INNOVATION THROUGH DESIGN

Understanding the challenges, improving the practices of using new materials application in the building industry

by

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ABSTRACT

In recent years, in addition to new forms of architectural expression, new means of conceptual and material production have significantly affected architectural thinking. Materials have regained a predominant role developed mainly by technological experiments and become key aspect of culture, innovation and experimentation. Although the application of materials is a fundamental determinant of buildings representation, in order to develop a successful design solution, emerging materials, systems, technologies and precedents must be considered. This research focuses on understanding new material development in material industries and on the material selection process for architectural projects. The aim is to identify and analyze the challenges of using new materials application.

In order to accelerate innovation in the building industry, the initial step is to reduce barriers of using new materials application, such as liability of long-term performance risk. The proposed approach (stated in this research) is to define a new role for (industrial) design that will facilitate new ways of communication (between architects, designers and materials industries) from idea creation to product and design development. This study will explore and seek to answer this main question: "If innovative materials application in architectural projects depends on the liability risk, how can industrial design act as a bridge/facilitator to assist in reducing the challenges of using and introducing new materials in the building industry?"

PREFACE

This thesis is an original work by Ceren Pektas. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Understanding the Relationship between Material, Design and Building Industries," No. 45078, January 15, 2014.

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INTRODUCTION

> We live in a world populated by structures - a complex mixture of geological, biological, social, and linguistic constructions that are nothing but accumulations of materials shaped and hardened by history.[1]

From prehistoric periods to Modern Age, materials have been the key aspect in forward progress of human kind. According to Oxford dictionary materials refer to "the matter from which a thing is or can be made."[2] In other words, everything around us is made of one or more materials and they have been a great source for designers by allowing experimentation and development of new products. In the past materials were limited to local sources. However, today's access to a tremendous amount of materials is possible with the impact of globalization on transportation along with "communications, international standardization and trade liberalization."[3] This crucial change not only accelerated evolution of materials and their technology, but also increased architects' and designers' interest in exploring potential of materials. Schittich, the writer of the article "The Surface in Contemporary Architecture," explained this vast development of materials a new material culture

1. Manuel De Landa, *A Thousand Years of Nonlinear History* (New York: Zone Books, 1997), 25.

2. Oxford Dictionary, "Material," http://www.oxforddictionaries.com/definition/english/material (accessed Nov 5, 2013).

3. James J. Corbett and James Winebrake, "The Impacts of Globalisation on International Maritime Transport Activity Past trends and Future Perspectives" (Global Forum on Transport and Environment in a Globalising World: Guadalajara, Mexico; Nov. 10-12, 2008), 4.

that is "complex and [in] a state of continuous change and adaption."[4] Furthermore, Antonelli explains the transformation of materials:

> Plastics can be clear as glass, as sharp-edged as stone and as metallic as aluminum. Aluminum can look like quicksilver; wood can look like more plastic. Solid metals are being replaced by ceramics and sheet metal by carbon fibers; wood can be as soft as upholstery. New technologies are being used to customize, extend, and modify the physical properties of materials and invent new ones. Materials are being transformed from adjuncts in passive roles to active interpreters of goals of engineers and designers.[5]

The choice of materials represent what an architect wants to express to society through building.[6] For example, building facades consist of different structural and non-structural components that not only provide protection from the elements, but also "characterize the face of a city."[7] According to Lovell the selection of materials is about "how materials can be integrated to meet the poetic and pragmatic intent of a building's envelope."[8] Despite the essence of materials and vast development of new material technologies, the adoption process of innovative materials application in the building industry is very slow compared to other industries like the electronics and automotive industry.

I believe that the research put forth in this thesis could make a real contribution to the manufacturers that are introducing new products and to the material selection process of architects by increasing their awareness to the complexity of using innovative materials in their practices. Industrial design can play

4. Christian Schittich, "The Surface in Contemporary Architecture" in *Construction Materials Manual*, eds. Manfred Hegger, Volker Auch-Schwelk, Matthias Fuchs, and Thorsten Rosenkranz (Basel: Birkhauser, 2006), 10-13.

5. Paola Antonelli, *Mutant materials in Contemporary Design* (New York: The Museum of Modern Art, 1995), 9.

6. Mick Eekhout, *Methodology for Product Development in Architecture* (Amsterdam: IOS Press, 2008), 217.

7. Christian Schittich, *In Detail: Building Skins* (Basel: Birkhauser, 2001), 9.

8. Jenny Lovell, *Building Envelopes: An Integrated Approach* (New York: Princeton Architectural Press; 2010), 38.

a crucial role in facilitating communication among different industries while achieving this awareness and improved knowledge transfer because the designer can be a key stakeholder in the development and specification of materials and products. The concerns and influences of clients and other professions, during the introduction, selection, and application of innovative materials in the building industry, can frequently be communicated by the architect in the interactions with the industrial designers and manufacturers. As such, the focus of this research is not centred around the client experience, education, education process, or to enhance their input and participation in the material specification process. Rather, this work is focused on understanding manufacturers' experience of the new material development and on the architects' material selection process.

