FUTURES OF EDUCATION, CULTURE & NATURE – LEARNING TO BECOME
(2022 – NO 1) 41-59

Architecture's Road to Sustainable Innovation

Reaching for Change, in Teaching and Practice

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ABSTRACT: *Current practice in the building industry is not sustainable. The United Nations 17 Sustainable Development Goals define a key set of the global challenges and targets that the world must move significantly towards to address the sustainability emergency. Architectural solutions, products and services contributing to the Goals are already there, in smaller scale. However, the bulk of the built environment is part of immense current challenges – the building industry is a major consumer of energy and natural resources, and a prolific producer of waste. To create new sustainable practice, we need to understand why new architectural solutions, products and services struggle to become market dominant. And we need to teach a new generation of architects and building professionals how to engage in, develop, sustain and promote emerging sustainable practices not yet formed. In this article we discuss findings from seven case studies to argue that dynamic capabilities are required for sustainable innovation to succeed. Rather than simply following established practise, navigating in emergent sustainable markets requires finding and forming new practise, which in turn make the ability to work freely among knowledge domains an essential capability in future professionals. This points to an educational potential in working with open-ended project- and problem-specific assignments to build the capabilities needed to reach sustainable change.*

KEYWORDS: *architecture; building industry; dynamic capabilities; systemic innovation; emerging markets*

Current practice in the building industry is not sustainable. The United Nations 17 Sustainable Development Goals define a key set of the global challenges and targets that the world must move significantly towards to address the sustainability emergency. The built environment, planning, architecture and design, interact with each of the Sustainable Development Goals. Architectural solutions, products and services are already there, in smaller scale, contributing to sustainable communities and quality of life (Mossin, 2018 and 2020). However, the bulk of the built environment is part of immense current challenges – the building industry is a major consumer of energy and natural resources, and a prolific producer of waste.

To create new sustainable practice, we need not just a "decade of action"[1] but what we would term a "decade of learning". Education for Sutainable Development is integral to the UNs 2030 agenda[2] but must also come into focus as an element of the "action", as new sustainable solutions in the build environment evolves through first full-scale implementations, evaluation and up-scaling.

We need to understand why new architectural solutions, products and services struggle to become market-dominant, to become the new mainstream practice. And we need to teach a new generation of architects and building professionals how to engage in, develop, sustain and promote emerging sustainable practices not yet formed. But to educate our students in navigating and taking leadership of the sustainable transformation of the sector, we must understand the process of sustainable development in depth.

This article investigates the nature of sustainable building material production and innovation in order to understand what the obstacles are, and how they can be engaged. The investigation is conducted through findings from a qualitative study of seven firms that we have identified as innovators of new sustainable solutions to the construction industry. The study has been done as part of the project "Innovation Leadership in Construction" which consists of two parts, a research part and a pedagogical part, incorporating the research-findings in teaching. The first pilot implementation in teaching is taking place that the candidate program "Settlements, Ecology and Techtonics" at the Royal Danish Academy - Institute of Architecture and Technology in the fall term of 2021.

As will be presented in this article, the study finds the need for a new understanding of firms in emerging markets for ecological transformations and points towards internal competence barriers to transcend from start-up company to established market player. To navigate in this field, simple heuristics that allows the inventor to operate seamlessly among a wide field of knowledge domains becomes essential. This is quite different from the specialized and hierarchical organized competencies needed in mature and hence more stable markets. It also points towards new collaborations between stakeholders in the building sector that blurs the boundaries of firms and softens the distinction between economic and non-economic drivers for a sustainable building culture.

To reach the targets of the Sustainable Development Goals, we need new sustainable practices and products in the built environment and we need that practice and those products to succeed at scale. In this article, we argue that this requires the development of new competences for all actors engaging in the building sector as well as new collaborations, providing the opportunity for innovation leadership for professionals capable of navigating this emerging scene.

Sustainable Transformation in Practice; Observations from Seven Case Studies

Empirically, this paper is based on a qualitative study conducted from November 2020 to February 2021 of seven firms that we have identified as innovators of new sustainable solutions to the construction industry. For each of these seven companies, an in-depth interview was

[1] Called for by the UN Secretary-General, September 2019: Decade of Action – United Nations Sustainable Development

[2] Education for Sustainable Development is defined by the UN as a key enabler of all SDGs: Education for Sustainable Development (unesco.org)

conducted with the management, and when possible, the original inventor. The interviews mapped the "life-story" of the identified invention; a timeline of what the companies themselves considered to be major turning points in transforming an idea into a marketed product. Based on this timeline, the main challenges were identified, which allowed us to discuss the underlying capabilities needed in order to solve these challenges.

The identification of the seven firms took place by combining quantitative and qualitative methods in two steps. In the first step, we identified more than 400 possible companies (companies that had either applied for public funding for eco-innovation or had had displays at the dominant sustainable building fair ("Building Green") in Denmark. For these companies, financial records have been collected for the financial years 2013 - 2019, which has allowed us to choose companies with proven turnover and an (in most cases) positive equity. In the second step, we made a qualitative analysis of whether these companies correspond to one of three strategies for sustainability defined by Pelle Munch-Petersen (Munch-Petersen, 2019):

1. Avoiding excessive material use and embedded impacts now (primarily upfront carbon).
2. Avoiding excessive material use and embedded impacts over time (Design for Disassembly and other strategies for low lifetime impacts).
3. Minimal design through passive indoor climate regulation.

Based on this identification process, the following seven cases were selected[3]:

- Small Planet (2012, 0-9 employees) invented Ecococon, a building system based on clay and straw.
- Søuld (2012, 0-9 employees) invented an acoustic matt made of seagrass
- Horn Group (2010, 0-9 employees) invented Ventilationsvinduet, a window with inbuild natural ventilation.
- Windowmaster (1989, 50-99 emplyees) invented control and monitor systems for decentral ventilation.
- Troldtekt (1935, 100-250 employees) transformed their production set-up for acoustic panels.
- Titan Nedbrydning (2017, 50-99 employees) invented Upcycling Orangeri, a social greenhouse made of reused brick, mortar and wood.
- Peikko Denmark (2006, 10-25 employees) adjusted their design for disassembly concrete joints to the Danish Market.

