UNDERSTANDING THE NPD – PRODUCTION INTERFACE: ADVANCED INDUSTRIALISATION AND GROWTH IN THE COMPOSITE INDUSTRY

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ABSTRACT

This paper provides an initial attempt to theoretically describe and understand how the composite product supply chain could reach advanced levels of industrialisation. At the heart of this work rest the interface between NPD (New Product Development) and Production as the central point where composite technology innovation takes place. This exploratory research is based on an analysis of qualitative observations gathered through interviews on different cases and interface aspects in the industry. The main goal is to create a theoretical framework on the growth strategies for the sector and understand what can enable increased levels of industrialisation within companies developing composite products and technologies.

Keywords: Advanced Composite Industry, Industrialisation, New Product Development, NPD – Production Interface.

1. INTRODUCTION

Composite material technology can offer significant benefits to a very diverse range of modern products; however it is still considered an industry in its infancy. How can this recently developed sector substantially increase its performance and what are the factors that would enable faster growth? This paper presents the initial steps of a qualitative research study in the composites industry and describes a theoretical concept of how an industry could make such a transition. The central idea behind this work is to provide a framework to navigate towards the increasing demand for sophisticated products in high volumes and further support the composite supply chain to reach increased market penetration and to realise the associated high production rates.

The main difficulty in the sector arises from the fact that designing and manufacturing composite products that utilise the inherent qualities of the material, requires a very deep understanding of the behaviour of this material not only during the material use, but also during manufacturing. This essentially means that the industry first needs to build up enough expertise on these matters before one is able to formulate product specifications that utilise the inherent material qualities. Consider for instance the case of the two crashed de Havilland Comet airplanes in the 1950’s (e.g. Withey 1997, Schijve 2001). These accidents unveiled a major flaw in knowledge related to the fatigue behaviour of aluminium under the load conditions of pressurised fuselages therefore causing the engineers to overlook the potential fatigue related problems in their design. Consequently, metal fatigue became a major engineering issue on the agenda of the airplane designer (Vlot, 2001). Similar stories can be found on incomplete manufacturing knowledge in early stages of the adoption cycle of new materials. The
development of theoretical understanding of the material in terms of how to engineer it (calculate loads, strength etc.), its behaviour in production and its performance in practical applications are essential for the advanced industrialisation of the sector. In our exploratory research we decided to concentrate first on two of these stages, the design and engineering stage, also referred to as New Product Development (NPD), and the manufacturing or production stage. We looked at practical cases that included these stages and analysed the growth strategies within companies working with composite technologies. This study of NPD – Production interface cases is leading to a theoretical framework for growth strategies and industrialisation in the sector.

In the rest of Section 1 follows a sketch on the nature of the composites industry and the issues it is currently facing. Section 2 discusses relevant literature on the subject of industrialisation and Section 3 describes the research approach. Section 4 presents some observations on the qualitative dataset and Section 5 a fledgling theoretical framework on growth strategies. Section 6 draws conclusions.

1.1 COMPOSITE MATERIAL TECHNOLOGY

Composite material technology has the potential to revolutionise high value industrial sectors and yield very significant benefits in industries such as aerospace, automotive, wind energy, marine and construction. Composites are contributing to the development of more durable, lightweight and higher-performance products, and help to deliver a low-carbon economy.

Polymer composites are engineered materials made from at least two materials that together produce advanced properties different from the monolithic materials that created them. Typically, they are composed from reinforcement fibres (made of carbon, glass, quartz, aramid/Kevlar), and a supporting matrix (polymer resin) and offer undeniable value for various applications. The main advantage of these high performance materials is their ability to build highly customised products with unusual geometries along with the possibility to create non-uniform weight distributions and directional strength or stiffness. Examples of the use of composites can be found in the new Boeing 787 Dreamliner and the new Airbus A350. The largest percentage of those aircraft structures is composite, lowering the structural weight of the plane and consequently consuming less fuel than existing airplanes in the same class. These advantages explain the interest in this new class of materials.

1.2 COMPOSITE MANUFACTURING AND INDUSTRIAL PRACTICE

Despite the many benefits of composite technology, the different applications and the mainly sector-specific industrial activities have severely limited the development of a coherent industry. Products made from composite range from aircraft components, boats, bike frames, bridges, wind turbine blades, and more recently car chassis. This diversity and broad spectrum of activities results in different levels of sophistication in manufacturing, fabrication or production processes.

The roots of manufacturing methods of composites go back to the manual process of dipping a brush in resin and covering layers of fibres with that resin (a technique known as “bucket and brush”). The recent use of pre-impregnated (prepreg) fibres revolutionised the industry of composites by standardising the quality of the raw material (Paton, 2007). However, the fabrication technique, known as lamination, still relies heavily on manual labour and product quality is again based on human craftsmanship skills. This created the air of a “black art” (Bloom et al. 2013) around composite manufacturing.
The introduction of automated manufacturing techniques offers the prospect of cost effective manufacture of large composite components. Automated processes in composite manufacturing appeared in the last decades, however it has been widely reported in the literature that automated techniques are facing significant difficulties and problems related to affordability, process reliability and overall productivity (Lukaszewicz et al. 2012; Ward et al. 2011; Newell et al. 1996). Possible reasons behind that are that firms developing those machines are principally automation and robotic application companies with lack of understanding in composite material, who only recently started developing expertise in composite manufacturing. Moreover, there are currently no automated processes available that can be used to manufacture relatively small and complex components to a high quality and at high production volumes.

1.3 UNDER THE SHADE OF METAL

Engineering design has been very closely interwoven with the metallic tradition. Composites design on the other hand, requires a different design mind-set. Most designers that are still trained in the metallic practice carry that tradition across into the design of composite parts. The result of this is the design and manufacturing of products that do not take full advantages of the novel possibilities inherent in composites. For example, the aerospace industry in the early stages of application of composite materials has used the ‘old’ knowledge and norms of metallic structures to design parts from carbon fibre. This resulted in what is called a "black aluminium" component (Tsai, 1993), components made from carbon to substitute existing parts, with an almost identical design to the metallic part they replace without realising the full potential of the new material. On the other hand, even when new knowledge is available adoption by industrial partners is not as evident as one might think. Design practices and rules that were developed very early in the history of composites use, when the materials were new and untried, are still very widely used across the breadth of composites applications (Potter, 2009).

2. CRAFTSMANSHIP, INDUSTRIALISATION AND SUPPLY CHAIN KNOWLEDGE

To understand the main mechanisms leading to industrialisation of the composite sector we need to go back to the basic principles of industrialisation. Those considerations could allow a clearer view of the enabling factors that can catalyse growth of the sector. Additionally, to recognise the patterns of how knowledge and fundamental activities are spread in the industry an approach focused on supply chain activities and the NPD – Production interface is vital for our analysis.

The division of labour and the disconnection of design, engineering and production from physical craftsmanship skills lie at the heart of the industrial revolution. Especially design and manufacturing are found in one and the same ‘hand’ during early stages of applying new materials. According to Pye (1968):

“Workmanship is using any kind of technique or apparatus, in which quality of the result is not predetermined, but depends on the judgment, dexterity, care which the maker exercises as he works. The essential idea is that quality of the result is continually at risk during the process of making”.

With increased levels of knowledge and increased levels of prediction regarding behaviour in manufacturing and use, industrial actors are able to migrate towards higher degrees of standardisation. The main idea is that the standardisation of a process by
automated machinery or low skilled manual labour can increase production rate and create products of standard quality. To reach controllable outcomes the machine operator has very little physical interaction with the process and thus his impact on quality of the product is minimal (Pye, 1968). This level of control is achieved by standardising and breaking down the process in order to codify relevant knowledge for each task and therefore to allow easily executable actions and reproducible outcomes.

One could say that in order to industrialise, first an integrated body of knowledge covering design, engineering, manufacturing and use needs to be in place. The industrial engineering literature is full of methodologies and approaches on dividing tasks in workstations and balancing production lines after such a body of knowledge is established. This is also happening in activities beyond the production floor, where outsourcing nowadays is a very common road. However, this approach that seemed to work well in the post industrial revolution area is currently falling short due to rapid technological developments. For example, when the actual tasks of detailed design and manufacturing in automotive are carried out by outside suppliers, the company is missing substantial opportunities to gain knowledge and as a consequence the company’s knowledge base tends to decline (Takeishi, 2002). Something similar happened recently to Boeings 787 Dreamliner where due to outsourcing design and manufacturing of parts an integrated body of knowledge regarding the design itself was largely missing (Tang & Zimmerman 2009). As tasks are divided (i.e. division of labour) or outsourced the integrated knowledge that used to belong to a single master craftsman or team is spread now across the whole supply chain or organisation network and it becomes a challenge to manage it when substantive amounts of new knowledge is simultaneously developed.

The issues arise when new technologies enter the field and a lack of integrated and embodied knowledge appears to be a burden in adapting to a new reality. According to Stigler (1951), supplying an immature industrial environment with the latest machines and methods is a seriously inappropriate model for industrialisation, particularly due to the lack of specialists who can improve raw material and products. Meaning, that without having the deep knowledge that underpins the new machines, users of these machines will be ‘condemned’ to consider this technology as a black box and thus preventing them to ‘play’ with the underlying principles in order to innovate and aim at a sustainable growth. Therefore, the solution does not rest in mechanisation or automation as such, but in progressive development and establishment of the capability to build the practical skills and the integrated knowledge around the new technology.

This integrated industrialisation of composite materials seems to have started decades ago, where increasingly all necessary skills and facilities were being encompassed within a single enterprise as has been reported by Harris (1991). However, what might have been working for single companies didn’t seem to be enough to allow other companies and the composite industry as a whole to maintain a steady growth model.

Based on these observations, we decided to investigate the growth strategies of some exemplary industrial players in the composite industry. As mentioned earlier, we zoomed in on the NPD-Production interface as being key to industrialisation. Knowledge on NPD and Production in composites rarely belongs to a single organisation and the different manifestations of this interface are fundamental for the successful industrialisation of composites. This is the main reason we analyse the qualitative data through a typology of this interface in the supply chain. This typology of interfaces was developed by Smulders et al. (2002) with the intention to provide an
overview on product innovation configurations. Figure 1 demonstrates an outline of those interfaces. The lead partner is considered to be the client or the company that is initiating the collaborative activities. There are four different types of lead partners, according to their in-house activities. The suppliers are divided accordingly which adds up to 16 possible variants. Gaining insight to the interfaces between design and production that currently exist in the industry will enable us to uncover the deeply rooted issues and the factors that hinder volume production in composite development.

![Diagram of NPD - Production interfaces](image)

**Figure 1. A typology of NPD – Production interfaces (Smulders et al. 2002)**

### 3. Research Approach

The main goal of this work is to describe the current state of the industry and gain deeper understanding on the complex issues that is facing. This paper is a report of the first interview round of the study. Eight semi-structured interviews with industry experts working in different companies and composite sectors were conducted. Despite the creation and utilisation of an interview protocol, the interviews were more exploratory in nature and the questions were adaptable for each individual Case.

Participants in the interviews were spread across the broader sector of composites and include traditional composite fields like aerospace and wind turbine blades as well as fields like construction and tidal turbine blades. Table 1 presents an overview of the sector, the activity for each interview Case and the type of NPD-Production interface these Cases represent. The participants had an average amount of experience in the
composite industry of 30.5 years. Seven of the companies that were interviewed are based in the UK and one in the Netherlands.

Each interview lasted approximately two hours (total hours of interviews: 17:07) and the recordings were fully transcribed by the researcher (total number of words: 101.241). Resulting data analysed at the NVivo 10 and coded using a content analysis approach.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Industry / Sector</th>
<th>Activity</th>
<th>NPD-Production Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tidal turbine blade development</td>
<td>Prototyping, NPD</td>
<td>3B+3C</td>
</tr>
<tr>
<td>2</td>
<td>Wind turbine blades</td>
<td>Design, Production</td>
<td>4C</td>
</tr>
<tr>
<td>3</td>
<td>Composite bridges</td>
<td>NPD, Production</td>
<td>4C</td>
</tr>
<tr>
<td>4*</td>
<td>Composite skills development</td>
<td>Technical Consultancy</td>
<td>No specific interface</td>
</tr>
<tr>
<td>5</td>
<td>Composite build-to-print</td>
<td>Production</td>
<td>3A</td>
</tr>
<tr>
<td>6</td>
<td>Metal composite development</td>
<td>R&amp;D, NPD</td>
<td>3B+3C+3D</td>
</tr>
<tr>
<td>7</td>
<td>Composite moulds / Build-to-print</td>
<td>Tooling, Manufacturing</td>
<td>1C</td>
</tr>
<tr>
<td>8</td>
<td>Aircraft equipment</td>
<td>NPD, Final Assembly</td>
<td>1D</td>
</tr>
</tbody>
</table>

Table 1. Interview Cases

The specific role each Case plays in the supply chain and its relationship with composite technologies contributes only a part of the overall picture of the composite industry. These five interfaces identified in this dataset will be discussed briefly in the next section. The main focus of this discussion would be on the knowledge required to reach advanced levels of industrialisation and strategies for growth and development.

4. Observations

Here we are going to discuss some of the main observations for the specific interface types leading to input for a fledgling conceptual framework of growth strategies presented in Section 5.

4.1 The 3A Interface: Lead Partner NPD – Supply Partner Production

Case 5 is considered to be a “Built-to-Print” firm; they only manufacture products requested by their lead partners. They do not have composite design capability (e.g. an in-house design team), but they only “offer design support” because of their production knowledge. This means that they can suggest design changes or alternative material to support their lead partners’ product development activities.

The specific company is gradually increasing production volume and is interested in attracting more large-volume clients. In terms of industrialisation their strategy seems to be investing in technologies that can decrease production time: “How you get from ramp-up to production. Looking for a quicker way in cutting prepreg. So we are investing in a ply cutter that will reduce the amount of time of the people cutting kits by hand. [...] So we can say, what used to take 2 man-hours, now takes 30 minutes. We have got a double bed in it so we got one machining and one loading so we can bring

* This case does not refer to a specific interface and therefore it not going to be analysed in the present paper.
the time back. [...] It is about understanding the process, it is about understanding volumes, the technologies available”.

Also increasing productivity has to do with the traditional production engineering methods on designing the production line that apply in all manufacturing settings and play a major role in accelerating yield: “Every single task must be broken down to under the time. [...] You have to break it down to bite size pieces so every six hours one falls off in the end of the line”. Finally, effective production planning is also a prerequisite: “Productionisation is all about having enough resource in the right place with the plant equipment, machinery or persons to move that product quickly through the factory and at the other side”.

During this interview other issues were also touched considering the NPD – Production interface. The most important were remote collaboration, design changes for manufacturability reasons and involvement of designers in manufacturing for training in order to manage the designers’ inability to think in terms of manufacturing and designing composites. In a more practical ground the manufacturing team was utilising a “taking it apart” strategy to cope with the lacking information from the lead partners in order to “discover how to make the drawing”. Essentially the team needs to understand the way of thinking behind the lead partner’s design decisions, guess why specific choices were made and foresee what could work best during manufacturing.

For growth they will need to invest in production technology but also ‘swim’ up the creation chain and become more knowledgeable in collaborating with designers and lead partners, not necessarily become designers themselves.

4.2 THE 3B INTERFACE: LEAD PARTNER NPD – SUPPLY PARTNER NPD

Both Cases 1 and 6 investigated in this interface are currently only R&D (3B), but there is a clear target towards developing their own production capability and industrialising their technologies and products (3C, 3D) or even grow towards an 1A lead partner.

Cases 1 and 6 have different starting points. The firm in Case 1 had a background in glider (small aircraft) design and manufacturing (1A lead partner). They were approached by a client to develop a specific part of their product/system, the blades for tidal turbines (3B). Case 6 was historically R&D (3B), developing a novel technology with the target to build a whole supply chain around many markets (space, aerospace, oil and gas etc.). Both Cases seem to hold a similar attitude in terms of developing parts “for other peoples’ systems”, they do not get involved with the rest of NPD but only offer parts that will be integrated to the systems of their lead partner. It is also worth noting that Case 6 is not a polymer composite technology, but the only case of metal composite in this sample; a very advanced new technology.

Currently, both firms only create components for testing. During the interviews they emphasised the significance of material data for material characterisation and accreditation: “So that’s the big eclipse here in composites is that you have to get material accredited. You have to get each material accredited itself, for the particular use you are putting it in” (Case 1). Also they highlighted the need to understand and standardise the manufacturing process which is currently considered to be a black box: “You look at the material performance against the production method used”. “We could make it faster, if we understood better what the minimum temperature we can get away with is” (Case 6). They typically lack fundamental knowledge of the behaviour of the material.
The fact that Case 1 already has lead partners that will purchase the products when ready, has acted as a catalyst in their attitude towards industrialisation. Consequently, they are mainly concerned about more practical issues like alternative manufacturing routes, design iterations and capital expenditure. In Case 6 however, the main concern in terms of strategy is funding schemes and attracting investors: “The problem comes when the industrial customers may like the technology, but they don’t like the technology if they cannot see an industrial supply. Small companies can’t industrialise supply unless they have industrial customers”. Also for them attracting “low hanging fruit applications till we get big enough to justify a factory” is the main strategy to gradually industrialise.

For growth, two things are necessary, first set out a strategy to become more knowledgeable in terms of their technology and manufacturing processes and second to create momentum in the various value chains of their lead partners.

4.3 THE 4C INTERFACE: LEAD PARTNER – SUPPLY PARTNER NPD AND PRODUCTION

Cases 2 and 3 belong to a category where the lead partner does not own any product development or manufacturing expertise. The lead partner in both Cases is a municipality or a ministry requesting a product that has to follow some specific directives. Beyond those directives, the supply partners have almost complete design freedom. Cases 2 and 3 are substantially different terms of the size of those companies (number of employees, turnover), however the main characteristic here is the development of all related knowledge and skills in-house, since the NPD-Production interface is internal.

In both Cases combinatorial changes in design and manufacturing were a common strategy in order to drive cost down or to increase production pace, i.e. to industrialise their production. In Case 2 the design was driven by manufacturing rate: “The production rate of the factory was maximum. Our job was to try to improve that production rate. Because they (the headquarters) just opened a new factory, we needed to make the new factory cheaper than it could ever was [sic]”. To achieve increased rates they had to modify both the design and the manufacturing processes: “The reason we went for this (design) was down to production speed”. “What we were trying to prove was that the savings you were making in the individual parts would be greater than the savings you would get in assembly”. Similarly, in Case 3 the design was driven by cost: “When you see how the biding is done it is prices always... So when you start with composites in civil engineering you always start with the cheapest material”. “...the most important part of our innovation was that we made the whole technique cost-price competitive. That was the final conclusion of what we did and what was most important to get it going”. What enabled cost decreases was again combinatorial changes “scribbling and sketching and at some point you get this (design) idea and then you see actually that production time drops tremendously and from there we are actually optimising with smaller steps”. “It is a mixed problem. You have to adjust in both (productibility and design) simultaneously”.

Serial production played a major role in industrialisation, decreasing the production steps and also redesigning the production steps. “We did it by making serial productions, automated engineering and customer specific finishing” (Case 3). Here the company focused on the coupling point where the product becomes client-specific and thus could industrialise the production activities before that specific point. Furthermore, in both cases production scalability was a factor taken under consideration in the early stages
of the product and production system development but was also re-examined again and again as an approach to decrease cost.

Case 2 highlighted the role of the first client (champion) to the success of the technology: “you are very dependent on champions within the people who give you orders. If you have no champion you will fail with the basic cost price argument. So when you have to sell products which are more expensive than your competitors you can only sell them on the second argument (architecture, novelty, corrosion resistance). Not price”.

In Case 3 the new product is substituting conventional bridge structures and therefore the only way to create a viable business in the long run was to decrease the cost and reach the price of conventional structures. The wind turbine on the other hand is a technology based on learning-by-doing (Kamp et al. 2004), consequently fast production pace can be enabled through internal knowledge and combinatorial improvements on design and manufacturing.

4.4 THE 1C INTERFACE: LEAD PARTNER NPD AND PRODUCTION– SUPPLY PARTNER NPD AND PRODUCTION

In Case 7 the interface corresponds to a mould manufacturing company. The moulds (known as tools) they manufacture are built from composite material and are primarily tools for prepreg. Mould development drops right in the middle between Design and Production and it is a very critical part of the process. In this Case the lead partner tends to have some expertise both in design and manufacturing of composite products and is interested to purchase a mould to enable production (usually for an external client). The specific firm not only creates moulds for composites, but also offers small volume production of “niche products” for clients. Their strategy is “low volume – high learning products” for clients in the aerospace, automotive, marine and defence industry.

In this Case new product/tool design decisions are driven by volume, cost and performance: “for a new part that has never been made before, the decision there would tend to be based around volume, cost expectation and performance requirements. So you have to look at all three of those, decide which way to go”. Industrialisation and increased production volumes come down to investment: “If I need to scale and I need more capacity I will buy another autoclave. If I need to cut more prepreg or material, it is another prepreg cutter, it is money”.

Another important issue that was discussed relates to the extensive expertise and intuition that is driving their processes when developing new products: “I think a lot of it comes down to experience. And I think we say, we evaluate this and then we do this... in reality quite often it comes as a flash and it is, yes we want to make that and that could be made up like this”. This deep and tacit knowledge is very hard to be recorded.

For growth they will need to invest in tool development technologies and enrich their activity spectrum in order to attract more lead partners and further industrialise their business.

4.5 THE 1D INTERFACE: LEAD PARTNER NPD AND PRODUCTION– SUPPLY PARTNER NPD AND PRODUCTION (SEPARATE SUPPLIERS)

Here we interviewed the lead partner, who was essentially the client of composite parts to be assembled into their products. This interface seems to be a very difficult one as the lead partner is liaising knowledge from different supply partners: “Initially we got one
subcontractor to design it, another subcontractor to build it, which is an extremely poor approach. And we weren’t involved into either, we were just involved in the specification. And that is [sic] proved to be very problematic, that is an example of non-successful, it hasn’t completed, it is taking a long time and I would say that it’s a hard moment”. The specific company had little previous experience in composites since their expertise is around designing the overall product system and final assembly.

For them, industrialising products involving composites seemed to be harder than non-composites “...in the sense that you need to know more”. The main difference that they found was that the conventional process of defining specifications that seemed to work in other products is not enough in composites: “...in the case of composites that method doesn’t work very well [...] because the specification doesn’t recognise all the problems associated in making composite parts”. Also lack of proper preparation in defining requirements during the early stages of development, insufficient dialog with the supply partners along with the contractual nature of the relationship created unresolved issues and friction between the partners.

What this company discovered through their experience is translated as a growth strategy in this interface. Making the dialog a formal part of the process was one: “what we are finding is that we need to put the dialog parts of the sourcing process into the process. It cannot be incidental. Or it cannot depend on whether people choose to go to the supplier and talk to them. It has to become part of the process of sourcing composites in order to make the job more smoothing and the outcome more acceptable”. Also open dialog between the actors would be another one: “there is the contractual relationship between the two companies, which I think places an immediate problem... that can be overcome by open dialog”. Finally, flexibility in defining specifications, rather than spending excessive time to narrowly defining them seems to be their preference as a future strategy in this interface: “Even the kind of things we are doing we are spending months and months in specifications. They are not getting better. They are just changing and the time we have to do the job is getting shorter and shorter”.

What this lead partner seems to refer to is to increase the collaboration among involved actors to secure the interface transitions. In order to play that role he needs to become more knowledgeable on the work field belonging to the supplying partners or at least facilitate the collaboration among the suppliers.

5. INDUSTRIALISATION AND GROWTH STRATEGIES

In this section we formulate a fledging theoretical construct on the growth strategies of the sector by reflecting upon the observations on the NPD – Production interfaces identified across the composite industry. Four main strategies were identified. Three of them are related with the degree of industrialisation (figure 2) while the fourth is related with the collaborative interface with industrial partners as a broader supply chain strategy. In Figure 2 the three strategies related to the division of labour are marked with letters (A, B and C).

Growth strategy A is the Technology Development and this was derived from Cases 1 and 6 (3B interface). This strategy is primarily focusing on standardising the material and its manufacturing process, while simultaneously attracting investors, venture capital or any other private or public funds that can enable the development of manufacturing capability.

Growth strategy B is Volume Production from Cases 5 and 7 (3A, 1B interfaces). This is characterised by investment in the manufacturing process to acquire new equipment
or skills and good industrial engineering practices like production planning and control. Here the term volume production does not strictly refer to the amount of parts being produced; it also refers to the range of services and activities that can add value to lead partners.

Growth strategy C is the **Integrated Environment** from Cases 2 and 3 (4C interface). The main enabler of growth is the full control on design and manufacturing processes and the decrease in cost resulting from combinatorial changes. In essence this strategy combines both technology development and volume production strategies. Growth in these environments seems to relate more with what Linton and Walsh (2008) call process-based innovation.

The fourth strategy is **Collaboration** and is related with good supply chain practices. This strategy has to do with expertise in the social interfaces that drive commercial relationships. During the interviews across all the interfaces, issues of trust related to intellectual property and relationships with customers or suppliers emerged as an important part of discussion. Building deep knowledge and skills not only in new material technologies, but also in collaborating across the commercial and social interfaces is vital for the growth of the sector.

![Diagram](image)

**Figure 2. Growth strategies**

### 6. Concluding Remarks

Historically, knowledge developed in composite technologies was based on old rules and routines prevalent in traditional industries. As a result, when composites became broadly available as a new class of material the growth of the sector was restricted. In this paper the strategies that could allow the sector to reach advanced levels of industrialisation and cover future demand were explored. Qualitative insights across NPD-Production interface, an interface explicitly aiming at volume production, were analysed in order to develop a theoretical framework on the growth strategies of the industry.

The understanding developed here indicates that the industry should work across the supply interfaces, building deep expertise related with technological and material
advancements, but also more importantly knowledge related with social interfaces in commercial handover situations. This integrated body of knowledge covering design, engineering and manufacturing would be the pivotal point to accelerate growth.

However, developing skills in this level is very much dependent on attitudes and norms: “If you think yourself as a craft industry the skills must lie in the people, so it is always difficult to ask the people to do something that they don’t know about. If you are process driven, then you bring in the machinery and you change the process and you bring in the people behind it” (Case 4). Growth in this sense cannot happen overnight. Change of norms requires change of routines, a process that can only initiate by changing the conversations across the sector. This is consequently the main point of impact of this work, to raise awareness on issues that go beyond the technical nature of composite material and reflect upon deeper concerns related with the growth of the whole sector.

**REFERENCE**