The first part of the research focuses on the background information about the process of new product development in architecture and the factors that affect innovative materials application in the building industry. In the second part, interviews with architects and designers are represented to investigate the information sources they use and the aspects that are important during the material selection process. Furthermore, in order to study the challenges of introducing innovative products to market and how well the issue of liability is addressed, interviews with manufacturing industry professionals were conducted. In the third part, the focus is on the new role of industrial designers, which can encourage the use of innovative materials application in the building industry by facilitating dialog between architects and manufacturers.

PART 1: BACKGROUND (FROM IDEA TO PRODUCT)*

> Materials have progressively emerged as providing the most immediately visible and thus most appropriate manifestation of a buildings representation.[9]

1.1. New Product Development in the Building Industry

New knowledge is an essential driver of innovation in material science.[10] Day4Energy is an example of innovative photovoltaic technologies that is started with a new idea. The products which "reduce the series resistance between silicon and current conductor" were developed by a Russian physicist and in collaboration with a Canadian entrepreneur, and they founded a successful manufacturing company in 2001.[11] Not only are new products introduced by suppliers and manufacturers are recognized as the main drivers of technological change in the construction industry, they also create new possibilities for firms to gain a competitive advantage over their industrial rivals.[12] In this chapter the aim is to give a brief overview of products developed for the building industry (according to their level of completeness) and analyze the role of design in the development process.

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* The title is inspired from Gernot H. Gessinger, "From Idea to Market: The Flow" in *Materials and Innovative Product Development: From Concept to Market* (Oxford: Butterworth-Heinemann, 2009).

9. Michelle Addington and Daniel Schodek, *Smart Materials and Technologies in Architecture* (Oxford: Architectural Press, 2005), 3.

10. Gernot H. Gessinger, "From Idea to Market: The Flow," in *Materials and Innovative Product Development: From Concept to Market,* ed, Gernot H. Gessinger (Oxford: Butterworth-Heinemann, 2009).

11. Ibid, 9.

12. Toke Reichstein, Ammon J. Salter and David M. Gann, "Last Among Equals a Comparison of Innovation in Construction, Services and Manufacturing in the UK," *Construction Management and Economics* 23 (July 2005): 632.

The definition of the term 'product' is derived from "to bring forth" (Latin for 'pro' =forth, 'ducere'= to lead, to bring).[13] A building can be considered as a complete product. It consists of great number of materials and components which are produced in workshops and factories, and then assembled at the building-site. Three examples of products used in the contemporary building process are given below according to their level of completeness/complexity:[14]

Low level of completeness (materials)
Cast-in place concrete is a composite material and can be transported as a ready mix, but the forming process takes place or occurs on the construction site.

Medium level of completeness (industrial products)
Concrete block and brick are examples of industrial products produced away from the building site and transported there.

High level of completeness (super components)
Pre-assembled glass facade modules only require bolting and sealing at the building site. They require the integration of different materials. Furniture and fixtures can also be considered in this category.

Building design usually necessitates the involvement of engineers, architects and interior designers. According to the size of firms and the performance of the building design developed, collaboration between an increasing number of various disciplines is required. For example, Foster and Partners' sees itself as an

13. Eekhout, 21.

14. Ibid., 21-23.

innovative architectural and integrated design practice firm[15]. They provide clients with different design services such as architecture, environmental engineering, structural engineering, interior design, industrial design and urban design. Increasingly the role of industrial design in the development of materials, industrial products and components is becoming a vital aspect of architectural practices since experimenting and finding new possibilities with existing and new materials application allows architects to gain competitive advantages in the current building environment. One of the most interesting approach to this increasing interest in the design of building components has been proposed by Eekhout:

> By the increasing level of the necessary knowledge of technical schedules, materials, production methods and assembly methods, the designing of components and the developing of building products begins to manifest itself by force as a full-valued scientific field.[16]

However, the development of a new successful product (from materials, industrial products, components to buildings) is not an easy task. Starting with "idea creation, concept development, building business core, to market testing and market launch," every stage presents different challenges.[17] Design is a crucial aspect that can be embedded in different phases of product development in order to achieve product competitiveness. Riedel and Roy define product innovation as the application of new concepts, inventions or technologies in the design of the whole product or key components. They show seven dimensions through which the competitiveness of a product may be enhanced through design and innovation. These are performance, technology, features, style, quality, cost/price and range. In other words, design and

15. "About us," Foster + Partners, http://www.fosterandpartners.com/about-us/ (accessed May 9, 2014).

16. Eekhout, 114.

17. Nikolaos Tzokas, Erik Jan Hultink and Susan Hart, "Navigating the New Product Development Process," *Industrial Market Management* 33 (2004): 620.

innovation can help reduce costs, improve performance and quality, and differentiate from rival products to offer a new product.[18]

To make success more likely, the concurrence of different skill levels has to be fulfilled.[19] Walsh argues that the designer acts as a "translator" between people with different knowledge, information, skills and desires.[20] Furthermore, according to Walsh and Roy, a "good designer" not only creates visually appealing products, but also "he/she acquires the necessary knowledge of what customers want, what can be most efficiently produced and what fits best in with the company's other products, corporate planning and image."[21] In other words, design involves numerous interactions with other actors in the development of a new product.[22]

> Through the conscious control of form, configuration, overall appearance and detailing, industrial design is capable of conveying to the user the abstract characteristics of a product, e.g. robustness, precision.... It can arrange for controls to be comfortable, pleasant, and easy to operate. It is capable of imbuing a product with a distinctive ambience, style and feeling of good quality which equates with the personal taste of the user.[23]

Much research on the role of design in product development has been conducted and it is recognized that design can affect competitive advantage of products by creating solutions based on improving visual, ergonomic and economical aspects of products. Design also plays a crucial role as a focus of communication between

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18. Robin Roy and Johann C. Riedel "Design and Innovation in Successful Product Competition," *Technovation* 17, no. 10 (1997): 538.

19. Gessinger, 1.

20. Vivien Walsh, "Design, Innovation and the Boundaries of the Firm," *Research Policy* 25 (1996): 515.

21. Vivien Walsh and Robin Roy, "The Designer as 'gatekeeper' in manufacturing industry," Design Studies 6, no. 3, (1985): 127.

22. Walsh, "Design, Innovation and the boundaries of the firm," 510.

23. Stanley Moody, "The role of industrial design in the development of new science based products," in *Design and Industry* eds. R. Langton (London: The Design Council, 1948).

different people with various skills and backgrounds during new product development.

1.2. Innovative Materials Application

Innovation simply can be defined as the "successful exploitation of new ideas."[24] In the literature, several theories have been proposed to explain innovation. Barrett and Sexton define successful innovation as "the effective generation of a new idea, which enhances overall organisational performance."[25] They emphasize four assumptions in this definition: (1) idea, (2) newness, (3) effective generation and implementation, and (4) overall organization performance. *Ideas* are starting points for innovation, but not all ideas are identified as innovations. The *newness* aspect distinguishes innovation from change. In addition, generating or transferring a new idea to a successful *implementation* is also a crucial factor of innovation. Finally, innovation must improve *overall organizational performance.*[26]

Chandy and Tellis suggests two common dimensions that underlie most innovation definitions: (1) technology and (2) markets. The first aspect, technology, indicates "the extent to which the technology involved in a new product is different from prior technologies" (see Figure 1).[27] The second dimension, markets, indicates

24. Gessinger, 12.

25. Martin Sexton and Peter Barrett, "Appropriate Innovation in Small Construction Firms," *Construction Management and Economics* 21, no. 6 (2003): 626.

26. Ibid.

27. Rajesh K. Chandy and Gerard J. Tellis, "Organizing for Radical Product Innovation: The Overlooked Role of Willingness to Cannibalize," *Journal of Marketing Research* 35 (1998): 476.

"the extent to which the new product fulfills key customer needs better than existing products (on a per-dollar basis)."[28]

		Customer need fulfillment per dollar	
		low	high
Newness of Technology	low	Incremental innovation	Market breakthrough
	high	Technological breakthrough	Radical innovation

Figure 1 Chandy and Tellis Model of Innovation. Source: Rajesh K. Chandy and Gerard J. Tellis, "Organizing for Radical Product Innovation: The Overlooked Role of Willingness to Cannibalize," *Journal of Marketing Research* 35 (1998): 476.

Both innovation models of Chandy and Tellis and Barrett and Sexton state that newness of technology and implementation are two important factors. In this paper the objective is to analyze innovative materials application in two aspects: (1) transference of existing materials in new contexts/concepts and (2) implication of new materials. The implication of new materials can also be analyzed in the context of two factors regarding newness of technology/material used: radical innovation and incremental innovation (see Figure 2).

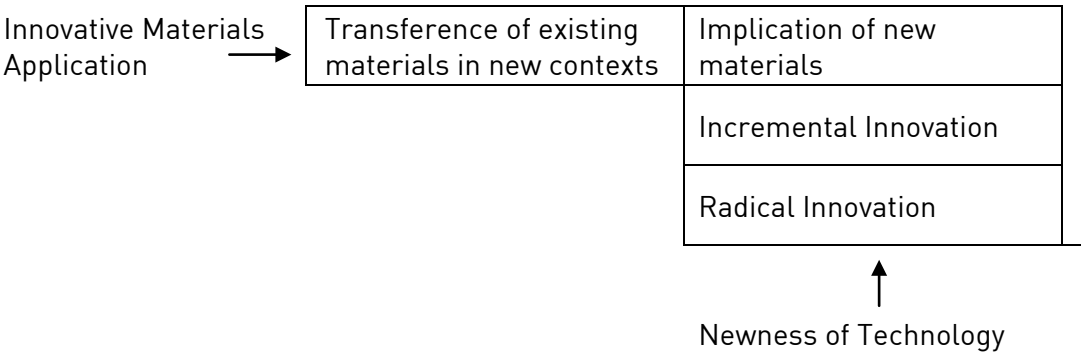

Figure 2 Innovative Materials Application

28. Ibid.

1.2.1. Transference of Existing Materials in New Contexts

As a result of the selection and interpretation process, lines and directions of building represent some specific content or meaning.[29] According to Tschumi, who is an architect, theorist and academic, and has re-examined the role of architecture in practice, "context is not a fact; it is always a matter of interpretation."[30] Context includes environmental, cultural, historical factors that affect how we perceive a space. Transference of existing materials in new contexts focuses on finding innovative ways of using traditional (building) materials to create new experiences and architectural expressions. One example of this type of innovation is finding new uses of old materials. Farrelly suggests that "it is possible to create contemporary architecture that incorporates reconstituted, reclaimed or reused materials from steel frameworks to brick walls."[31]

Case Study: Stone

> The finished wall's character is defined by the spaces between the stones as much as it is by the stones themselves. The time between placing one stone and the next on a wall is the space in which a wall is conceived. The thinking that goes along with the placement of each stone incrementally adds to what is, ultimately the wall conceptualized.[32]

29. Annette Svaneklink Jakobsen, "Experience in-between Architecture and Context: The New Acropolis Museum, Athens," *Journal of Aesthetics & Culture* 4 (2012): 3.

30. Bernard Tschumi, *Event-Cities 3: Concepts vs Context vs Content* (Cambridge: MIT Press, 2004), 12.

31. Lorraine Farrelly, *Basics of Architecture 02: Construction + Materiality* (Switzerland: AVA Publishing, 2009), 153.

32. Dan Snow, *Listening to Stone* (New York: A Division of Workman Publishing, 2008), xii.

Stone is one of the earliest materials used for construction. The Göbekli Tepe temple in Turkey (9000BC) is one of the world's oldest known stone construction. Another example of stone construction is the tomb at Saqqara in Egypt (3100-2890 BC), where cut slabs of limestone were used for lining and roofing a small chamber. [33]

Minerals are building blocks of stones. They contain elements joined together in a consistent, repeating pattern. There are lots of different types of stones with different textures, colours, sizes and compositions. Rocks can be classified in three types according to the way they formed: igneous rocks, sedimentary rocks and metamorphic rocks. For example, igneous rocks are formed by the cooling and solidification of molten earth material.[34] According to the speed of the cooling process, minerals might be visually identifiable (such as granite), can be very finely grained (less than 1mm) or not contain any minerals at all (such as the obsidian glassy texture because of lack of crystal growth during cooling process).

The oya-ishi stone is an igneous rock that has been used as a building material for centuries. It has a warm texture and is a fireproof, easily carved, versatile material.[35] Chokkura plaza and shelter in Tochigi, Japan, by Kengo Kuma & Associates is a great example of innovative use of oya-ishi stone (see Figure 3). They designed a perforated wall inspired by the porosity of the material. The structure is

33. Francis D. K. Ching, Barry S. Onouye and Douglas Zuberbuhler, *Building Structures Illustrated: Patterns, Systems and Design* (New Jersey: John Wiley & Sons, 2009), 2-13.

34. "Igneous Rock," Encyclopedia Britannica Online Academic Edition, http://www.britannica.com/EBchecked/topic/282318/igneous-rock, paragraph 1 (accessed April 17, 2014).

35. Web-Japan, "An old oya-ishi stone mine," Nipponia No. 23, December 2002, http://web-japan.org/nipponia/nipponia23/en/feature/feature13.html (accessed May 5, 2014).

located adjacent to the existing building and stones are supported by a 1/4 inch (6mm) thick steel plate.[36]

Figure 3 Daici Ano, Chokkura Plaza & Shelter in Tochigi, Japan, by Kengo Kuma & Associates. Source: World-architects, http://www.world-architects.com/en/kengokuma/projects-3/chokkura_plaza-7437

Another example of transferring stone in a new context is based on a new process of recycling called 'StoneCycling' was discovered by Tom Van Soest. The process developed as a result of the growing need for sustainable building materials. The process produces new high quality building materials by using waste construction materials such as glass, brick and concrete. Non-waste adhesives are also being used to create semi-finished products that can be processed into everything from bathroom and kitchen tiles to windowsills (see Figure 4).[37]

36. Blaine Brownell, *Material Strategies: Innovative Applications in Architecture* (New York: Princeton Architectural Press, 2012), 26.

37. "StoneCycling," http://stonecycling.com/ (accessed May 6, 2014).

Figure 4 StoneCycling. Source: "Blended Materials by Tom van Soest, http://lin-morris.com/blended-materials-by-tom-van-soest/.

1.2.2. Implication of New Materials, Products and Components

As Schodek discusses, new developments of materials create many opportunities for designers:

> It is hard to imagine, for example, a design world without plastics-themselves once a new material. More recently, developments in carbon fiber and other technologies have made products stronger, lighter, and easier to use.[38]

Newness is a key distinguishing factor of innovation that can be determined by the technology involved in the material and its product development compared to previous applications. Therefore, according to the newness of technology, materials can generate both incremental and radical changes to products, methods and processes. Incremental innovation involves small changes based upon current knowledge and experience. On the other hand, radical innovation involves a breakthrough in technology that often changes

38. Daniel L. Schodek, "Nanomaterials in Design" in *Materials Experience: Fundamentals of Materials and Design*, ed. Elvin Karana, Owain Pedgley and Valentina Rognol (Great Britain: Butterworth-Heinemann, 2013), 209.

the character and nature of an industry.[39] Radical changes constitute the most efficient development in the industry since these type of changes are based upon technological breakthrough and high customer fulfillment (see Figure 1). Minor incremental changes are more frequent in the construction industry.[40] For example, the creation of new materials such as structural steel and reinforced concrete in the mid-1800's lead to radical changes in the construction industry. The combination of these materials (steel and concrete) provides a strong support system and costs less than other materials like brick.[41]

Increasing concerns regarding building materials impact on the environment has led to the development of more sustainable materials. For instance, the Bioplastic Façade Research Project, completed in October 2013, includes an interdisciplinary group of material scientists, architects, product designers, manufacturing technicians, and environmental experts. They developed a new bioplastic material made of 90 percent renewable materials. The team explains that "thermoformable sheets of bioplastics will represent a resource-efficient alternative (to oil-based plastics, glass, or metal) in the future, as they combine the high malleability and recyclability of plastics with the environmental benefits of materials consisting primarily of renewable resources."[42] This new bioplastic was

39. Sarah E. Slaughter, "Models of Construction Innovation," *Journal of Construction Engineering and Management* 124 (1998): 227.

40. Lauri Koskela and Ruben Vrijhoef, "The Prevalent Theory of Construction is a Hindrance for Innovation" (paper presented at the 8th Annual Conference of the International Group for Lean Construction, Brighton, July 17-19, 2000).

41. Natalya Sergeeva and Milan Radosavljevic, "Radicality of Ideas: Challenging Radical versus Incremental Challenges in Construction" (paper presented in 26th Annual ARCOM Conference, Association of Researchers in Construction Management Vol. 1, UK, September 6-8, 2010): 404.

42. "Arnoskin Spiky Pavilion Made From Bioplastics by ITKE", Deezen, last modified November 9, 2013. http://www.dezeen.com/2013/11/09/arboskin-spiky-pavilion-with-facademade-from-bioplastics-by-itke/ (accessed March 20, 2014).

used in the façade of the Arboskin pavilion, by ITKE in Stuttgart, Germany (see Figure 5).

Figure 5 Arboskin Pavilion in Stuttgart, Germany, by ITKE. Source: Deezen, photograph by Roland Halbe. http://www.dezeen.com/2013/11/09/arboskin-spiky-pavilion-with-facademade-from-bioplastics-by-itke/

Case Study: Nanomaterials and Advanced Materials

Nanotechnology is a very broad field that requires collective knowledge and expertise from different disciplines such as physics, chemistry, materials science, biology, etc. According to Ashby, Ferreira and Schodek, "it is one of the final great challenges for humans, in which the control of materials at the atomic level is possible."[43] Nanomaterials are not newly discovered materials but the manufacturing of materials like metal, ceramic, polymeric etc. on a nano scale creates outstanding mechanical, electrical, chemical, magnetic, and optical

43. Daniel L. Schodek, Paulo Ferreira and Michael F. Ashby. Nanomaterials, Nanotechnologies and Design: An introduction for Engineers and Architects (UK: Butterworth-Heinemann, 2009), 4.

properties which offers unique possibilities to designers.[44] Some examples of these possibilities are quite artistic.

The exterior façade of Lumenart House of Light in Zagreb, Croatia, by Rusan Architektura has a unique application called "LotuSan paint." According to Ternaux "this external paint coating has an extremely water-repellent surface, its micro-structure is modeled on that of the lotus leaf in order to reduce the surface contact area with water and dirt to a minimum. Treated facades thus remain dry and clean."[45] Therefore, this advanced paint prevents the white exterior surface of the building from being marred with dirt overtime which is more sustainable than traditional paints that must be refreshed more often (see Figure 6). [46]

Figure 6 Lumenart House of Light in Zagreb, Croatia, by Rusan Architektura. Source: Open Buildings, http://openbuildings.com/buildings/lumenart-house-of-light-profile-3444

Advanced materials are described as "any material that transformed through advanced manufacturing techniques, that features a series of exceptional

44. Schodek, "Nanomaterials in Design" in *Materials Experience: Fundamentals of Materials and Design*, 214.

45. Elodie Ternaux, *Industry of Nature: Another Approach to Ecology* (Amsterdam: Frame Publishers, 2012), 203.

46. Ibid.

properties (mechanical, electric, optic, magnetic, etc) or functionalities (self repairing, shape change, decontamination, transformation of energy, etc) that differentiate it from the rest of the universe of materials."[47] An example of advanced materials is the Eden project designed by Michael Pawlyn opened in March 2001. It is constructed of "inflated ETFE membrane panels, which are 1% of the weight of double glazing. The steel frame was very light, letting in more sunlight and adding solar gain".[48] The design of the structure and hexagonal forms is inspired from soap bubbles (see Figure 7). [49]

Figure 7 Eden Project in Cornwall, UK, by Michael Pawlyn. Source:http://media.treehugger.com/assets/images/2011/10/biomimicry-eden-project-schumacher.jpg

In both types of innovations, finding new ways of using existing materials and the implications resulting from the use of new materials can foster growth in the building industry, but, most significantly, innovations can improve the built

47. "Design and Advanced Materials as a Driver of European Innovation" European Union (2013), 70, http://www.damadei.eu/wp-content/uploads/DAMADEI_report_low.pdf.

48. Ibid., 115.

49. Ibid.

environment we live in. Innovation, on the other hand, is resultant of human's motivation and desire to constantly come up with something new, and this human behavior will be discussed next.

1.3. Desire

According to Wesley Cohen, "innovation not only plays a central role in explanations of economic growth, industrial dynamics and international trade,"[50] but according to Reichstein, Salter and Gann it also "creates possibilities for firms to gain competitive advantage over their industrial rivals."[51]

> The laboratories and think-tanks of the automotive and aerospace industries are now the world leaders in the development of innovative materials. The ultra-tear proof, highly insulating, extra-lightweight materials and coatings developed by these centres of excellence also offer new opportunities for sophisticated building concepts. However, it is not unusual for many years to pass before the development of a highly specialised material in a high-tech industry is transformed into a marketable building product. This may be because the potential of the innovation transfer is not recognised immediately or because the funding for protracted, expensive approval procedures is not forthcoming.[52]

Construction is a collaborative activity including different organizations that are responsible for production, assembly and installation of systems, as well as a range of professions, such as architects, designers, engineers, consultants and users.[53] New components developed by suppliers and manufacturers are the key

50. Wesley Cohen, "Empirical Studies of Innovative Activities," in *Handbook of the Economics of Innovation and Technological Change,* ed. Paul Stoneman (Oxford: Basi Blackwell, 1995), 182-264.

51. Reichstein, Salter and Gann, 632.

52. Christiane Sauer, "The Architect as Building Materials Scout," in *Construction Materials Manual* eds. Manfred Hegger et al. (Basel: Birkhauser, 2006), 14.

53. David M. Gann and Ammon J. Salter, "Innovation in Project-based, Service-enhanced Firms: The Construction of Complex Products and Systems," *Research Policy* 29 (2000): 959.

drivers of technological novelty in the industry.[54] Therefore, new and existing materials, technologies, and systems must be considered during the design process in order to accelerate development of innovative solutions. There are different factors that can affect a firm's ability to innovate. In this section the aim is to find out the aspects that influence designers' and architects' desire to innovate in the building industry, and understand the character of innovative behavior in that industry.

Construction is a large project-based activity that consists of a temporary coalition between different organizations with the intention of finishing a task over a specific period.[55] The necessity of temporary collaboration between different organizations is a distinguishing aspects of construction activity and could act as a barrier during the design and assembly of building products. Nam and Tatum discuss that construction is most often categorized as a more conservative and low technology sector that involves low levels of research and development activities compare to other sectors.[56] They studied characteristics of constructed products that engender limitations for the construction technology/industry. They analysed five important aspects of products of construction: (1) immobility, (2) complexity, (3) durability, (4) costliness, and (5) high degree of social responsibility.[57]

Nam and Tatum explained the *immobility* aspect in a study conducted in 1988 and mentioned that the production process of construction is mainly a site

54. Reichstein, Salter and Gann, 631.

55. Gann and Salter, 965.

56. C.H. Nam and C.B. Tatum, "Major Characteristics of Constructed Products and Resulting Limitations of Construction Technology," *Construction Management and Economics* 6 (1998): 133.

57. Ibid.

operation that involves "the erection and repair of immobile structures and facilities."[58] Although construction technology has changed drastically since then, compared to other industries such as electronics, furniture etc., products of construction (including materials, industrial products and components) have a specific use in that they are usually fixed after they are assembled. For example, an unsatisfactory phone can be returned to the producer. However, an installed product like wall tiles or partitions cannot be moved easily. In the combination of different types of materials, equipment is used in construction that creates a high level of *complexity*. Also, these products "must resist the forces of nature over an extended period of time."[59] Therefore *durability* is an important requirement. One of the negative consequences of durability for innovation is that it creates inclination/tendency to use tested and tried products and methods.[60] Additionally, *costliness* of constructed products arises as a result of both complexity and durability. Finally, these products carry *high degree of responsibility* to the public. As a result, these five characteristics of constructed products create a set of barriers in trying new materials and methods, thereby reducing the development of innovative applications and leading to more conservative design.

A similar study was conducted by Reichstein, Salter and Gann.[61] They concentrated on liabilities that construction firms experience during innovative activities (and compare these liabilities with other sectors) based on data from the UK innovation

58. Ibid., 134.

59. Ibid., 135-136

60. Aletha M. Blayse and Karen Manley, "Key Influences on Construction Innovation," *Construction Innovation* 4, no. 3 (2004): 147.

61. Reichstein, Salter and Gann, 631–644.

survey. An important implication of these findings is that the "liability of immobility"[62] and "uncertain demand"[63] are described as key aspects that differentiate innovative behaviour in construction from other industries. The authors explained that the construction process requires high levels of in-situ production and that the final production takes place on-site. This last factor might create uncertainties that are not experienced during the development of highly efficient products produced in the controlled environment of a factory.

Janszen summarizes different aspects of construction products: "they are location bounded, have a very long life span, high cost and a great influence on the quality of life"[64] which compels customers to stick to proven methods. Thus, triability of construction products is low. Nevertheless, Gann and Salter discusses that government regulatory policies have a significant impact in shaping direction of technological change and these policies should be approached strategically to achieve positive outcomes.[65]

Characteristics of the construction industry such as immobility, complexity, durability, costliness, and high degree of social responsibility have a great influence on innovative applications of products. It is important to understand how these characteristics might constitute barriers to innovative behavior during material selection process, because such understanding will raise awareness and stimulate architects and designers to find a new approach during the process of innovative materials selection and application.

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62. Ibid., 632.

63. Ibid., 633.

64. Frens Pries and Felix Janszen, "Innovation in the Construction Industry the Dominant Role of the Environment," *Construction Management and Economics* 13 (1945): 44.

65. Gann and Salter, 960.

1.4. Material Selection (for Architectural Projects)

> Design process can be perceived as a successive concretion of the description of future characteristics of an artifact, and it leads from the incomplete to complete, abstract to concrete, and conceptual to precise descriptions.[66]

As is well understood in the design industry, the design process involves the analysis of vast numbers of ideas, material and processes. Grabowski states that although the aim of the design process in architectural projects is to achieve a single built design, vast range of design concepts are generally generated and evaluated during this process. [67]Material selection is only one of these stages that architects go through during building design. The Royal Institute of British Architects (RIBA) explains an architect's plan of workflow in seven key stages:[68]

Strategic definition is identifying the client's key project requirements.

Preparation and brief is developing project brief based on objectives and parameters including quality aspects, sustainability aspirations, project budget.

Concept design is based on preparation of proposals for structural design and building services systems.

Developed design is the preparation of coordinated and updated proposals.

Technical design focuses on preparation of project strategies including all architectural, structural information.

Construction phase involves offsite manufacturing and on-site construction.

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66. Hans Grabowski, Ralf-Stefan Lossack and Clemens Weis, "Supporting the design process by an integrated knowledge based design system," in *Advances in Formal Design Method for CAD,* eds. John S. Gero and Fay Sudweeks (London: Chapman & Hall, 1996), 209.

67. Yasha Jacob Grobman, Abraham Yezioro and Isaac Guedi Capeluto, "Non-linear Architectural Process," *International Journal of Architectural Computing* 8, no. 1, (2010): 43.

68. "RIBA Plan of Work," Royal Institute of British Architects, 2013, www.ribaplanofwork.com (accessed May 29, 2014).

Handover and close out is the handover of building and end of building contract.

In use stage is updating the project information based on the clients feedback, maintenance or operational developments until the end of building's life.

Successful implementation of the workflow can be achieved through collaboration and integration between different disciplines including architects, designers, engineers, planners, etc. Aksamija and Ali explain that "as buildings become more complex due to the introduction of innovative technologies and increased awareness of social and communal needs, design process requires significant modifications of previous practices to respond to newly emerging requirements."[69] Material selection can start from the very first stage of construction and also affect the quality of space when the building is in use.

1.4.1 Material Selection Methods

Selection of materials constitute an important part of the design process and different methods can be applied while developing new concepts and solutions. Van Kesteren describes material selection as a problem solving activity which requires comprehensive and constant flow of information.[70] Selecting materials not only has a huge impact on quality and performance of a product, but it also affects our surrounding built environment. Ashby and Johnson present four materials selection

69. Ajla Aksamija and Mir M. Ali, "Information Technology and Architectural Practice" (paper presented at the AIA IL Conference: Breaking New Ground, Illinois, November 7-8, 2008.

70. I.E.H. Van Kesteren, "Product Designers' Information Needs in Materials Selection," *Materials and Design* 29 (2008): 133.

methods: *analysis, synthesis, similarity and inspiration.* [71] Selection by *analysis* is a systematic method. It identifies and translates product requirements into material objectives and screens a database of materials to rank their ability to maximize performance metrics. *The synthesis method* is based on experience and analogy. It exploits the knowledge gained from previous problem solving activity and synthesizes it with the new design requirements. Selection by *similarity* is a designer's aspiration of using similar materials that meet the requirements of successful products. A search of similar materials can help find new possibilities and also improve creativity in a design solution. The environment and other designers are only two factors that allow designers to generate new ideas. *The inspiration method* provokes creative thinking by interaction with materials, products, books, etc. All four strategies have positive and negative aspects in terms of material selection. Therefore, Ashby and Johnson[25] suggest that the best solution is combining the most useful features of different methods. The results obtained in this research are important to have a basic understanding of different methods that can be used during the material selection process.

In this paper the material selection process is analyzed in two main stages: (1) research, and (2) key indicators/material selection criteria. Different and numerous methods can be applied to each phase of selection. For example, the research stage might include both the inspiration method (magazines, books etc.) and synthesis method (experience).

71. Michael F. Ashby and Kara Johnson. *Materials and Design: The Art and Science of Material Selection in Product Design,* 2nd ed. (Oxford: Elsevier, 2010), 128.

1.4.2. Information Sources

To come up with innovative design solutions, finding information about new and existing materials is one of the first steps of the selection process. Therefore, this section will focus on literature about the sources designers use to receive information about materials, and investigate whether these sources are sufficient to efficiently address problem solving activities as it relates to the use of innovative materials. Karana, Hekkert and Kandachar define materials selection in product design as "the selection of appropriate material(s) for designed products by considering related design criteria such as manufacturing processes, availability, cost, function, shape, use, as well as meanings, associations, emotions, characteristics of users, cultural aspects."[72]

Van Kesteren has demonstrated that in order to achieve an efficient materials selection process, the content and presentation of the information related to materials should be arranged according to the designer's needs.[73] Van Kesteren conducted a study to find out currently used information about materials. The researcher interviewed thirteen product designers and examined the following questions:"What information sources are used during materials selection? How satisfying and useful is the information provided about materials and how is the information found?"[74] As a result of the interviews, Van Kesteren divided information sources used in materials selection into three sections: (1) general material

72. Elvin Karana, Paul Hekkert and Prabhu Kandachar, "A tool for meaning driven materials selection," *Materials and Design* 31, no. 6 (2010): 2932.

73. Kesteren, 133.

74. Ibid., 133-134.

applications, (2) independent sources and (3) materials on supply. