order is reassigned to the second closest development point which will help to serve the order by sending resources or even by manufacturing part of the batch if not all the order. As a result, this will minimize transportation costs and delivery time.

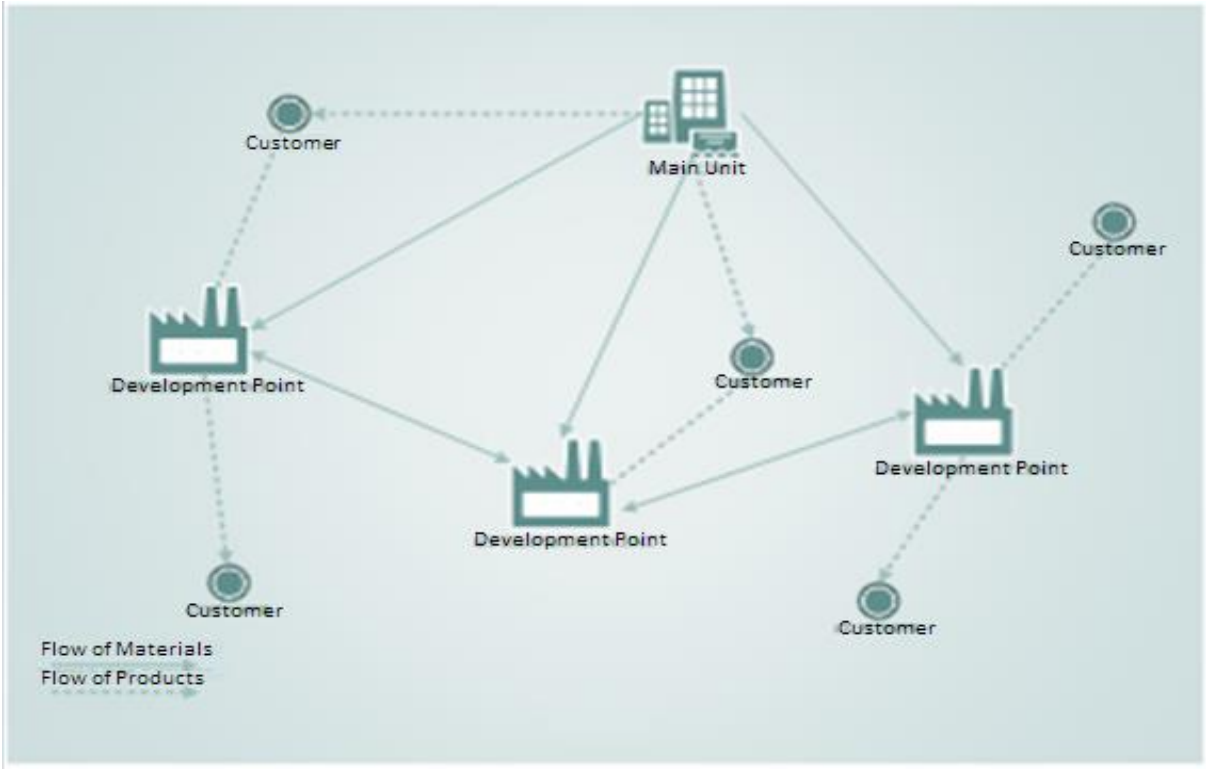


Figure 4 Distribution Scenario 1: Development Points

2. Grow the mycelium inside mobile units during the delivery to the customer

The second scenario is more flexible and designed for customers who are far away from development points. In this situation, the production of the mycelium boards will be completed inside the delivery vehicle while it travels to the customer, as per Fig.5. To elaborate more, the first stage of production, meaning the creation of the molds and the first stages of the mycelium growth inside of it, will be performed in one of the facilities and then

the batch is loaded onto the truck letting mycelium complete its full growth until the final stage of the board production, while it travels to the customer.

To conclude, this way reliability will be maintained even when an order comes from a distant customer.

Figure 5 Distribution Scenario 2 Mobile Development points

3. Attach a unit for production at the customers' location

The third scenario is particularly aimed to satisfy the order demands from companies that have large needs of boards and want to implement mycelium as part of their production process. The idea is to attach to the company site a dedicated and full-fledged production unit, funded by the commissioning company as part of investment Fig.6. The Mush Materials' role is instead to keep this unit running by continually supplying materials and personnel and maintaining the machinery upgraded and functioning. This way, the customer will have a steady flow of the final product stripped of transportation costs, except for the initial investment and at the shortest possible time of delivery. To sum up, this method is fitting to serving large and continuous orders and represents a possible expansion through the consumers' network.

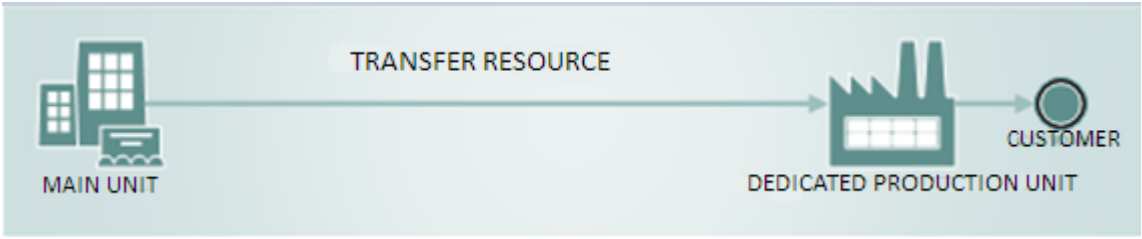


Figure 6 Distribution Scenario 3 Attached Development point

Capacity

Capacity measurement is a natural following step, that is needed in order to ensure the reliability and resiliency in a time of the system. The average mold for developing mycelium board products it is assumed to be 40cm X 40cm X 2cm. Considering the production cycle, the current set up can produce 100 small modules to be combined in an approx. 0,32m^3 volume of 16 m^2 area in 4 days employing 1 person, as shown in fig. 7.

This calculation gives the average capacity of the production based on the mycelium boards assumed as standard; any difference in the size of the required molds will, of course, have a direct impact on the capacity.

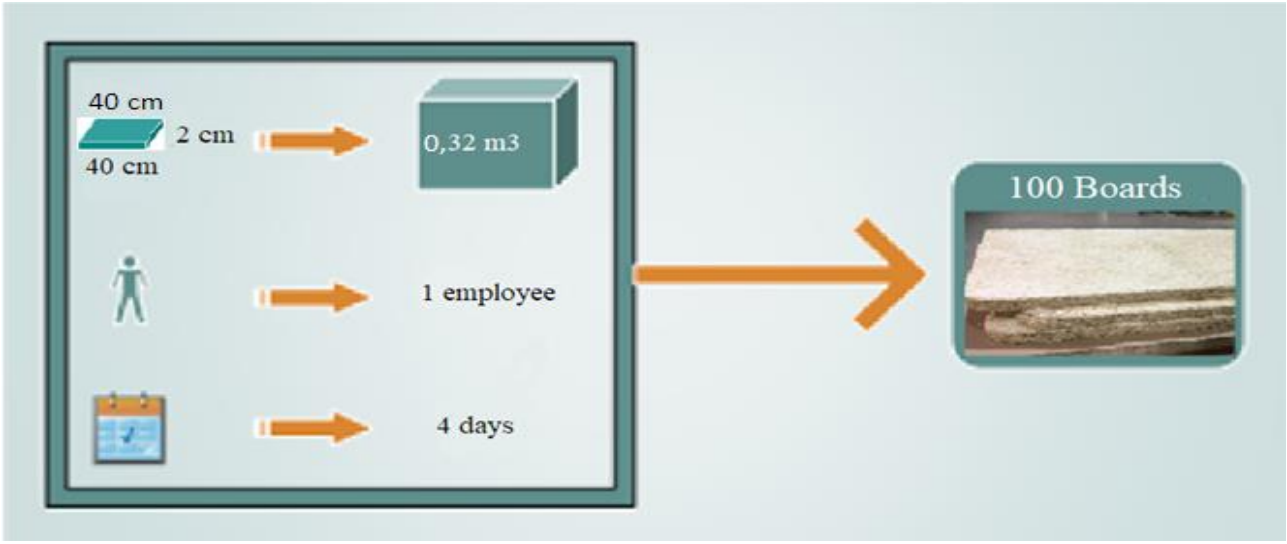


Figure 7 Assumption regarding the unit base measure of Mycelium Boards

Capacity Constraints

The first thing that needs to be considered before deciding on the capacity strategy which ones might be the constraints of the system:

- Staff and skill level: The level of skills required in mycelium board production is high. In fact, dealing with fungi and the cultivation of a living organism requires a piece of specialized knowledge, standardized procedures, good practices, and attention to details. However, staff can be trained on the necessary knowhow and become efficient in the manufacturing process, reducing mistakes, and optimizing capacity.

- Technology: Technology naturally plays an important role in mycelium board production. Any technological advancement can lead to an improvement or an optimization of this process. An important feedback tool in this regard is the implementation of monitoring systems, which will assist in maintaining the stock levels and its quality. These systems will help to track the production process providing information and statistics, that can be used to optimize the process and/or to test technological improvement. In conclusion, the end goal of actualizing technology in the production and management processes is to help to minimize mistakes, keeping the production steady, and ensuring an outcome that is compliant with the established standards (Interview with Kristian, CTO)

- Material availability: As previously seen, the materials utilized in mycelium board production are the fungi and agricultural waste. Having the main facility placed near local farms, according to the "Gravity center model" previously chosen, will give the supply chain continuous access to the amount of agricultural waste needed for production at any given time. Regarding the fungi availability, they can be stored and preserved for long periods at the production site without having a high stocking cost. Thus, Mush Materials can have a relatively high safety stock level reducing the risk of shortages and the material availability does not represent a big constraint to the Capacity.

- Storage of finished product: This is one of the main bottlenecks of any manufacturing process capacity. This is still true for the mycelium board production. The higher the volume of the production, the bigger the space required for the storage. In the case of mycelium boards, one of the attenuating factors can be the number and the type of shapes produced, since more modular shapes can be easily compacted and piled reducing the requirement for space.

So according to the capacity analysis, in the long run, the manufacturing bottleneck will be storage because a lot of space is required in order to store the mycelium mixture as it expands and takes its final shape.

Capacity strategy

At this point, the capacity strategy is ready to be defined and implemented. Complementary to previous theories, is that mycelium boards manufacturing lags demand: since it is a component product whose level of request is depending on trends in other

markets. Since the ordering system is MTO and the product is customized according to customer needs, production cannot be started unless the order is submitted or at least until there is knowledge about the demand. Therefore, the choice for the capacity strategy is the chase demand. When opting for this method, one of the requirements to successfully carry it on is executing a flexible and responsive warehouse and production management.

For instance, let us assume that the planner is foreseeing a substantial risk for overstock due to demand sensibly lagging in one or more of the items, in which mycelium is a component. Through a chase demand strategy, in order to minimize costs, the facility will be able to bring down to a minimum level of activity certain lines of production, without affecting the volumes in the level of storage at the warehouse. On the other hand, when facing high volume demands, utilizing the full storage capacity will be needed for the well-oiled production.

Forecasting

After deciding upon the capacity strategy, a forecasting method needs to be designed. The starting points to evaluate this are the choices made for procurement strategy (multi-sourcing and gravity center for agricultural waste and single sourcing and in site storage for the fungi spore) and the firm's capacity strategy (chase demand strategy).

All considering, the best forecasting method for Mush Materials will be the adoption of Collaborative Planning Forecasting Replenishment (CPFR) techniques, which include constant communications between Mush Materials, customers, and suppliers. This method is widely used in supply chain contexts as it serves as a roadmap to establish smoother communication among partners. Moreover, by adhering jointly to this frame, firms can coordinate and conform their planning systems, share information easily and correct their forecasts for the benefit of all the included parties (Hill et al., 2018). It is considered particularly suitable for complex and not fully disclosed supply chains, like the construction industry one.

Besides, exchanging information about sales and demand forecast will shorten the time to market of mycelium boards, minimizing even further the estimated lead and delivery times and, naturally, the costs for under and over forecasting. Furthermore, such a way of working will increase the rate of success for future item launches: more insights can be gathered, and

more realistic expectations are formulated. Summarizing, the CPFR will allow the supply chain to respond faster to demand changes, enabling the firm to commit and deliver to the customers at a steady pace.

Namely, Mush Materials can expect the following anticipated changes in demand:

- Seasonality: Although this sector is expected to run on an overall stable demand, more mycelium boards and materials are going to be ordered over some specific events such as back to school period or construction intense timeframes. (Interview to Kristian, CTO)

- Change of taste: More and more companies will try to adopt a mycelium board as material in their effort towards sustainability. Therefore, seconding the changes in the taste of the customer, stimulated also by an increased offer and variety of products, will be an exciting challenge in the future.

Process design

Another essential aspect of the scale-up of the supply chain for mycelium boards is the design of the processes from order placement until the final product is delivered. However, a few questions need to be pondered about before output reaches the final form.

A first aspect that needs to be considered is the variety of products. As seen in the "Four Vs" analysis for the mycelium board the variety is high due to the ductility of the manufacturing process and the possibility to tailor the batches production according to customer's needs.

As highlighted by the "Four Vs" tool, in this context (High Variety - High Volume) the main trade-off tends often to be between Volume and Variation. Therefore, in order to minimize such trade-off, the author suggests is to modularize the growing molds and to apply mass customization techniques to the manufacturing system (Paparoidamis et al., 2019)

First of all, modularization can be defined as "the partitioning of a complex process into a simpler one, so that each portion can be dealt separately"(Paton et al., 2011). It is usually applied during the design phase of a product to boost the responsiveness to customer demand. However, in this paper, a more creative and a wider approach is proposed by

suggesting three ways of incorporating modularity in the manufacturing: two modularizations of the molds used to shape the mycelium in place and the use of a basic form of mycelium material that can be differently shaped by the application of key pressure points before the final cooking and hardening of the product.

- Modular molds by shapes: the molds will be composed of multiple parts that can be assembled to shape the substrate-spores mixture in different manners. In this way, Mush Materials will not have to create new and different plastic molds for each customer, but rather will be able to build a set of a predetermined type of molds by rearranging their parts, much like building shapes with LEGO blocks.
- Modular molds by blocks: The final shapes may also vary in their tridimensional shape thanks to the insertion of blocks inside the mold, which will create new volume configuration inside the mold, and consequently a new shape. Having a basic form of molds that combined can create different final items.
- Modular shapes by pressure: Shaping a basic intermediate product by pressure, could also a be way to implement modularity. A basic cubic shaped mycelium product still not completely hardened will be the starting point. The desired shape will be obtained by applying pressure on specific points. It will be then made permanent with the final stage of mycelium growth and the cooking in the convection oven.

Additionally, mass customization will be a natural complement to the above-mentioned modularized production system. According to the Oxford Business Dictionary, mass customization can be defined as “The ability to create tailored marketing messages or products for individual customers, or a group of similar customers (a bespoke service), while retaining the economies of scale and the capacity of mass marketing or production” (Oxford Dictionaries, 2009). The author concludes that this mechanism suits particularly well this context: Mush Materials will present a certain variety of products, that can be then adjusted to the needs of the customer (who acts as a co-creator in the process). According to Da Silveira et al. (2001), there are 6 success factors for implementing mass customization. In the following list, the author is going to elaborate on how all six can and should be applied to the mycelium boards manufacturing.

- Customer demand for variety and customization: As stated before, the demand for this product is characterized by a high level of variation, thus meeting the favorable condition
- Appropriate market conditions: According to the previous Product Life Analysis, the market of mycelium products is already defined as an exponentially growing area. Therefore, by implementing a mass customization system not only the firm would be handling a high potential product, but also gaining a significant competitive advantage.
- Value chain readiness: The postponement, a fundamental phase in the mass customization of a product, should happen under the control of Mush Materials so that the demand for supplier and distributors would remain constant since the company has access to all the data from the process needed to elaborate an accurate forecast of the materials needs.
- Technology availability: Based on the previous elaborations and the Mush Materials founders interviews, it clear that the technology required to implement mass customization is largely available on the market. For instance, to realize the modularization all that is needed would be a software that analyses the desired shape and decomposes in smaller components or gives a map of the key pressure points.
- Customizable products and shared knowledge: These characteristics, which the author has already described, can also be observed by the fact that the customer can assume the designer position in the production system. This kind of relationship allows the firm to have an optimal translation of the customer needs into highly specific orders.

A second aspect that needs to be addressed is the laborers' skills level required. This is higher than average since it concerns the cultivation of live fungi. The employees will have to be well trained in the process where standardized procedures good practices and careful handling are essential for its success and reproducibility.

In conclusion, while capacity analysis revealed that storage will be the warehouse main bottleneck, the author suggestion of modularizing the molds and applying mass customization principles to the portfolio of a product should support Mush Materials in their expansion on this front

The management of projects and performance

At this point, it has been presented how to fully exploit a high potential innovation and it has been suggested how to map out the processes behind the board's creation, as schematized in Fig.8. Now, it is introduced an analysis of practices that are conducted on a management level: mainly project and performance management.

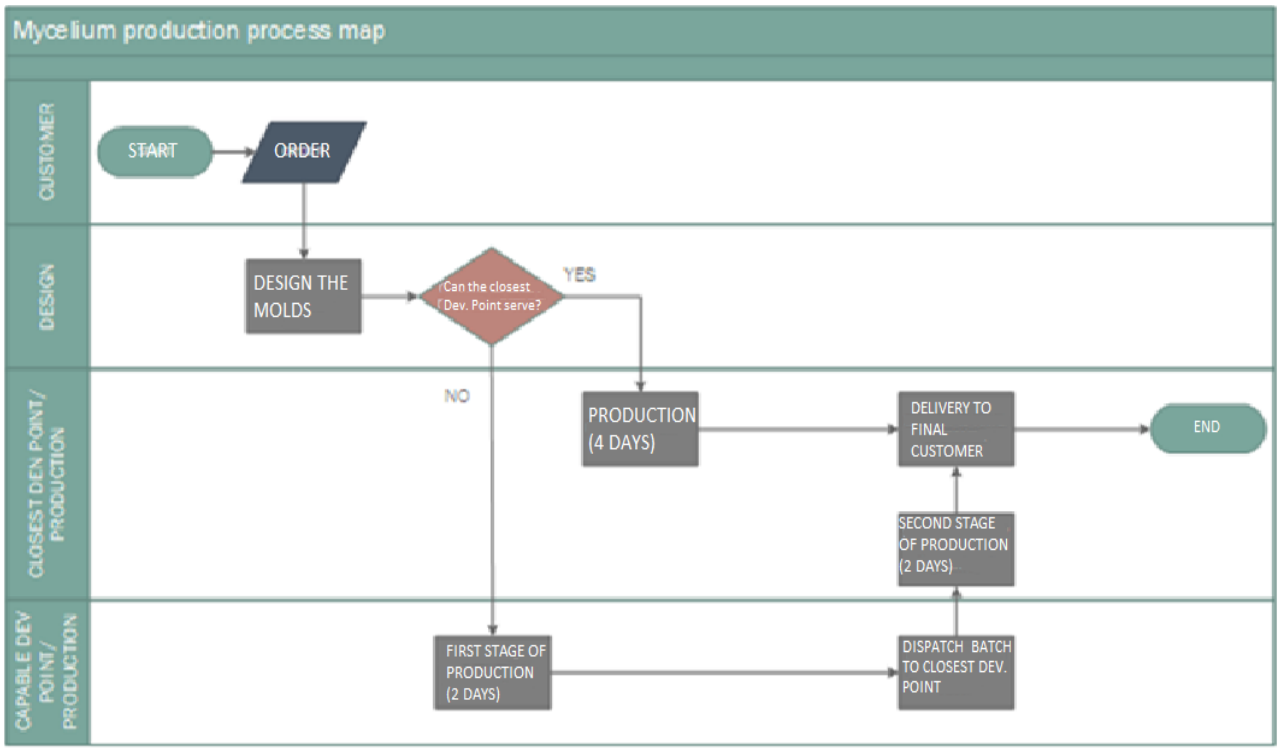


Figure 8. Illustration for Mycelium production processes and owners

Types of projects

Mush Materials can expect to have a continuous flow of the standard product-oriented project rather than individual projects, which require a special project team assigned to them. There could be different kinds of projects within the company, such as dealing with new customers, expanding the facility, coming up with new textures and attributes for the material, launching new products, or setting up a high-volume marketing campaign.

Depending on how many projects the company encounters, it should organize its structure accordingly: the most suitable structure would be a linear functional organizational form. When dealing with a project, selected trained employees from each department will be assigned to a project manager.

Another aspect to be considered is the possible tradeoff between cost, time, and performance. Different projects require different results and it is extremely difficult to say which one Mush Materials will be faced with and should focus on. However, the author believes that performance should be the top priority, the case firm needs to prove that the mycelium boards can assume the same characteristics of the particle one and fully satisfy the need, with no exception, with the added benefit of eco-friendliness. Matters of cost and time are always expected to improve, as the company grows and acquires more expertise. In the long run, for the company to stay competitive, it needs to show consistent performances in time, and it can offer a cheaper alternative. The perfect case would be, of course, when everything is done according to plan and no trade-offs are presented.

Depending on its capacity and its capabilities, a start-up company should be aware of its strengths and weaknesses and evaluate whether undertaking some projects is viable and more importantly profitable. For instance, if a big customer wants a one-time big scale delivery, careful considerations need to be made around the availability of the firms' resources to execute their process on such scale. A limitation identified in the case of Mush Materials (Interview to Kristian, CTO), is space when dealing with high volume orders. Since the mycelium shapes need about 4 days and specific conditions to be stored, so it becomes clear how production space and storage condition as discussed previously. As a result, the most suitable choice for the well-being of the overall operations could be to reject big scale project proposals until ready to face such constraint.

Planning and budgeting projects

Exploring further how the project should be managed an in-depth knowledge of procedures and tools to be used it is required for a positive outcome. All projects should start with planning: breaking them down the project into activities, estimating their time and cost, and assigning material and human to them. In this context, the author suggests using the Work Breakdown Structure (WBS) and the responsibility matrixes as it is the best for new companies like Mush Materials. Here is an example: an example of a project of working with a new customer that could be:

WBS: Deliver 5 test mycelium foams, for each of their 10 products to an electronics producer looking into collaboration with the firm.

The activities are defined, and the responsible persons are assigned to each activity as follows:

Level 1: Establish sizing, volume, consistency of mycelium texture

Level 2: Develop necessary molds with the supplier

Level 3: Mix ingredients, fill molds, let sit and dry.

Level 4: Storage and transportation to the customer.

Level 5: Supporting the customer and making further agreements.

Tasks	Technician	Manager	A worker	Designer
#1	2			1
#2		2		1
#3		2	1	
#4		1	2	
#5		1		2

1- Main responsible person; 2- Second person to support the process

The given example can be treated as a project and - if it happens repeatedly – can be included in established operations. Nonetheless, to maintain a smooth organizational flow in the company it is helpful to develop standardized tools to reoccur the process.

Once the responsible resource has been assigned and the path is clear, the next step is developing a budget. This can be made as top-down, by asking managers/engineers to estimate the costs, or bottom-up, by taking each part of the project, estimating the costs for each activity, and then summing them up. Depending on the project's nature, either way, could be a good fit. However, underestimations can be a problem, especially at the beginning of the development and expansion of a company, when there is not enough know-how and managers tend to be eager for high results.

The failure to adhere to an initial budget can have huge consequences. Hence, for the beginning, it would be suggested the bottom-up strategy, since all tasks are analyzed one by one, with the involvement in the decision-making of more than one person, who will be able to keep each other in check. If projects, such as developing test mycelium foams, like in the example, start becoming repetitive, then the top-up approach will be more suitable.

Scheduling, implementing, and ending projects

Planning and budgeting are followed by scheduling. For this, there are multiple tools such as the Gantt chart or network activity diagrams. In the scheduling phase, the time and order of activities are detailed, so that the whole team is aware of what can be started and when. Sometimes, some activities are propaedeutically and the whole project depends on how they are done. In the example above, designing the mold and its manufacturing (level 2) is the crucial one. It is a simple task, but if there is no shape for the foams to grow in, then the other procedures and activities cannot even start.

While the projects are being implemented a manager should track the performance of the projects by using ratios, such as the Cost Performance Index (CPI) or Schedule Performance Index (SPI) (Paton et al., 2011).

- The CPI is calculated as (budgeted cost of work performed)/(actual cost of work performed). If the number is 1 then everything complies with to the budget; if it is higher than one, then the project is requiring fewer resources and results are better than expected and if it is lower than one then estimations are lower than actual costs therefore project is draining an unexpected amount of financial resources.
- The SPI follows the same logic and it is calculated similarly, only using the time in place of the cost. The final value will show whether the performed work keeps up with the scheduled one.

Last but not least is defining the ending of the project. An example used, it is essential to receive customer feedback on whether they have received what is expected and how their experience could have been improved. These are decisive information that can influence the company future decisions like, chooses to switch from particle boards to mycelium equivalent. Proper communication between firm and customer from the very beginning builds up trust and good reputations for both parties, which is what Mush Materials should be keen on having.

Performance management

Regardless of whether the Mush Materials is a project-oriented company or not, their performance should be monitored to inform the management on the effectiveness and efficiency of their operations in a timely manner. Performance management is all about

reviewing how the processes are performed and their progress status, in a systematical way that allows them to keep them on track and aligned with the firm's mission and strategy while highlighting the areas where performance can be improved.

Mush Materials' storytelling for this product can have various formats; it can be along the lines of "pushing sustainability forward, starting with natural boards" or in an easier way "encouraging and providing sustainable construction material". If this is their main statement, then the next point in their storytelling will be how they want to achieve it. What is needed for them to accomplish the said goal?

An issue frequently talked about is the misalignment between the ideas of top management and the implementation at the "bottom". Many times, the mission is not communicated to the employees, or if it is - then it is easy to lose its track amid all the everyday tasks. Therefore, a performance management system is intended to make sure that what is important for the mission and strategy is monitored, measured, and that operations are aligned with it.

Especially in a start-up, such as the Mush Materials, several aspects can be evaluated and measured. The results can be used to improve the aspects which are lacking. However, it should be kept in mind that the best way to successfully design and maintain an evaluation system is to make it not burdensome but rather flexible and reliant on active feedback. The measures need to be compared to a standard and the resulting information should be able to be used for corrective policies and actions. However, the right balance is important, if too much time is allocated to measuring and too much data is collected, then it can end up being a waste of resources, and a "less is more" approach should be developed.

The processes in this paper's study case are defined (at least the general ones), so it is easy to identify measures that will capture how well the processes are done. One possible way to develop a performance measurement system is by taking 4 perspectives to look at the company:

Perspective	**Possible Key Performance Indicators (KPI)**
Financial	• Sales per Month, • Profit margin, • Market share (± percentage variation)

Customer	• N° of new customers per Quarter, • Customer Order Fulfillment rate • Customer retention rate, • Customer feedback (quantitative)
Organizational	• Cost of storage per Unit, • Space utilization (How many Pallets per products are stored), • Average transportation costs per Unit, • Lead time, • N° of different designs produced, • N° non-conformities per Batch, • N° Business partners per Quarter
Growth and Innovation	• New production technologies developed, • N° of patents registered, • New consistencies produced, • N° Collaboration with external R&D actors (e.g. Universities)

The financial perspective is a very important one, but often overrated. Mush Materials should be able to have an increasingly higher and higher standard level for its sales and market share since the innovation on which the company is based is (at least in the author's opinion) something with great potential.

The customer perspective is all about how good the interaction with the business/client is and how likely are to recommend their experience and convince new customers. Some of these measures can be hard numbers, e.g. expecting a number of 1 or 2 new customers per quarter, and some measures are more intangible, but can still be quantified, e.g. customer satisfaction. On this topic, customer satisfaction, in the beginning, can be derived from direct communication with the end-users, especially now that Mush Materials is still small, with a few clients. Once it expands and there are multiple volumes and orders to be handled, the customer satisfaction can be measured by sending surveys, where the answers are ordinal and then can be easily compared to the desired standard (for example achieving an 8.5 out of 10 for the overall buying experience).

The organizational level comprises matters of internal processes, especially the technical aspects of the business, such as procurement, storage, production, and transportation. This is the category that should be most monitored the most since in many regards they are the core activities of the company. If everything is done effectively and efficiently in this category - assuming that the product is affirmed and performing strongly on the market - then the other KPIs will automatically increase as well. When talking about the organizational/operational perspective, it would be useful to also define the operations performance objectives clearly, since the KPIs should work towards increasing these 6 performance ones:

Objectives	**Example of KPI's**	**Comments**
QUALITY	% defects, customer satisfaction	Because dealing with a living organism, the quality is a critical aspect subject to risk. The quality of the product heavily relies on the proper and optimal growth of the fungi and, as a consequence, impact the final performance. In terms of functionality, the mycelium boards are expected to perform equally, if not better than particleboard. Moreover, the reusable nature of the product will allow Mush Materials to rework any faulty piece into a new object (Interview to Kristian, CTO)
SPEED	Lead time, Delivery time, Tak time	Because of the 4 Days lead time limit that the final growing of mycelium takes, there is no way of reducing this time in the production process. So, the only areas of improvement are complementary services, such as transportation and handling time.

DEPENDABILITY	% of orders completed on time and in full quantity, and wholly compliant with the firm's standards	It can be increased with an efficient and up-to-date demand forecast system and multi-tier inventory management that will allow the customer a good flow of products at any given time. Mush Materials' raw materials are never going to run out completely since one is produced as waste regularly all around the world and the other can be grown internally. The issues that could heavily affect the capability of delivering are that related attend to the fungi cultivation
FLEXIBILITY	The time needed to change an order and still deliver on time	Mycelium products are exceptionally ductile since they can either be mass-produced through the use of combined modules or carved to satisfy any kind of shape the customer might want. Customization and rapid response to each demand should be Mush Materials' strength to gain a competitive advantage over competitors

COST-EFFICIENCY	Man-hour/ Production per Unit	Overall, the production for the firm's portfolio is cheap to source since the process is fairly straight forward. However, the successful execution of the process is based on the skills of the responsible employee. In other words, one person with the right expertise can produce a big number of products, in a batch system like this one.
INNOVATION	N° experiments conducted, New technologies and consistencies developed, N° of patents registered	The pluripotential nature of this material by itself is quite innovative. It is a recent rediscovered business, which can be easily copied and replicated, but the registration of patents should discourage any incumbent threat. It is crucial for a product in the development stage that the intellectual property and the resource invested in its research and enhancement are protected. The idea of mycelium added to different substrates, in different proportions gives the possibility of a very wide range of products which can be created from it. The fact that mycelium boards can be made to be naturally compostable at the end of their life is most definitely a game changer in the field of processed wood.

Considering the above-illustrated table, the paper proceeds to illustrate a comparison of performance objective between particle boards and their mycelium equivalent by Mush Materials. The comparison graphically illustrates how the author, based on information collected in the interview and on personal research and analysis, has assigned two scorings for each category at present and in the near future after the recommendations of this paper are implemented at the firm. The overall criteria are that the goal is that the sum of the scores can be summed up to 1 - with this assumption in mind - the values are based on the authors' observation and analysis of the literature plus the data collected in the interviews.

Then, all of the above is plotted on to a radar chart, where the different performance objectives are reported. The tool used to describe such differences is the below Polar Diagrams shown in Fig. 9a and Fig. 9b (Hsuan Professor, 2018; Paton et al., 2011).

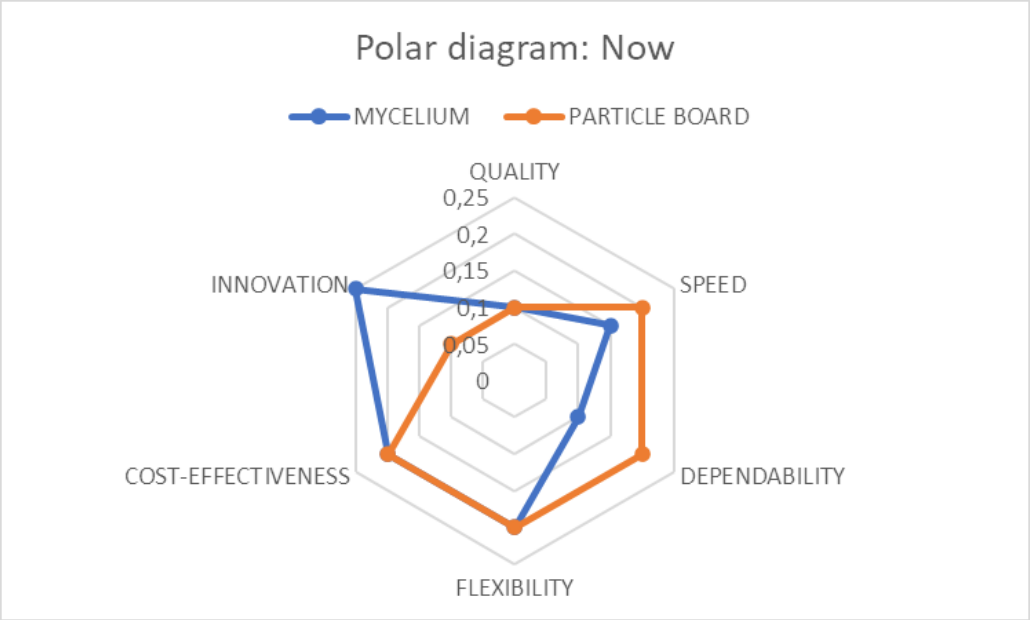


Figure 9a Model adapted from Hsuan Professor (2018) based on info from interviews

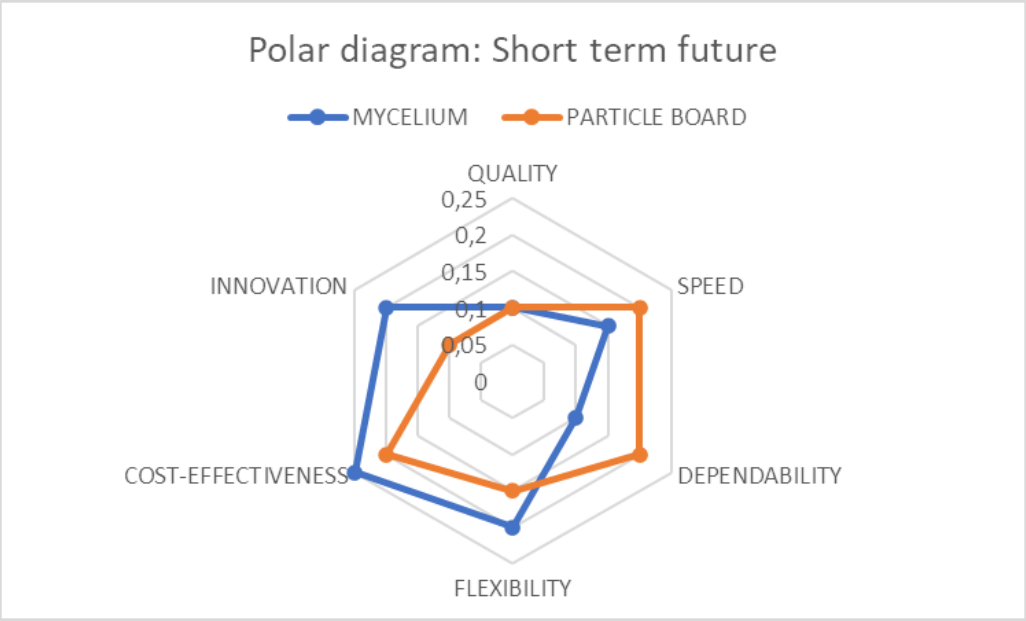


Figure 9b Model adapted from Hsuan Professor (2018) based on info from interviews

From an overall look, it is possible to say that both materials do not perform high in all of the categories. One of the features of the Polar diagram on Performance Objectives is that it can highlight the weak spot where to focus on when developing a measurement system in order to obtain maximum benefit from their improvement. It should also be considered that very often companies can be very successful by only exceeding a few of these objectives and levering their strengths against the underperforming ones. Therefore, while it would be ideal, it is, in reality, almost impossible to fulfill all the performance objectives at all times.

Anyhow, as it can be seen by the diagram above particle boards outperform mycelium in (1) Speed: they are produced faster and most of the facilities can count on an already operative market; in (2) Dependability: there is little risk associated with the production and delivery of particle boards as it is a mature product and most intrinsic obstacles have been already acknowledged and acted upon. The leadership in these two performance objectives is estimated to be undefeated both at the present and also in the near future.

On the other hand, mycelium boards score higher in (1) Innovation: given their pluripotential nature and the variety of possible applications still not explored, it is reasonable to assume that this aspect would be the competitive advantage of mycelium boards, the ability to suit multiple needs with a unique material; in (2) Flexibility: by implementing a modular way of design and production Mush Materials will be able to react

effectively to any customers' adjustment or last minute request, for this reason they might not be able yet to contend with their competitors at the present time but surely they will be in the near future; (3) in Cost-effectiveness: this can be a controversial point since at the present producing mycelium is not cheap at all (Interview to Dan, CEO) as the technological costs are still quite high and the production volume is limited, however given the low cost of raw materials, it is very likely that in the near future economies of scale will be established, decreasing the amount spent on the R&D, while keeping the revenue up and even gaining a market share over the particle boards. At the same time, governments will eventually start to promote more environmentally conscious material and taxing polluting ones, and this will increase the cost for manufacturing particle boards, which are going to indirectly pay for the negative externalities generated. For this reason, it is an educated guess that the future cost-effectiveness of particleboard will be inferior compared to the mycelium alternative. Lastly, regarding Quality both are believed to be scoring low as mycelium is subject to spoiled batches and particleboard is also exposed to multiple damages during production and storage (e.g. breakage, humidity, low-quality raw material). Whereas particle board suppliers are used to material handling, the mycelium materials production requires special attention to reduce – even if not eliminate – the risk. Unfortunately, the special and standardized mycelium handling policies increase the cost per unit, therefore the quality aspect should be evaluated case by case for a more precise evaluation.

Conclusion and Final Recommendations

In this paper were proposed several options for how a company, in the case study presented Mush Materials, implementing the mycelium items innovation can manage the supply chain matters of their business.

After having illustrated the production process of the Mycelium boards and a systematic review of the literature regarding Environmental Innovation manager in the Introduction, the argumentation started by describing on how to manage the product as an innovation with the help of tools such as the product life cycle, the "Four Ps" and the "Four Vs". The author has come to the conclusion that mycelium as innovation is at the beginning of the growth phase and that represents an incremental innovation as Product and Position Innovation, while is a radical one as Process and Paradigm Innovation. Furthermore,

through the “Four Vs” tool, it has been established that a mycelium producing company’s output will have high volume, high variety, low variation in demand, and low visibility.

A map of the entire supply chain has been presented, analyzing the Procurement stage for the main components of Mycelium boards production: agricultural waste and fungi spores. Given the availability and risk involved with the recommendations were proposed for supply and inventory costs and strategy, also taking into consideration the type of relationships with the preferable suppliers. Specifically, a multisource solution according to the model of center of gravity and a cyclical review system as inventory strategy has been recommended for the agricultural waste”, while single sourcing and a Quantity-fixed reorder level system were the option reputed best for the fungi spores.

Then the Distribution stage of the scale-up supply chain designed has been taken into consideration. Three distribution scenarios were presented to better support the case study firm in all possible directions: namely multiple development points, Mycelium growth on the mobile unit, and unit production at the customer location. These solutions will enable Mush Materials to adjust the way they distribute depending on the size and distance of the order.

In order to execute a supply chain Capacity assessment, the author has first analyzed the Capacity constraints like the staff/skill levels, material availability, and the technology which all resulted to be from low to moderate. However, the one that represents the actual bottleneck for the supply chain is the Storage and for this reason, it was recommended a chase demand strategy, along with a flexible and responsive warehouse and production management; as a forecasting method, the one judged to be the most appropriate has been the CPFR.

To complete the design of the Mycelium boards scaleup supply chain a process design has been drawn in order to identify and address other possible constraints. As seen in the “Four Vs” analysis, a discrepancy in this trend for the item brings the manager to solve a trade-off between Volume and Variety. The author's suggestion to solve this issue is to modularize the production (Modular molds by shape and by blocks and Modula Shapes by pressure) and to apply mass customization principles to the portfolio of the product should support Mush Materials in their expansion on this front. These solutions were detailed in the “Process Design” section, there were also discussed the 6 success factors of mass

customization and the level of involvement and role of customers in the design process, placing them in the co-creators or regular users' category. Implementing these solutions will contribute to a more flexible and cost-effective supply chain. Some of the constraints discussed and their suggested solutions are summarized in the table below:

Possible issues	**Related Solutions**
Low-Quality Level	- Single/Multiple sourcing: each substrate should have a designed supplier as well as back up reference partner face shortages - Communication: Encourage collaborating parties to a more constant exchange of information regarding supply to counterbalance the lack of smooth communication and provide constant feedback to other actors in the chain
Capacity Uncertainty	- Share Data in the Chain: Set up regular checkup meeting and target together with external and internal stakeholders to detect early on shortages or overstocking situations - Modular products and molds: Modular mycelium boards can be produced in high volume and be combined differently to live up to the high variety that co-creator customers expect
Delivery Time	- Flexible distribution scenarios: The presented model offers 3 different scenarios to better suit the distribution configuration to Mush Materials present and future needs

The last part of the scaleup supply chain design concerns the management of the projects and performance A process map was developed (Fig.8), making it clear in how orders would be handled at the Mush Materials. It was also discussed on how projects should be dealt with throughout their stages of planning, budgeting, scheduling, implementing, and ending.

Last but not least, performance management was covered. Four perspectives on how one can look at the company's performance were shown: financial, customer, organizational, growth, and innovation perspective. A particular emphasis was given to the organizational

perspective, where possible KPI's were selected based on six performance objectives, that are quality, speed, dependability, flexibility, cost-efficiency, and innovation. Mycelium boards, as they are produced at Mush Materials, were compared against particle board on a double-time horizon scale and on the above-mentioned performance objectives to see the strengths and weaknesses of their production. Especially useful was to plot these in comparison to the competitors in polar diagrams, that highlighted where Mush Materials portfolio could beat the competition and where it could be beaten by particle boards.

Finally, based on all the above data the author has elaborated on what the next steps for Mush Materials could be all along with the paper. Here they have been schematized in three tables, where they are distinguished in short, middle, and long term recommendations and presented along with the literature review Statements that were their starting point and the paragraphs in which the executive ideas are presented.

Statement S1 From Literature review		
"Most authors agree on the existence of a particular branch of Innovation Management, that deals with environmental impact. At the present, the level of awareness is fairly low, and it is very context-related and business-specific. Sustainability must be a core value for a successful implementation of environmental innovation processes"		
***Short Term (6 mo - 1 yrs)* Recommendations**	**Medium Term (1yrs– 3yrs) Recommendations**	**Long Term (3 yrs. – 5 yrs.) Recommendations**
• Promoting knowledge to the academic audience, encouraging more studies and research to be done on future applications • Financing more detailed studies and research on different areas of applications, in the context of various markets and comparison with competitors and research	• Target sustainability-oriented niche customer, even if mycelium's performances are comparable to particleboard, sustainability is still the main selling point and it should be exploited	• Keep promoting coherence between the sustainable mission and the business practices carried forward
***Paragraph with executive ideas**: Performance management*		

Statement S2 From Literature review		
"Environmentally sustainable innovations thrive when solid partnerships are established, and universities are involved. However, they can't be long-lived if not supported by the introduction of new materials and designs that replace old ones with the better environmental performance"		
<u>Short</u> Term *(6 mo. - 1 yr.)* *Recommendations*	**<u>Medium</u> Term (1yr– 3yrs) Recommendations**	**<u>Long</u> Term (3 yrs. – 5 yrs.) Recommendations**
• Keep close the partners acquired through **feedback and communication** • Make sure to obtain **technical and formal certifications** that Mycelium boards performance is the same if not superior to particle boards	• Choose **partnerships based on products** e.g. joint ventures with bigger players • Invest in the development of **new materials and designs** • Rethink production process and portfolio offered to **incorporate modularity** in the way of working (WoW)	• Plan out a pertinent **distribution network** following one of the described models
Paragraph with executive ideas: *Distribution, Capacity, Four Ps, Four Vs*		

Statement S3 + Statement S4 From Literature review		
S3: "Laminated processed wood industry is highly saturated and in need of modernization process toward more environmentally conscious disposal of waste. The business context is characterized by a general lack of awareness and communication along the supply chain. Future innovation may take place by first approaching the market with modular upgrades of current products."		
S4 : "Customers in a green innovation context are likely to be more involved but should be at the level of co-creators to preserve the functionality of a company. Modularity could be a way to resolve the performance- sustainability trade-off perceived by clients."		
<u>Short</u> Term *(6 mo. - 1 yr.)* *Recommendations*	**<u>Medium</u> Term (1yr– 3yrs) Recommendations**	**<u>Long</u> Term (3 yrs. – 5 yrs.) Recommendations**
• In light of the complexity of this industry and their strong inclination toward low-cost and high performing material, **this paper advice Mush Materials to hold on a full-scale launch of their product in this category** • Reach out to actors in the mycelium supply chain and **strengthen those relationships**	• From this argumentation point of view, it would be more proficuous **launch Mycelium products as an alternative to disposables**, such as mycelium coasters, buffers, or light protection helmets • To aim **at the construction industry,** Mush Materials should try entering the market, at first, **with some add-ons to existing products rather than full objects** e.g. extension board for tables; or other small additional pieces like the lamp	• Keep funding project that helps develop more **efficient technologies for shortening the lead time**, prolonging the shelf life and internalize the procurement of fungi spores
Paragraph with executive ideas: *Procurement, Capacity, Distribution*		

After this analysis, the author believes that this innovation has great potential and that suitable management of the supply chain, embedded this innovation could result in a game-changer competitor in the building industry. The presented product would also have an effect on the supply chains of all actors and in the way they are perceived in the eyes of their customers.

However, at present, the author does not believe this to be the best strategy for Mush Materials. The adverse factors are that the construction industry has high complexity and a strong inclination toward low-cost and high performing material, the yet not proven and not certified equivalence of performance of Mycelium boards compared to the particle ones, and the fact that as a start-up company they require a target market in which thrive rapidly, before being able of bigger investments for research, storage and so on.

The author stands firm in the belief of Mycelium materials as an Environmental Innovation with huge potential and that eventually, mycelium boards will be able to take over the market of process wood both in the furniture and construction industry.

From a business point of view, however, the author firmly advises Mush Materials to hold on a full-scale launch of their product in the construction industry for the moment, but to keep this as a goal for the future expansion of the company, hence the recommendations on pursuing further research and improvement on the technical aspect of the production and the features of the Mycelium boards.

As a more immediate business goal, it would be more proficuous to launch Mycelium products as an alternative to disposables, such as mycelium coasters, buffers, light protection helmets, or similar products. Furthermore, to start getting recognition for their products and their firm in the construction industry and the somewhat related furniture one, Mush Materials should try entering the market with some add-on rather than full objects e.g. complementary pieces for constructions, like doors or extension board for tables; or even small furniture pieces like lamps.

After this analysis, it is plausible to believe that this innovation has great potential and that suitable management of the supply chain embedding this innovation could result in a game-changer competitor in the building industry. The presented product would also affect the supply chains of all actors and how they are perceived in the eyes of their customers.

Academic implications

This paper has various possible academic implications. Here is a list of the main ones:

- The interdisciplinary approach taken during the literature review positively contributes to the academic discussions. Investigating Waste Management as a Branch of Environmental Innovation Management is in itself a source of innovation, which substantially diverges from the classic collection of practices to dispose of an end-of-life product. Furthermore, the two disciplines can interact with and contribute to each other and some of them can be exchangeable, thus, enriching the literature with new interdisciplinary topics.
- The use of modularity, not only as innovative practice, but mostly as the foundation to scale up incrementally and steadily the supply chain for a small reality with limited resources like a startup is also a relatively new concept, or better a new application of an already well known one.
- The lens of Operations Management has been used to offer a context-dependent take on a common Sustainability issue: the better option is available, but it is preventing from entering the market by a series of barriers. Most often the easier way to the bigger public is to provide evidence-based studies. (Howick et al. 2011, Rousseau 2012, Sackett et al. 1996) This paper precisely offers an example of interlinking Operation management, Sustainability research, and a case study.
- This thesis s an exciting instance for the academic community. It clearly shows how it can be proficuous and interesting to postulate solutions for new and underexplored material from a scientific and business point of view, as well as collaborating with a young start-up company, with little to no structure and hence more flexibility in a way: the creative power of a literate's mind can surely benefit from such a challenge.

Empirical implications

Throughout this paper, some interesting empirical implications can be found. Here is a list:

- The operational methods used in this thesis may go against the elegance of closed-form general solutions for formal problem formulations, which is the currently preferred style in some of the top journals analyzed. However, elegant solutions to abstract problems hold validity and real interest-only for a small peer group in academia. In reality, context

and evidence-based solutions are what business and society need, and specifically Mush Materials needs to figure out how can be impactful in its business environment.

- Lastly, one more step is necessary. A bigger effort is necessary for "translational research", which is turning research results into easy-to-use practical tools. Practitioners and decision-makers need these tools to develop intuition and convince themselves of the robustness of a proposed course of action. Too much useful knowledge remains buried under jargon and Greek symbols in highly technical papers meant to impress peers rather than being broadly accessible to those who could make excellent use of it (Wassenhoven, 2019).

Future research

Future research can be surely done around those sectors mentioned in the recommendations, like businesses around disposable items. In particular, conducting a SWOT analysis in other markets can highlight new opportunities for Mush Materials.

Furthermore, it is a wish of the author to give more visibility to a firm like Mush Materials and others who deal with mycelium production. Therefore, she hopes to contribute further to the literature on this material by reaching out to other small realities around the globe to compare and enrich the global understanding of this matter.

Limitation

- Participation error: interviewees not understanding the questions, or influenced by an external factor (current mood and amount of time dedicated to answering)
- Participant bias: any factor that might induce a false response
- Researcher error: Any factor that alters the researcher's interpretation of the gathered data (hidden meaning and clues missed)
- Researched bias: any bias consciously or not induces in the researcher's recording of responses (leading questions, nonverbal cues toward an answer rather than the other, English as a second language
- Concerning the limitations of this study, the author acknowledges the drawbacks of the systematic literature review methodology, especially those concerning the literature sampling criteria and analysis.

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Appendix

1.

Author(s) Name(s)	Main takeaway	Direct quote	Section to which it refers
Trigkas 2012	Study analysis of the wood and furniture industry underlining the importance of (green) innovation. Plus, providing a benchmark that could be used later on in the paper to compare particle board to mycelium boards	"The study provides useful data concerning innovation in the sector, and the efficiency analysis proposes a benchmarking tool to set margins for business operation improvement. Industries struggle to strengthen their competitiveness in global markets. The findings show the absence of a strategy in the wood and furniture sector concerning innovation, and utilization of the relative expenditures. The present study expands on previous research and knowledge, offering a profound analysis of the effects and improvement of innovative activity in the wood and furniture sector"	Literature review
Grimpe 2013	The importance of firms and university born start-ups to expand knowledge. Two types of knowledge transfer: formal and informal. They are both needed for a partnership to work out and produce	"Our results also have important management implications. Firms interested in setting up a relationship with a university to transfer knowledge and technology should be aware that the full potential of such a transfer can only be realized if both transfer	Literature review

	a solid innovative product/process	channels are used. The reasons for this are twofold: Firms require not only the codified knowledge, e.g., in a licensed patent but also the tacit knowledge surrounding a particular technology. In this sense, establishing a permanent relationship with a university with varying degrees of formality or informality seems to be key in benefiting from knowledge developed externally at universities. Moreover, our empirical analysis highlights the importance of the absorptive capacity for KTT and its exploitation within the firm"	
Hooge, S (2016)	Pro-interdisciplinary because companies already are partnering up to create more sustainable products + link to the fact that innovation sources have changed	"Organizational mechanisms of collaboration exceed open innovation logics to focus on the collective creation of favorable conditions for the emergence of new industrial ecosystems"	Literature review

2. Transcription of the interviews

Kristian Ullum Kristensen, Chief Technology Officer, CTO

1. Please, briefly introduce yourself and qualification

C: should we get started? OK so first of all thank you for agreeing to this and for being so understanding. So, you have seen the questions, right?

K: yes, I just saw them yeah

C: And May I have your permission to record this call for like methodology reasons
K: yeah
C: Ok, please introduce yourself and company Mush Materials?
K: yes well hello my name is Kristian and I'm a master student at the Technical University of Denmark where I studied design and innovation and then I'm also the cofounder of this small startup (Mush Materials) where we develop and research in mycelium technologies and mycelium products. I function as the CTO (ndr. Chief Technology Officer) in the company where Dan (Dan Skovgaard) is more like the CEO

2. Can you tell us about the functioning of the mycelium manufacturing?

K: Yes, well it's the technology... the mycelium technology can be used in various product categories and the mycelium functions as this natural glue in organic materials so it can be used to many things where traditional glue is needed.
So you would need some kind of organic material and then you would add the mycelium which is the root system of a mushroom and then you would need to copy the natural, let's call it "environment" of the mushrooms in form of the correct humidity temperature and so on. After some weeks the mycelium will have found this organic matter together and you will end up with a strong and lightweight material. That's like the basic of the mycelium manufacturer

3. What is your Supply Chain's issue? What is the issue you would like this thesis to elaborate on?
K: Oh well Our issue right now it is definitely the price of a potential product and this would mainly be about to the time that it takes to grow a product.
Because we can get the substrate and the organic material for free or even get paid for taking it and we can grow our own mycelium meaning that we can grow a resource instead of depleting one which sounds fantastic but it takes so many days to grow and produce a product if you want to do it all

4. What is the industry where you would want to study your scale up?
K: Right now we're watching within the building industry or the construction industry where we see a large potential with this technology we see that this industry is screaming for more sustainable solutions but again it's also very traditional industry where the prices are very low for conventional materials. So, we will definitely get some issues when competing in this industry with these very cheap materials it's the construction industry
5. A possible way to bring mycelium in this market could be to substitute an incumbent. In the case of the construction industry this could be particle board/particle board, correct?
K: Yes, that is the incumbent, and it would be the product to substitute

6. Could you tell could you tell us a bit about like what are your thoughts on these or why particle board?

K: The particle board industry is such a massive industry and I mean it would be difficult to compete with the current prices. Plus, when it comes to particle board it's also right now not possible for us to compete with the strength and mechanical properties so it would maybe be smarter to compete with products like particle boards or maybe NDF ?? nature boards where the requirements are not that strict.

7. Who do you think your customer will be?

K: Uhm, that would be like architects, engineers, building companies, building clients and so on maybe also building merchants you know who are selling building materials on that stuff to customers. Basically, all B2B.

If you've seen my questions now you know after the SRL on environmental innovation, how innovation can be used to handle waste and so on and I find out that mostly literature revolves around these 4 statements. So I would like to ask you if we could go like 1 by 1 and then you could tell me like what are your thoughts on them if you agree if you don't agree if you think something should be said or done and get your overall feeling about them when thinking of your company. (I will read it aloud and you will have 5 minutes to think about it and reply)

S1:

Most authors agree on the existence of a particular branch of Innovation Management, that deals with environmental impact. At the present, the level of awareness is fairly low, and it is very context-related and business-specific. Sustainability must be a core value for a successful implementation of environmental innovation processes.

K: Yeah, I think it's correct when you say that the sustainability has to be a common value for a successful implementation, but I don't think it can only drive on this.

I think you're forced to think a lot of business into it if you want to survive and compete many tradeoffs when it comes to sustainability and running a sustainable business where you need to earn some money. I think it is correct when you say that sustainability has to be a car value successful implementation

C: yeah OK but do so says that the level of awareness like is fairly low and very like business specific so some innovation might not work for some context

K: yeah, I think that's correct

C: so, we now move on to statement 2. I will read it aloud and you will have 5 minutes to think about it and reply

S2:

“Environmentally sustainable innovations thrive when solid partnerships are established, and universities are involved. However, they can’t be long lived if not supported by the

introduction of new materials and designs that replace old ones with better environmental performance”

K: I think that's definitely true I think a transparent collaboration between different partners and universities is the key to green innovation. These partnerships should also be the ones in which to invest time and money by researching a new materials and designs which also opens up for new business areas and opportunities so that's definitely true

S3:

“Laminated wood industry is highly saturated and in need of modernization process toward more environmentally conscious disposal of waste. The business context is characterized by a general lack of awareness and communication along the supply chain. Future innovation may take place by first approaching the market with modular upgrades of current products.” Instead of full-grown products…

C: Just for clarification, For wood and furniture industry meaning like you know processed wood so very general.

K: Yeah um so the third statement would be that, ok….I think the industry is definitely needed station and there are many green washers in this industry will try to sell sustainable products that may not be that sustainable. And then a lot of bad materials and chemicals are used, and this led to a greater amount of waste (hazardous waste). Waste that could have been reused in other products or recycled if it were designed for that or communicated better between the steps from its designer to the manufacture and down to the end user. In conclusion, yeah I think I think it's a great idea to start by approaching this enormous market with some smaller modular upgrades of current products and thereby slowly try to infiltrate this market with some more sustainable products and materials so that's definitely a good idea

C: yeah so that makes me happy

C: OK so now the last statement about customers. As before, I will read it aloud and you will have 5 minutes to think about it before replying.

S4:

“Customers in a green innovation context are likely to be more involved but should be at the level of co-creators to preserve the functionality of a company. Modularity could be a way to resolve the performance- sustainability trade-off perceived by clients.”

C: For co-creators’ customers, here we are talking about how much customer can impact the design process. In this case, Co-creator means that you (the company and the customer) start from a common base and then you build up with customer better solution. This implies a tradeoff because we're not God we can't multiply stuff for free and so

modularity can be a way to resolve the performance/sustainability tradeoff perceived by the clients

K: OK and what do you mean with the performance tradeoff?

C: So sometimes the literature finds that many customers are set off because even though the product is sustainable cannot perform the same way of the non-sustainable equivalent therefore do not choose that product even though it's more sustainable because you cannot perform as well

K: yeah makes sense OK well the sustainability minded customers I think definitely more likely to be involved as they have a natural interest in creating healthier products and a better will and I think it's extremely important for a company to involve these people when designing products and services as they are the ones who are going to buy and use the products in the end. This modularity, in the way you are suggested could definitely be a good idea or a good way to solve this tradeoff which the clients perceives by doing this the clients would maybe be more willing to include this new materials without taking this massive risk when it comes to the performance of it because you could easily swap out a module if something goes wrong or it breaks. So that is that could be a good idea yeah

8. OK So now we're approaching the end so don't worry *Presents 4Vs analysis* I am going to show you this tool is called the 4Vs analysis. In Supply chain, we use this tool to rank the product according to how it scores and highlight eventual tradeoff and discrepancies. I have made the following based on the idea matured on Mycelium through the literature and the visits at your facility. Please, let me know your level of agreement and any other thoughts you might have.

K: *confused* I am a bit unsure could please walk me through this…

C: Yes, below each measurement you have the question to answer

For instance, the first is volume how many units of a given type of product series are produced and I've assumed in this thesis I've thought of mycelium as in a batch production so produced of course by batches

So, I put high variety of course I put high a variation in demand quite low because I don't think of it as a seasonal product

Visibility is ranked low because sometimes yes you want to say that it sustainable but maybe in the construction industry saying that you know it comes from more the fungus that can be quite discouraging

So, I would like to get your thoughts on this positioning and of course if you don't agree or…

K: Yeah I'll just think for a moment… *Takes 5 Minutes to think* Well, I agree on most of it maybe the volume it might be difficult to have a high volume of units due to the time that it takes to grow one.

So, it might be better to have a low volume and take a higher price for that that might be the only one I question and the variation that's only demand, right? Not relying in each product.

C: Yes, correct. Only in demand, it is to see if there's seasonality in the demand.

K: yeah OK that's fine then and yes, the visibility uh yeah can only be little because of the way you produce the materials. You cannot produce it on the streets, per se because you need a very sterile environment

The variety just how many types of product service have to be manufactured by the same facility yeah that makes sense… yeah, I think the only one was the first one

C: The volume?

K: Yeah…

C: Ok, but follow-up question would be that is the company works to implement a modularity approach that could be like the key to produce like high volume and then combine it. As you said even if you produce more you can always redo it like so there is no waste, right?

K:Yeah, actually that's true… yeah!

C: Ok, so little spoiler for you but in the thesis I will suggest to face this tradeoff between having a high volume and high variety it's a tradeoff (from operations point of view) either you have a lot of variety or a lot of volume. So that's why I propose modularity as a way to let's see aid this this imbalance

K: yeah so yeah that sounds really interesting something we haven't thought about so I'm looking forward to reading it

9. the 9th question is very general like Can you briefly describe your firm business model?

K: like if it's yeah that might be a question for Dan, but I can try.

Right now we are planning to establish a small test point where we can roll these large mycelium bolts for the construction industry and this will work like a traditional manufacturing business model where we are the one sole manufacturer the bolts and then we sell them to the businesses so B2B.

But we are in the process of rethinking this business model a bit again due to the high cost of the price cost price of mycelium bolts and this could be this could be a business model where we could rent out a machine for demolition or building companies or introduce their own waste at their building sites and then use our technology and mushroom to grow materials directly at the at the site but this is just thoughts right now

10. What is the main mechanism in the furniture industry that you can see Mycelium struggling with?

C: Yeah OK good so yeah, I think the last question actually we have it covered. It seems that the main problem is the price…

K: Yes, definitely, and maybe also the performance and durability also talked about. Also the appearance you know the look of the material many people find this material very

interesting but does not find the look very appealing but that that's of course a job from our designers to solve that are the three main things.

C: ok nd then now this these are other questions OK I mean… well done you finished thanks for I don't know any thoughts or comments, or contribution and you want to make like freely

K: I look forward to reading it all

DAN

1. Please, introduce yourself and the company

Hello, I am Dan and together with Kristian we have founded the Mush Materials. I have more than 2' years of experience in the building industry and I was hungry for more innovation. So, I went back to school and encountered Mycelium as a material. I found it fascinating and I wanted to get involved and bring something new to the market.

2. Can you tell us about the functioning of the mycelium manufacturing?

So, can you tell us a bit about the functioning of mycelium manufacturing

D: So, you bring to your facility some sort of substrate uh it could be weed or hemp, could be whatever you want to use even Flowers or whatever. Then, you sterilize that or pasteurized that then you mix it together with the spores from a certain species of mushroom depending on the substrate. To store it together into the conventional bag you leave it there for like 2 weeks or 3 weeks depending on the substrate at the spores again.

After that, you shred it down after that time you could put it into kind of containers or most of any kind of mold that you want and it could be like negative shapes and believe the material in that shape or another 3- 5 – 7 seven days then you actually got the kind of material the shape that you want and you just need to use dehydrate the material. This process can happen by heating the material or just leaving it outdoor or anywhere the environment is hot and very well aerated, so it doesn't get any kind of contamination: that's like the manufacturing of mycelium

C: OK thank you and can you give us an example on how like changing the raw material and the type spores can impact the final product?

D: Can you repeat that?

C: yes, I said can you give us an example on how changing the combination of substrate and spores can influence the final product?

D: Yeah, so basically what we do and most people do is that we try to mimic nature- SO the difference that you can bring is of course if you want to use some sort of substrate you need to find that kind of mushrooms that will grow in that substrate so it could be if we use kind of like hemp then we need to find something that will grow inside that or that kind of plants, as you would call it. Other that you start to basically to just all 5 para meters are like 1. humidity when you when you grow the surface 2. The amount of sugar in the substrate 3. the time that you grow it together 4. how much you sterilize it: that means how much CO_2 you bring into the bags 5. and then how much light and bring into the bags depending on where you place your bags as basically some of the parameters that you can judge (and adjust).

Just like with plants the more you optimize these parameters the stronger the material gets because the roots of the mushroom simply just grow faster and stronger. Therefore, the faster and stronger the root grows the stronger the material will be in the end of the of the process.

C: Of course, that makes sense so when you say you mimic nature like you take on mushrooms that would grow where hemp put grow right? like in the same external condition…

D: yeah if that is possible so if you use wood from Norway then you would use roots from Northern Europe so you would probably try to see if you could find mushrooms which is already growing on wood in Norway. If that's possible and if it's not possible then you try to go has close as you can to that mushrooms.

C: So, you already have compatibility basically

D: yeah exactly

3. What is your issue?

C: OK so now can you tell us a bit about the let's say like challenge that Mush Materials is having?

D: concerning the manufacturing or the process of materials?

C: yeah like basically what is the outline of the assigned case study

D: yeah, I think that is just from the top in my mind if you start selling our products than of course it's a new way of thinking materials. So just bring it into some sort of industry you need to make that industry informed but if we look upon that there are like some challenging factors for Mush Materials like the biggest challenge is the time.

If you compete to other kinds of wood or kinds of plastic materials or metal or whatever we want to compete with the time to market is really low compared to mushrooms material.

Because, You see the mushroom material needs to have this process when you grow it for about 30 maybe even 40 days altogether to have a full-on grown material and if you compare it to plastic where it a few seconds and if you compare it with metal in the process of manufacturing it takes seconds as well or maybe minutes.

Also, it's the same with materials like particle boards or particle board takes nearly no time to produce a particle board in that part of the manufacturing process.

So, it's definitely something about like the time that you spent for the mycelium product to be ready to jump from the factory to the market in that time frame or like that production phase.

At the same time, of course you got the whole supply chain running and then you got all the growing of the material

4. What is the industry where you would want to study your scale up?

C: of course, the underlying issue is also a general lack of knowledge around the mycelium and the technology needed to produce it right cause it's new

D: yeah I think I think it's not a lack of like knowledge about the mycelium in itself it's more lack of people to understand like industries understand that you should use more time to produce this product in the start of the supply chain manufacturing and then in the end it should be easier.

But that, nearly no matter what kind of industry you looking into, it it's not what the industry is ready for… if an industry is asking for one board or less of particle board then they just want to have it immediately they don't want to wait like 30 days to get it…

C: yeah because they don't take into account the time that it takes to properly discard of it like they only take into account the time that it takes to production

D: right exactly um

5. Could you tell us something about particle board industry? Who do you think your customer will be?

C: so, in this case study we decided to do a comparison with the particle board industry, and draw a scale up plan for your mycelium boards in the private industry right?

D: Yes

C: OK where do who do you think will be your customers like your immediate customers who would you peach this idea to?

D: That's what we have been talking a lot about because it's always difficult to be sure of what kind of market do you need to go to and how the customers are looking on this.

One can imagine a lot of things but we're talking about some sort of like nature board made out of mycelium and you compare it to like particle boards or particle board or other kind of wooden plates or wooden boards I think the matter it's all about to find a customer that likes the story and likes the sustainability of the story and can compare or can deal with the price of it.

So, in the start you need to target customers who are willing to pay even like 3 or 4 times over the price of particle board but then on the other hand gets all the advantages of mycelium.

In this case, if we are talking about nature boards or mycelium boards, you have us not even circular but more. We are constantly regenerating our resources not impacting with our production or after the product is disposed. The way that we are producing you just have the board as outcome you don't have any waste at all.

In the end you don't have any waste and we don't use any kind of glue in your boards and stuff like that and then you can have another advantage as well which is that that the boards have like a higher fire resistance compared to normal particle boards and particle boards. I think if you could find a customer with that it would be like a niche customer sort of like pilot projects to go into that market but it's very difficult to say who.

We approach on specialized companies and people that we think are interested we are working with some bigger companies who are willing to go in this direction as well but it's a long one

In Denmark, we have the architectural group called Leena group. They are very fond of sustainability solutions for the building industry, it could be science companies, and like it could be like different kind of companies in Denmark

C: OK but we are still talking business to business, right?

D: yeah, I think so mainly because if you need to bring this into the market you need to bring it into some of the bigger markets. I don't think that you can find enough customers in just one areas market to start off and I don't think that

At the moment, we don't think that you can find enough customers (B2C) in the business across the (Danish) market that are willing to pay the price and then get enough needs out of this. So yeah in our case we think that if this should succeed you should really make business out of it you need to go B2B and you need to find even more important you need to find a fitting application.

That's the difficult part that's the part where Evocative, MyCo and all the big mycelium manufacturers and small ones Crown doesn't seem like that…

Any of them have found like a sustainable business solution to make their business work.

C: So, partnerships are key for the success of this launch let's say more than like a relationship of producer-customer more like a partnership because then it's easier to get them on board with a collaboration like this no?

Dan: you need what we, you, me and Kristian talked about this is the fun to do, you can do this yourself as one company's rights or push through a company and then push it into to an industry but if you want to go anywhere you need to team up with larger companies.

They have the money for it and contacts to get you know in the business or that stuff that's what we're trying to do

Because it's a long run to do it yourself: it's nearly impossible.

C: Of course, it's nearly impossible when you're doing it with something that the market knows let alone if you're trying to introduce something completely new

D: yeah yeah exactly it is that normally if you're talking about the innovative products you normally take like a known product and you innovate it like 5% - 10% and add that to the product and then you try to set that new innovative product but reduce like not just new color materials but regenerated materials. I have been through the construction industry and this is like fast forward 10-15 years in one step because the industry is not even ready for that yet.

So you need to be sure that that everything that the behavior of the industry is falling your production of mycelium material I don't think we're there yet I think it will take like 3-5-10 years depending on what kind of companies will go into these collaborations

C: and of course, more if more people write on this and more people raise awareness, so it all goes faster and that's why we're here

D: exactly of course

6. C: OK so I'm going to read you 4 statements which are the result of the SRL that I've done on the literature. I have reviewed the most recent literature around green environmental innovation/ innovation management based on waste management. You have previously seen these question in my communication email, nevertheless I am going to give you 5 min to think about them before you answer.

D:OK so... OK that's cool

S1:

"Most authors agree on the existence of a particular branch of Innovation Management, that deals with environmental impact. At the present, the level of awareness is fairly low, and it is very context-related and business-specific. Sustainability must be a core value for a successful implementation of environmental innovation processes"

C: how do you feel about this statement like do you agree or do you not agree...

D: *takes some time to think* D:Ok, so I think that basically it depends on what kind of industry you go but if you're talking about going into the building industry or the construction industry I think all these kind of like a CBS stories or storytelling about that reuse waste material and that in the ancient world we got all this sustainability stuff like that I think it's a good story but in the building and construction industry it comes down to price all the way down the road

So, you cannot just come having these sustainability value that you need more than that, you need to act on its value or not.

S2:

"Environmentally sustainable innovations thrive when solid partnerships are established, and universities are involved. However, they can't be long lived if not supported by the introduction of new materials and designs that replace old ones with better environmental performance"

C: Now, we move on and this is kind of what we said before right

D: I think definitely I think the right in all the solid partnerships or collaborations not just with would like different kind of companies in the industry but as you say as well with universities needs to be involved or other type of study lines and all that have an interest in r&d.

But you need to have all this kind of like collaborations across all kinds of industries

C: OK but it's important that these partnerships are based on you know introduction of new materials and not just like yes, we're partners like it needs to be based on something that is real then something that it's operational

D: Yeah, I think so. Otherwise I think it's very difficult to bring it through

S3:

"Laminated wood industry is highly saturated and in need of modernization process toward more environmentally conscious disposal of waste. The business context is

characterized by a general lack of awareness and communication along the supply chain. Future innovation may take place by first approaching the market with modular upgrades of current products."

C: Wooden furniture industry and processed wood industry are the same I was just looking for synonyms. Here, the supply chain it's full of like actors and sub actors and subcontractors and yeah, it's very complex a world

D: Definitely I definitely think that the first part is true like if you're talking about the wooden furniture this highly saturated and I think it could be, in my point, it could be lack of awareness and communication along the supply chain but it could also be that the consumer really doesn't know what sustainability is really. You see if people see wood, people will think nature and associate it with something sustainable. That is true about the raw material, but they forget about what was done to that wood. Like, in this industry, you would polish it and if you painted it or whatever…

I don't know if the lag is coming from the supply chain or is coming from consumer that doesn't go ask for it and what I can comment based on what I know

Plus, it also seems right the last part….

C: So not approach with brand new products but rather with modular product like at the additions to current products

D: yeah because if we talk about the construction industry… At least that's what came up with Kristian.

For our thesis, we looked into 15 industry to see where we could use the mycelium and where it would make the best sense to go with mycelium product. While the industry we looked into the most was the furniture industry/wooden furniture industry and what we found out after talking to a lot of like individual clients, B2B clients and designers was that it's a lot about the design and of course the sustainability.

In the building industry, it's also about the design meaning that it needs to be similar to what they already know otherwise they probably won't buy it.

C: So, don't you think that mycelium in the long run will be perfect for both industry? Because of the like OK now it's expensive to produce but it's only because it's a new product not because the raw materials costs are high.

So, don't you think that in the long run mycelium could beat the current products both on price and on design even that you can like shape it as you want?

D: I hope so! But I am not sure that one will ever be able to bring the price down to it same kind of point because once again if we go back to when we talked about the producing process was like the whole process of making it's 34 days altogether. In that time, you might need to re handle the same material maybe once or twice or more than you do a wooden and brings the cost higher.

Although , I think you should be able to go pretty close to other kind products but if you can actually compete 100% on the price no it's too soon to say…. yeah, it's just a guess

At the moment, the price is definitely an issue even though you'll find certain companies who are doing it in a larger scale then definitely that we are but kind of like a big scale.

S4:

"Customers in a green innovation context are likely to be more involved but should be at the level of co-creators to preserve the functionality of a company. Modularity could be a way to resolve the performance- sustainability trade-off perceived by clients."

C: OK which brings us to the last statement, so this is actually very interesting because we talked about this before. Co-creator means that yes, they should be involved in the creation, but she should not have like blank paper to be able to do like whatever it is because the company then has its own resources and its own limitation.

D: Can you explain what you mean by modularity?

C: Yes, so modularity here means producing in modules. Instead of producing a 1-piece full grown object yeah you have predetermined number of little pieces that you can recombine to create multiple outcomes. Kind of like Legos…

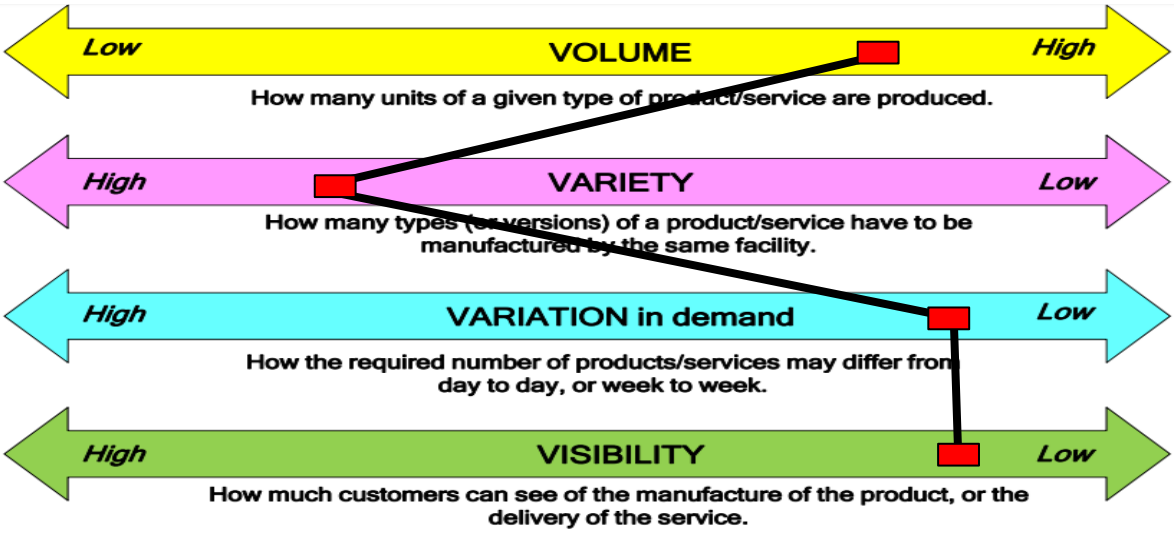
D: Ok, that is what we call architecture of a design…. yeah of course if that is possible it would a big advance if that is possible.

It should be possible, I don't see why it shouldn't, but this also comes down to collaborations between the companies.

C: So far basically your thoughts align with the literature that exist. Do you feel accomplished?

D: yes finally

7. Would you agree with the following positioning?



C: So this is a tool we use to like position a product in regards to this four dimension that you can see so volume, variety, variation in demand and visibility so this is what I think a mycelium is do you agree do you disagree like what do you think ?

D:so, the first one you see that the volume of mycelium…

C: Yes, my assumption here is that it's produced like in batch like in a batch system so like multiple items at the same time

D: OK yeah and what's the other?

C: That would be variety so how many types of a product or service have to be manufactured by the same facility so like how big is your portfolio of products that it can be produced

D: yeah, I think it's like one of the advances it with mycelium materials is definitely that it's quite easy to produce many different kinds of product and application so I agree on that one what is the next one?

C: that would be variation in demand so like seasonality. So, if the demand of mycelium experiences a lot of highs and lot of lows or if it's kind of keeps steady.

D: I think I think it kind of keeps steady or maybe yeah maybe but that's low side. For me this bit difficult to be honest with you about because we still need like one of these cases where we can see that somebody is actually selling products in a constant rate right now nobody is talking about what they are selling.

C: yes, and the last one is about visibility so how much customer can see of the process behind the production of the object

D: yeah what do you mean by that the customers themselves can see

C:yes how visible is just the surprising like how is it highly visible or like For instance, when I get a sandwich from the deli it's highly visible because I see the man like building my sandwich right?

D: yeah,

C: here for mycelium I assumed low because in the shop or whatever it is you get the finished product you don't know the lead time to grow, at the temperatures, etc.... you didn't see this one

D: oh, so sorry I agree it's low yeah, it's definitely low. So, what they should not about at the moment it's that's another story but at the moment is it's really easy for a company who's working with mycelium products you just say

At the moment it's a long story is it's really easy for combating who's working with mycelium products they just say that they got this amazing product and they produce in nearly no time because nobody knows about the supply chain restriction behind.

For example, Ecovative site where they are telling the world that they produced this mycelium materials in 4 - 5 days but that's only the last growing period. They don't take into account the rehandling, the manufacturing process takes 45 days, but they get "casually" forget to mention the first 40.

The only reason they can do that this actually because the visibility of the products is not feasible for the customer and the companies so that's a sad story. Anyway, I agree with visibility is definitely low

8. For Dan: What is the main mechanism in the furniture industry that you can see Mycelium struggling with?

C: so then for last question I guess you already answered that…

D: yeah, kind of. Do you want me to be more specific on that one?

C:Well, before you said price like basically in the construction industry it's all about the price and mycelium is not really competitive. Would you like to elaborate on?

D: That's true. Plus, depending on if you're doing furniture or building industry or what kind of industries you choose you got different kinds of rules and regulations that you need to live up to in order to be compliant. There's do's and don'ts and some of them are quite easy for mycelium materials to live up to and others are quite difficult and if you go into the construction industry some of these rules and standards are very high. So, the construction industry use if you do like this sort of material boards to replace particle board or particleboard, you need to live up to a lot fire regulations, material tests and all that stuff which is basically….

It's not impossible for the mycelium it's feasible but going through the whole process takes years. Then, when you have a qualifying material with certification then you need to make sure that the building industry is ready for the material.

Because if you say interesting mushrooms or fungus in the building industry that is the word that they don't like. It's too close to something rotten and unsafe which in reality is quite the opposite.

Every time, we approach someone new the first question is how can you be sure that this is not still growing when we place it into walls or ceilings?

C: And how can we be sure?

D: This actually is that's quite easy it's just like an average cardboard, if you water it do you see like a tree coming out of the cardboard? No and it's the same way but people can resonate better with cardboard. Mycelium would be the same thing just a different plant, once it is dead it's dead.

But nonetheless, on one side you have to go through the whole struggle and the certification of properties of the materials and the test of the materials the other side you got the whole chain of the old construction industry maybe they've been doing the same stuff for the last 30-40-50 years and they are changing but the pace of how they change it's too slow.