The interviews were coded in three steps. Firstly, the interviewers (Mikkel A. Thomassen and Pelle Munch-Petersen) individually noted down observations from each interview. Secondly, these more than 100 individual observations were classified into 29 cross-cutting observations that were presented for the rest of the "Innovation Leadership in Construction" project group (Natalie Mossin, Anne Beim, Ingeborg C. Hau), which enabled us to identify the six overall themes shared by the case-studies:

[3] Year of establishment and no of employees according to Proof.dk in brackets.

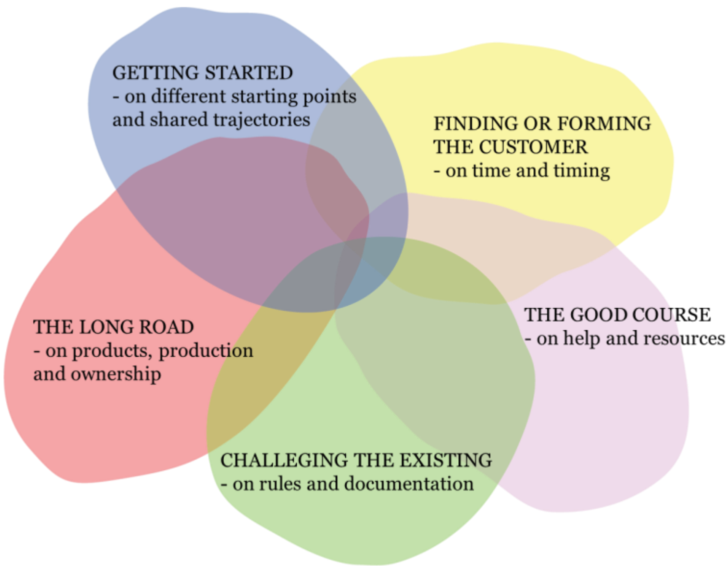

Figure 1

The themes reflect that sustainable innovation is a long journey with many commonalities even though each product and company differ. A substantial part of the challenges relates to the systemic nature of eco-innovations (Söderholm, 2018) as well as innovation in the built environment (BUR 2001, Havenvid 2019). The inventor not only has to design and produce a new product, he or she also has to challenge and change existing rules and regulations and create customer awareness and market channels, demanding tasks for small companies. However, the greater purpose of the invention enables the inventor to attract resources even when funding is limited and the business case from a purely economic perspective is weak.

Education and Sustainable Transformation

When examining the role of education in driving new sustainable practices, we have to also examine the idea of what a university is (Kristensen m.f., 2007). Currently, graduate students's employability and lifetime earnings are positioned centrally in the Danish Government's assessment of an education's value-creation. But in the Humbolt tradition, education is a means to simultanious learning as well as personal development and moral formation (Bildung), bringing forward new potential rather than merely a training to fill predefined functions in society. This idea of what a university is, values its ability, through teaching and research, to generate more than known skills. Humboldt's ideas transformed western education in the early 19th century, and are, although under pressure, urgently relevant when considering education in the context of the change to established practices and customs required to meet the climate emergency.

As seen through the lens of employability, students graduating into positions within the Danish building industry must be as compatible with current practises, tools and processes as possible. This makes sense insofar the aim is to minimize short-term unemployment rates of newly educated professionals. In this optic, candidates must be trained to understand existing challenges and potentials and equipped to do the work needed to solve them. But this implicitly preconditions that emulation of established practises in the market and the industry is the measure of educational success.

Students must in this optic, conform to - and be a product of - the same logic as the ones driving the industry today. This can lead to specialization and compartmentalization of the concepts of construction so each challenge – as far as it can be predicted in advance - can be tackled with great competence and precision. But such a linear understanding of construction has to be discussed as it relates to the forming of new practises and sustainable innovation. If sustainable innovation is understood to be a non-linear process, then this negates the need for a holistic approach to construction where professionals are comfortable and trained in challenging the existing ideas and agendas in a complex interplay of values and knowledge.
Humbolts ideas of formation on both a University and personal level, is an educational lense that allows for the idea that a student can graduate with skills to work in the building industry as well as the moral formation to challenge existing practise.

To discuss this, we present observations from the seven case-studies to substantiate the argument that the challenge of sustainable construction can only be tackled through a trans-disciplinary holistic approach. Our findings point to sustainable innovation entailing a broad array of competencies and abilities to participate in nonlinear processes with multi-facetted outcomes. In this article, we will thus argue that *dynamic capabilities* are needed for sustainable innovation to happen. Professional agility and a broad understanding of production and construction are key attributes of the inventor.

The cases we have analyzed in this study are all placed in the market and as such they both represent the current market and a change to it. This is in part why the road from idea to market is long and hard as the firms set out to challenge the existing logic of a well established industry. Nonetheless, our findings point to the need for a more radical approach to new practises in construction and that education hold a key role to support this new mindset. As such, a central outcome of education must be the ability to challenge existing ideas and present logics of the construction industry. New materials and products for large and complex structures like buildings will not be stand-alone solutions and hence existing practices and stakeholders cannot be ignored and exactly therefore students must understand them in order to encompass the new in the old. To innovate sustainably takes an understanding of what constitutes current practise, but it does - per definition - also mean that new generations of professionals will not simply conform to it.

Temporal Aspects of Firm Capabilities Needed for Sustainable Innovation

The character of a sustainable solution will have to change over time in order to become successful: from a novel idea, to a solution that works in a technical sense onwards to a solution that is not only on the market but also capable of generating an income on which further product- and process-development can be made. The road from invention to innovation is long.

The *Tech Readiness level* (TRL) framework is a well-established framework to describe how products mature from the most basic level (level 1: basic principle observed) to its full real life use (level 9: Actual system proven in operational environment). Originally it was developed by NASA in 1974, and then transcended into other areas, perhaps most notably as a an innovation policy tool of the European Union (Heder 2017). In order to compensate for the very technical approach of its origin, TRL has been supplemented with a commercial readiness index (CRI), that express the degree to which the market is capbable and willing to deliver the technologies (Animah and Shafiee 2018). What we would like to suggest is that as a supplement to these technical and market based measurements of maturity, an understanding of the maturity of companies abilities to invent and upscale is needed. Put differently, the internal capabilities has to progress in a way that corresponds to how technologies and markets emerge; handling the early phases takes one kind of company configuration, handling the later stages takes another. Understanding these shifts pinpoints the potential role education can have in promoting sustainable transformations and consequently we suggest, that the concept of *Tech Readiness Level* is supplemented with a *Company Readiness Level* (CRL) index that informs us about the firm capabilities that are needed to handle the different phases of innovation and market introduction.

The seven firms represent different levels of matureness. As discussed above, they have many themes in common even though their products differ. At the same time, during the interviews, they highlight different aspects according to where they are on the innovation journey. Based on this, a chronology can be established by which our observations can be sorted: what kind of challenges do early-stage companies experience compared to companies facing larger-scale market introduction; perhaps even on an international market? And what kind of capabilities do they need to have in order to solve these challenges? In other words, what should we look for in order to see if the *Company Readiness Level* corresponds to the *Tech Readiness Level*? For simplicity, we will group our findings into three overall phases:

- The emerging firm (company readiness level 1 - 3) covers the competencies needed from identifying and conceptualizing the initial idea to make it work technically in an internal setting.
- The growing firm ((company readiness level 4 - 6) covers the competencies needed to produce and test the solution in real life, including third party testing and documentation.
- The consolidated firm (company readiness level 7 - 9) covers the competencies needed from the first commercial sales to full-scale production and market presence internationally.

Challenges and Capabilities of the Emerging Firm

The very early processes of forming an idea, and perhaps also forming a company to host the idea, are hard to discern, as they involve a few visible actions. Van de Ven et al (1999) has termed this initial phase “gestation” - something is underway, but it is not visible until some kind of shock, to be in the terminology of Van de Ven, releases the various thoughts into an overall idea on which a formal startup can be based. This corresponds well to observations from the seven case studies. The fundamental sustainable idea and ambition often go a long way back for the inventor - for instance, as in interest in a traditional now little used building material. But it is not until some external motivation - for instance, a prize or prodding by a well-connected person - that the latent interest transforms itself into a startup activity to which resources are devoted.

What kind of skills is it that a firm and its inventor need to possess in this initial phase? Curiosity and openness to the new is one element. This equals the imagination observed in the case studies, as their proposed solutions are more than just extrapolation of current practices. At the same time, in spite of an ability to see many new opportunities, the inventor also have to have the ability, or conviction, to commit to a specific set of opportunities. A commitment that is perhaps only possible because the inventor has the understanding that he or she has an insight or knowledge that no one else possesses. As pointed out by Thea Mikkelsen, creativity in the end depends on an “overconfident I” (Mikkelsen 2009). From an educational point of view, there is a delicate balance to strike between informing about preconditions and limitations to invention and at the same time not destroy its "overconfident" source.

Based on this initial "spark", the actual product development begins by which the idea is given direction and substance by sketches, mock-ups etc. A surprising observation for us is that this activity is not devoted much attention in the life-stories of the companies. For some interviews this is understandable as the basic technical invention was made many years ago or was imported from the international mother company; but for companies driven by products and materials and still with the inventor as the managing part, we did expect the "birth" of the product to be a more prominent part of the innovation narrative. The ability to design and prototype the solution so it works in its basic technical terms are essential in company readiness level 2. But based on the experience and understanding of the interviewed firms, in the overall picture, also a very limited part of what it takes to succeed.

What is more of a bottleneck is the ability to attract funding. As one of the emerging firms explains, "in the first couple of years, we had to spend half of our time on funding". Other companies explain how they continue with other assignments to keep up a basic level of income. So, a key capability from company readiness level 2 and onwards is the ability to convince external inventors, private or public, about the benefits of the solution and how it fits their multiple, and not only financial, targets.

Another key activity following soon after, if not during, the product invention is the identification of the right position in the market. The firm market strategy has to correspond to its resources; if you are a small firm with limited funding, it does not make sense to start out with head-on competition with big established players or in product applications that depend on a total transformation of standards and regulations. In many of the observed cases, the most obvious use of a product in terms of technology or long-term scalability has to be abandoned in favour of niche markets with less competition and barriers.

In short, company readiness level 3 is about the ability to secure funding and identify the right market segment. The right market segment is a market segment where the level of constraints and competition does not exceed the resources of the firm.

Challenges and Capabilities of the Growing Firm

In the initial phases, production takes place internally and for newly started companies, manufacturing of the first products can be rather basic, for instance, made as part of a research project or studio work; for established companies existing production facilities from the mothercompany can be used. In either case, production is costly timewise but the in-house production gives valuable insight on materials and equipment and keeps financial cost low.

As the solution approaches the market, external suppliers and manufacturers have to be involved. This is a tricky situation for the inventor because he or she has to convince suppliers to invest substantially in processing materials that in the outset is only requested by the inventor himself and thus for the supplier represents a sunk cost (the loss of value if an investment is not used for its original purpose). For companies without existing product facilities, the search for partners on the supply side is a significant challenge from the moment the first solutions are ready to be tested in a full-scale project; and continue to be so even when the solution has matured as the original partners on the supply side may not have the set-up to deliver large scale. To illustrate, in one of our case study, it took a long period of searching before the inventor managed to locate an Italian manufacturer they trusted and with the equipment to press the new biobased material the right way. In another case, the first many years of manufacturing was managed by building communities of "do it yourself" housebuilders; but it was not before an alliance with a manufacturer from Lithuania was formed, that the product really took off and the original inventor dared to take up the development of his product once again. As this suggests, even if the invention is targeted for a local market, on the supply and knowledge side, it is in most cases international from the beginning.

Regulation and standards are another key area of attention as the solutions aim for 1:1 testing and first sales. The seven firms analyzed were each aware of this issue from the very beginning; regulation is a framework condition under which all products are designed. One of the funding partners in one of the case studies started out with a broad interest in biogene materials but chose not to pursue the most flammable, as they would be almost impossible to use as a building material due to current fire regulations. In another of the case studies, the company choice of an Orangery as the way to re-use materials was driven by the fact, that this building-type was below 50m2 and not intended for living, which makes it much less regulated. In spite of this attention to regulation, both companies ended up facing significant challenges with fire regulations. In order to solve this, different approaches was used. In one example, the solution was to identify local authorities that are willing to deviate from the standardized fire regulations. In the other case study the product mixture was redesigned by adding fire retardant substantives, which solved fire issues but also gradually transformed their single source product made of 100% biobased materials into a composite solution.

To sum up, the ability to partner up and collaborate with suppliers even when funding and bargaining power is limited is critical at company readiness level 4. The same is the ability and willingness to be flexible, and perhaps compromise on the original product design and functionality in order to cope with national regulations and how they are interpreted locally.

For the first full-scale projects, this ad-hoc strategy is feasible. However, another approach is necessary when a higher volume of tests and sales is the target; ongoing modification of products and sales that work in some municipalities but not in others are costly and time-consuming. Consequently, the companies started to invest in, somewhat costly, third party testing performed by certified and acclaimed test institutions. Some of the testing aims at proving that the solution is compliant with (the intention) of existing regulations on fire, structural integrity, moisture, worker security etc. Another group of testing aims at documenting the improved performance on sustainability. Thus, the companies have the dual task of proving compliance with both existing requirements as well as future needs on sustainability not captured in the existing regulatory framework. Put differently, the innovator has to prove his or her solution both against the existing paradigm (which is costly to change) and against a new paradigm (which is costly to establish).

As described above, understanding and managing the strong commercial interests of existing companies, including how these interests are built into the regulatory framework, is essential for the inventor. To take part in how regulation and standards are interpreted and changed is not only time consuming, it also requires capabilities of an almost political character which is often not the core interest or competency of the original inventor. For this reason, the employment of a "problem solver" is important here, as the case studies point to the managing of external tests and influencing the regulatory framework as essential capabilities on company readiness level 5.

The final part of this middle phase is full-scale testing, which is a test in a real-life environment where the solution is tested by an end-user in its totality and with the incorporation of all the initial product modifications. Product- and market refinements is a neverending process, however, at this stage, the main configuration of the product and its function is settled in order to achieve scaleability.

The main challenge here is to identify the first client. As the product is new, naturally, there are not many clients around; a market for this kind of service with many buyers and sellers is currently not in place. And even when potential clients have been found, it still takes a lot of persuasions, as it is risky to be a first mover in the building industry (even when the product is offered at a reduced price). Search costs as well as contractual costs are consequently high and dependent on personal relations that allow for trust-building and exchange of information that are not easily quantified. Companies that are new on the market relies heavily on personal relations; but even for companies with an established customer base, the first project still comes down to what a project-manager described as: "...that coincidentally I learned that our sales department happens to talk to a very progressive client".

Thus, at company readiness level 6 the company has to learn not only *being on* the market but also how to *be* the market. In the absence of a market working by the rules of large numbers and arms-length principles; it all comes down to the creation of sales based on personal relations, which again depends on time and connectedness. All these activities that are not yet met by an income of any significance continues to make the ability to attract funding critical.

Challenges and Capabilities of the Consolidated Firm

What is particularly challenging in the final phase of market entry is volume. Being successful is less about invention and more about inventories, less about creativity and more about coordination, less about possibilities and more about planning.

In order to ramp up production and sales, investments in large numbers are needed. The point at which the original management team opens up for external co-owners varies; some of the studied companies seems to manage with private means as well as public funding, but in most cases, an investor with money and knowledge has to be identified in this phase. Unlike public funding agencies working in the early phases, investors here will often have a more narrow return on investment perspective. For this reason, the ability to build a reliable organization and draft a convincing business plan becomes essential here at company readiness level 7. Interestingly, this task appears critical even when investments are provided internally as in the case one of the family-owned companies where the board had to be convinced about the financial benefits from 'turning green'.

At this stage, neither management, sales or investment is something that can be based solely on the trustworthiness and actions of the original inventor; rather, it is often expected from investors that this person "takes a step back" in order to make space for a more structured management team. The company turns from personal to "professional".

Compared with the first sales, a very different approach is necessary to reach large numbers. In response, a sales department with key account managers, customer intelligence and sales reporting systems is established. Facilities and staff to access and document environmental performance are also built up internally; third party test facilities are still used to provide "neutral" and certified tests, but the company is far less dependent on them compared to earlier phases.

At the same time, as the market mature, more competitors will enter the market. For this reason, the company has to constantly develop their solution to stay competitive. Again, this can imply that the company has to build on (and perhaps move away) from the initial set of ideas on which the company was founded. In one case, the threat from high-volume, low-prize overseas manufacturers of functionally similar acoustic panels was one of the reasons why they realigned their products and production in a more sustainable direction.

The shift towards a more explicit sustainable product makes it natural to adjust the management team, as witnessed for two of the larger firms. As stated by one of the interviewet CEOsa "in order to convince the employees, the first move towards sustainability has to come from us in the top-management”. In a way, the ability to de-personalize the company from the original inventors without losing the legacy of the founders is central for companies working at company readiness level 8 and 9. Creation of narratives that connect history and future might play a central role here, as one of the firm observed “We always had a sustainable product, we just forgot to tell it”.

The consolidated firm still has to maintain many of the same activities as the emerging and growing firm. However, this is done from a very different financial position, with greater bargaining power and less scepticism on the supplier and customer side. For instance, in stark contrast to the experience of the smaller firms, one of the big companies with a long market presence experience that their sub-suppliers are very interested in contributing to a green transformation as “they would like to grow with us”. It is also the experience of this company that they can challenge even some of the most prominent players in the market. Similarly, for another company reaching maturity, after having been forced to produce internally for more than 10 years, they are able to settle a deal with one of biggest manufacturers in Denmark (notably, still under the brand of the inventor). The battle of regulation is also turned around; from fighting against the present regulation, to be a part of it and perhaps even protecting it.

This suggests that the balance between managing internal and external relations shifts. For the small emerging firm, it was easy to ensure internal alignment but hard to control the environment. For the consolidated firm, it is the other way around: external relations become easier to handle and affect but the internal zorganization becomes more challenging as the organization grows and compartmentalized”. People specialized in staff management, financial reporting or managing board relations will enter the company as it grows and perhaps even is listed on the stock exchange (as in one of the cases).

The argument presented here is simplified, as a big company still has to pay attention to external customer and supplier relations as they become more diversified and global. It is interesting to see how the bigger companies starts to work with second and third-tier supplier relations in order to ensure responsible sourcing of wood. It is also noteworthy how they engage in other industries like the electrification of forklift to achieve continuous cradle to cradle improvements. Sustainable sourcing, also outside the domain of the construction industry, is a key discipline for the consolidated company.

Challenges and Capabilities as They Evolve

In order to mature the sustainable product, key competencies of the firm have to evolve over time. The figure below is a simplified sketch based on the seven case studies, pointing to the observation that in order to succeed with a sustainable solution, multiple competencies are needed; it is not enough to do the product design hoping that someone else will do the rest; the inventor has to build not only products but also markets, regulations and value chains.

The inventor further has to have the ability to do this without the back-up of routines or big organizations, which puts additional pressure on the ability of the inventor to constantly orchestrate and rearrange internal and external resources. As the figure illustrates, the importance of each activity shifts over time, and not everything has to be in place in the outset. However, adding to the complexity, if the solution is truly new, there is uncertainty not only about the end solution but also about the innovation process itself; it is not possible to say beforehand precisely what activities needs to be addressed at what point, and unlike minor product modifications, a linear project plan is consequently hard to draft.

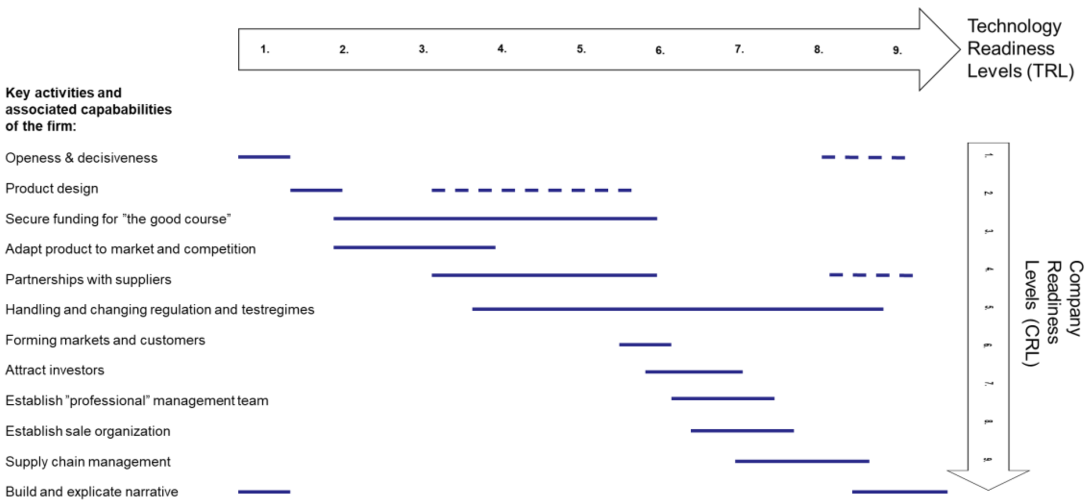

Figure 2

Designing Products, Markets and Industries

Is it not surprising that the challenges of the firm change over time, and consequently, that the capabilities of the firm have to change as well. However, it is noteworthy how different a firm has to behave in the initial phases when the basic configuration of a market, a product and production set-up is established, compared to the later stages of up-scaling and full market entry. Not only are the required skills different, they are in many ways' contradictory. What makes sense in the early phases of maturing markets does not make sense when working in a mature market and vica versa. It is well known that the road from having a product that works in a technical sense, to one that works in a market sense, is long and difficult. Our study suggests that the barriers in transcending this so called "valley of death" are not only about external conditions (such as lack of customers or capital) but can also be found internally as a shift in managerial logics. In the following table we have outlined how key functions of a firm (what it delivers, how a sale is made etc.) are solved differently when operating in maturing vs mature markets:

Key functions of the firm:	**Early stage - creating products and markets**	**Mature stage - scaling products and markets**
Delivery	A system (large span of value chain)	A component (small part of value chain)
Sale	Network (personal)	Market (impersonal)
Management	Personal	Routinized and buy-in
Identifying potentials	Intuitive and tacit	Calculated and codified
Planning	Ad-hoc	Define and follow strategy
Relation to other firms	Colleagues - part of an "association"	Competitors - part of a market

Seen from a mature market perspective, it is tempting to perceive the studied firms, especially the smallest ones, as idealistic person-driven-entities that defy the gravity of market mechanisms and succeed not because of, but in spite of, being "professional". Indeed, they are to a large degree idealistic and person-driven but this is not something that is "unlogical" when the market is in the making: it is a very rational way to behave - perhaps the only way. If the resistance towards organic building materials is large, it makes sense to form an association and consider all other companies delivering organic materials as friends rather than foes. When the market size for a truly new product is impossible to document (as there is obviously no past sales record), it makes sense to rely on intuition rather than thorough return-on-investment calculations; when uncertainties are dominant, it makes sense to be very agile and not stick to a fixed longterm strategy.

The same goes for specialization. Consistent with most textbook wisdom on competitiveness, the ambition of the studied companies is in the outset to deliver a well-defined, highly zspecialized product. Not only because a narrow product range fits with the limited resources the companies have at their disposal; the ambition of delivering a well-defined product is often also in line with the specific interest that sparked the establishment of the company in the first place (for instance, how straws can be used as a building material). But in most cases, the companies learn that they have to expand their scope and internalize adjacent technologies and services that are not in place in an emergent market. As observed by one of the companies: "We have learned that the best expert is ourself; no one really understand the properties of the new bio-material we work with". Or as observed in another case, the original core ambition was (and is) to deliver re-used materials for construction, but in order to do so, the company have to design and build the very building (the orangery). Likewise, the companies working within the aforementioned "minimal design through passive indoor climate regulation" strategy, experience that they get nowhere with their ventilation solutions unless sensors and software systems are included and the compatibility with existing hard- and software is ensured. For that reason, the emerging firm has to expand its activities and hence its capabilities at the time when it is most fragile.

Only later, when supply-chains, demand and regulation are aligned and a dominant design has emerged, is specialization in single parts of the value chain possible. What we observe is, in other words, that the company has to do the most when its financial resources are the smallest. Clearly, bringing new sustainable solutions to the market is from a short-term risk-averse investment point of view not the most lucrative business to be in.

Dynamic Capabilities and Sustainable Innovation

What is it that a company has to know and do in order to introduce new sustainable solutions to the building industry? As discussed above, the short answer is: almost everything! There is no activity or skill that makes anything else happen automatically. A product design with brilliant technical specifications and aesthetics is of little use if regulations are not handled. Or the other way around: even the best lawyer or technical expert that can navigate regulations have little chance if the products cannot attract first customers that are willing to pay an additional price because of the sustainable values represented by the product and the inventor behind.

What we identify as important when launching not only a new product but also maturing a market not yet in place, is the ability to make constant shifts in what problems you solve and how you solve them. This resembles the notion of *dynamic capabilities* understood as "the organizational and strategic routines by which firms achieve new resource configurations as markets emerge, collide, evolve and die" (Eisenhardt and Martin 2000, p. 1106). Unlike ordinary capabilities that work well under more stable conditions, "effective dynamic capabilities in high-velocity markets are simple, not complicated" and allow the manager to focus on broadly important issues rather than specific details that might turn out to be less relevant in fast-moving markets (Eisenhardt and Martin 2000, p. 1111).

Thus, the ordinary capabilities needed when operating in a rather stable environment, as the one found for established markets, is truly different from what is needed in emerging markets where neither the production technology, the regulating standards nor the market expectations and sales channels are given. This again holds implications for how companies are structured. Ordinary capabilities, that support production and sale of products in current environments, are "reasonably ubiquitous and can be sourced at competitive prices" (Shoemaker, Heaton and Teece 2018, p. 4) either to suppliers or by hiring people. Ordinary capabilities work well for gradual process innovations whereas the identification of new products and services, including markets where rivals have not yet appeared, call for innovation driven by dynamic capabilities that are hard to codify and hence depends on "a unique managerial orchestration process" (ibid). Ordinary capabilities are about following rules; dynamic capabilities on the other hand "...are never based entirely on routines or rules" and "good managers think creatively, act entrepreneurially and, if necessary, override routines (Teece, Peteraf and Leih 2016, p. 9).

In this perspective, it becomes clear why firms, like the ones observed in the seven case studies, operating in markets not yet established are of limited size: the lack of market structures does not give the external stability that allows the company to work in a compartmentalized hierarchy; the company depends on the ability of central management (often the inventor) to orchestrate problem-solving among specialist domains and at some point, he or she becomes an informational bottleneck from which the firm can expand no further.

It also becomes clear that management in emerging markets is not about following rules, but about finding out which rule to follow (or perhaps even create). From an educational point of view, if the purpose is to develop new sustainable practices in the building industry, the key thing to learn is not one particular established practise within a professional discipline, but the meta-ability to switch between tools and practices. As operations are not easily codified and as it hard to predict in what sequence problems need to be solved, the "invisible hand of the market no longer suffices" (Teece, Peteraf and Leih 2016 p. 9), nor does hierarchical structures that rest on the premise that tasks can be solved independently by specialized departments coordinated by managers with limited insight in each speciality (Grandori, 1997). In uncertain environments, ongoing asset orchestration within and outside of the firm depends on personal management based on dynamic capabilities. And hence rather than learning techniques for solving tasks within one knowledge domain (for instance, "sale", "design", "strategy"), what students have to learn is to make meaningful relations between domains. And as no one can be an expert in all matters, what they have to learn are generic rules that allow them to stay within a part of the solution space that corresponds with each speciality, and on top of this, make domains come together in a meaningful way.

Sustainability can be conceived as another specialty added to the long list of specialities involved in building. And to some degree there is merit to this claim as witnessed for instance by the blooming business of LCAs and other kinds of sustainability certifications. What we argue here, however, is that sustainability demands a new practise in all domains; and that education aiming at teaching the comptentces required to develop new sustainable practices and products, must enable individual students to develop the ability to combine different and perhaps even conflicting fields. Furthermore, in sustainable innovation 'sustainability' is not a specialty added to a conventional product design process. Rather the idea is rooted in sustainability in a way that defines, qualifies and arranges all value systems of the innovation.

We have termed the ability of navigating different fields *dynamic capabilities*; however, it might not be so different from time-honoured ideas of what being an architect entails: a professional that is confident in a very open solution space, who knows every piece only to some detail but are capable of putting them together in order to maintain and yet transform an abstract ambition into a literal product.

Concluding Discussion: Key Qualifications and a New Educational Practice

As previously discussed, to have sustainable innovation succeed, it is crucial to understand the nature of sustainable innovation and that it differs in multiple ways from conventional product design and conventional (non-purpose driven) innovation. As the focus for sustainable innovation is on 'the sustainable' it represents a new value system placed in the innovation process. Innovation is only considered a success as long as the agenda of sustainability is preserved. As such, commercial success is secondary as a driver in sustainable innovation. This makes the process of innovation more complex and the outcome less predictable.

Key Qualification

In conventional innovation, the process from idea to the product can be linear. For the sake of argument, let us imagine an improved insulation batt of mineral wool. The idea is: a better lambda value (better insulating quality). The product then goes through different stages (hereafter referred to as compartments) known from earlier product design in the company, and in each compartment, specialists ensure different capabilities, i.e.functionality, fire resistance, documentation, regulations, ect. If successful, the idea becomes product ready for the market:

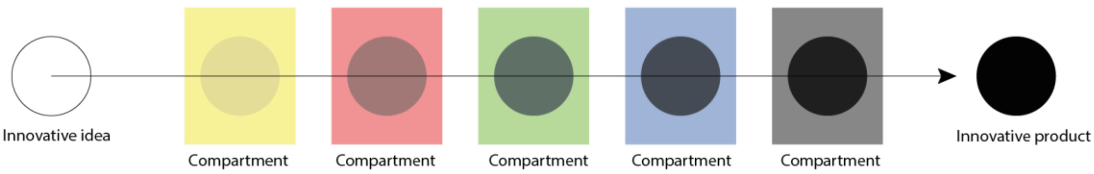

Figure 3 - From idea to product in a conventional product design.

As the production of mineral wool is well known and the company has a production already, the process of innovation can be prodomently linear. This is furthermore the case as the market is well established and customers are known to the producer.

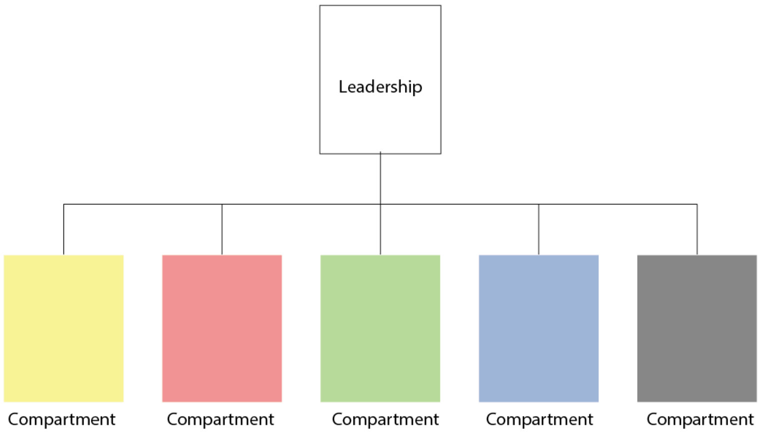

Figure 4 - Structure of the process of conventional product design.

This means that the process leadership can be highly structured as only limited amounts of information need to be transferred between compartments. Each speciality 'takes care' of its responsibility and sends the product on its way. Management ensures that the actions of one compartment do not interfere with the work of the next. But as it is a known way of production innovation the responsibility of management can be mostly administrative and do not entail hands-on actions or high levels of in-depth knowledge of the design process or the product. In the cases of sustainable innovation analyzed in this paper, the process is different.

A highly structured approach and predictability is not possible as the product is developed without the framing context of an established market. As the market becomes established and the product design is done the innovation becomes less about *product innovation* and more about *process innovation* and as such the process becomes more akin to conventional product design over time.

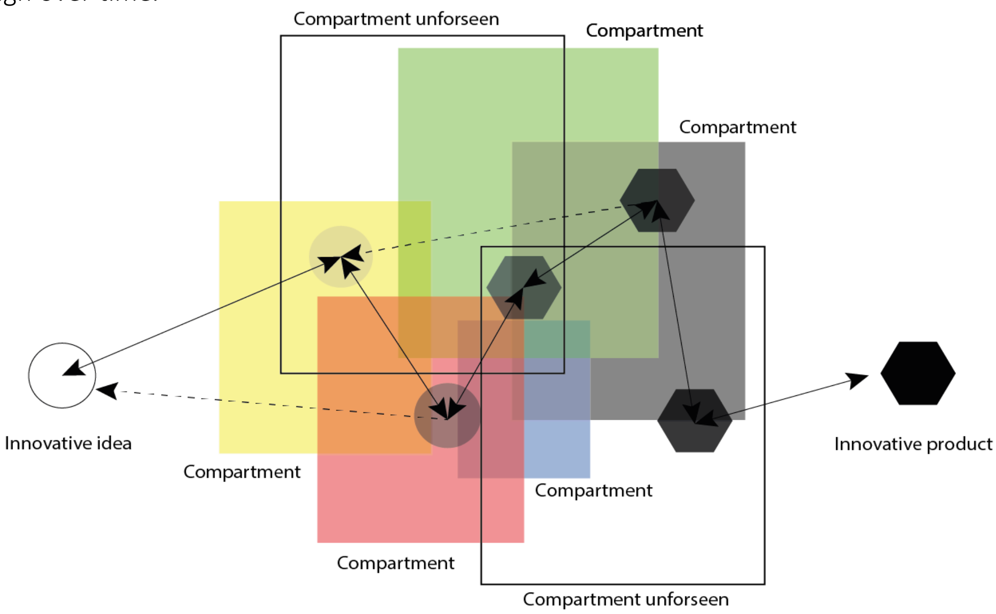

Figure 5 - From idea to product in sustainable innovation product design.

Initially, sustainable innovation is "disordered" in a classic sense. The compatibility of the idea and the final design is fluid in the sense that sometimes the product changes substantially in the process of design. This is due to the fact that the idea is tied to 'the sustainable' first and foremost and if the product loses its ties to the sustainable as it moves in-between compartments, then everything has to be renegotiated - and even the initial idea can come into question. In those cases, functionality, composition, application etc., can change. Furthermore, not all compartments (specialities and challenges) can be anticipated in advance. And they overlap, meaning that they are intertwined. For instance; if the fire testing points to more fire retardant, then it might conflict with the idea of non-toxic, sustainable production that in turn conflicts with the application of the product leading to a discussion on the fundamentals of the innovative idea, its toxicity, its fire performance and functionality at once and as some challenges can not be foreseen they must be dealt with as they emerge no matter where innovative product design is in its process.

The structure of sustainable innovation is thus less linear. The leadership of sustainable innovation becomes one defined by agility and sufficient levels of knowledge in all aspects of the productions. All compartments must be understood and dealt with head-on in order for the innovation to succeed. That means that leadership of sustainable innovation is less about administrative talents and much more about know-how and the ability to work in an unpredictable environment.

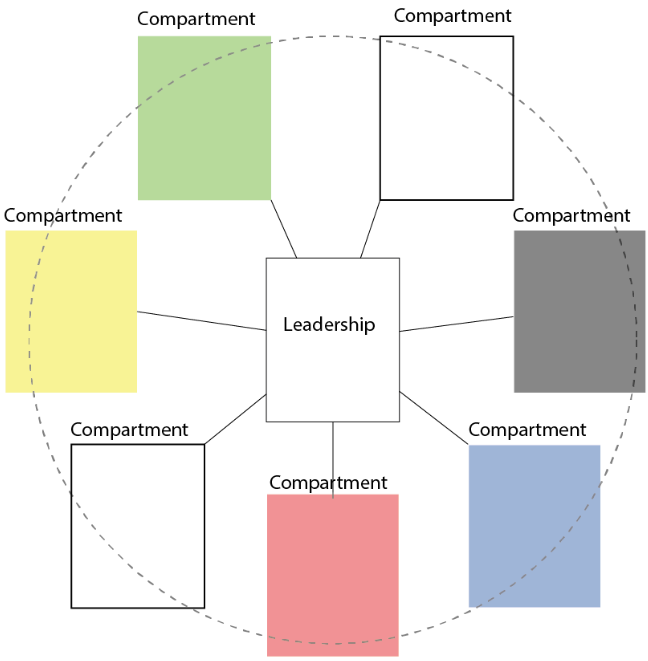

Figure 6 - The structure of sustainable innovation process

Leadership in sustainable innovation then becomes a role where navigating the uncertainties and 'bumpy road' to success are vital attributes. Leadership is placed in the product design in a very direct way. Often the inventor and the leadership are the same person in the early stages, and this central person is the one that moves along with the challenges and potential to understands how all compartments interact. Dynamic capabilities are in these situations what characterizes the inventor.

Finally, it is important to note that at a point (this could be a decade into the process) the product reaches a stage where the 'bumpy road' is at its end. All compartments align as functionality, regulation, documentation, and finding clients, ect. are well established. Now we see a decrease in complexity and the emergence of a production that has more in common with conventional production. All the external innovation and surrounding components the inventor had to handle or produce to prove the value and functionality of the sustainable innovation become obsolete and unnecessary. Now the inventor can return to the original idea and improve on this alone. In this stage we see administrative leadership and boards move in as the production can become more streamlined and simplified. The conventional production takes over as the process of purpose driven sustainable innovation ends.

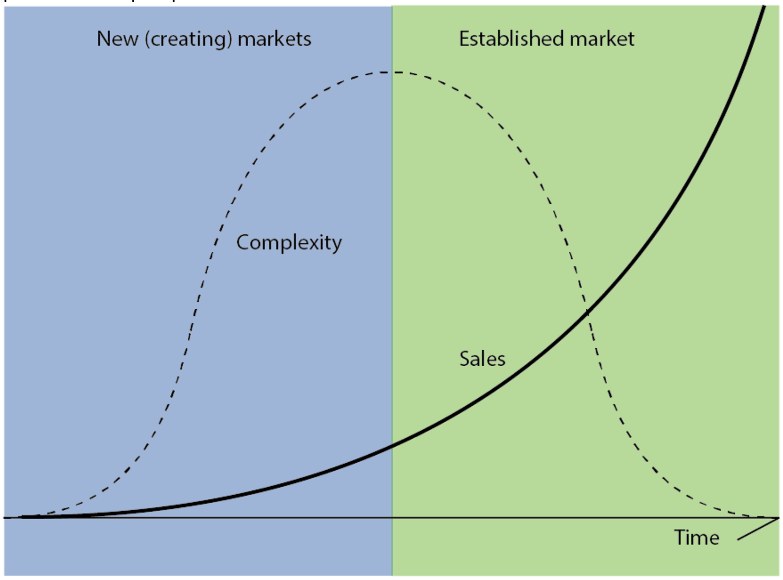

Figure 7 - From rising complexity to new 'conventional' production

A New Educational Practise

To return to Humbolt, a new educational practice must enable future generations of professionals to work skillfully in the building industry but must also underbuild the personal development and moral formation to challenge existing practices.

Architectural education already contributes in many asforcts to the foundation for new sustainable practices:

- The research on which teaching is based develops the theoretical concepts to understand and interact with the built environment
- The education gives students specific tools by which houses are built and designed
- The project- and problem-specific assignments establish areas for imagination and investigation of new futures
- The education train students in ongoing open-ended learning-processes that are essential for navigating unknown territories

What we would like to point towards is that the education of architects have the capacity to play a perhaps even more direct role; by engaging with the key conditions for successful sustainable innovation.

Based on the arguments of this article, critical conditions for successful sustainable innovation can be summarized as:

- the ability to get the right ideas, and to substantiate what 'right' constitutes as a combination of different value systems (environmental, technical, aesthetical ect.)
- the ability to work in an unpredictable and "disordered" environment
- the ability to acquire knowledge in a number of specialities fast

The ‘right’ sustainable idea is often one that in many ways is a reaction to an established way of working in the building industry. The unsustainable state of construction is the inspiration that prompts the idea. That means that education must dive into the established logic of construction in order to find inspiration. Sustainable innovation does not come about by chance but rather from a fundamental understanding of the problems build into current practise in architecture, construction, engineering etc.

To evaluate current practice, students must be well educated in what *sustainability* entails. The lens of *sustainability* challenges the logic of industrialized western production in a multitude of ways, and by looking closely at how the sustainable challenges prevailing ideas of materiality, technology, society and production is a way to find a novel take on the solutions of conventional construction. As such, sustainability is a value system that education needs to clarify and discuss in order to make it operational as a guide for innovation.

In conclusion, getting the ‘right’ idea takes knowledge of existing practise and an operational take on sustainability.

Secondly, education must train students in working on projects that are open-ended and where success requires agility and the ability to turn non-linear (“disordered”) sets of input into a productive outcome. At the Academy this is done in the setting of project- and problem-specific assignments where an initial formulation of a problem is qualified as work on the project brings in new input and learnings from the testing of mock-ups and demonstrators.

Thirdly, education must ensure that students can work in a *holistic* way. This means that students understand enough to ask appropriate questions even when they are far outside their traditional professional framework. The student must understand their own profession but equally important, they must have an understanding of surrounding professions related to their craft.

As outlined at the beginning of this article, this challenges the idea of a knowledge-based society with highly specialized professionals governed by administrative leadership. In order to lead sustainable innovation, dynamic capabilities, including creative and holistic approaches, are what divide failure from success.

In education, we can support the building of these capabilities by teaming up with other faculties and institutions in order to broaden the discussion and by insisting on taking in all stakeholders in construction, both in designing education content and in evaluating the work of the students. Furthermore, architects, engineers, contractors, legislators, professional clients, constructing architects must be in dialogue and work together in order to train themselves in navigating an environment under pressure from different and conflicting interests related to the need of new sustainable practice in the building industry.

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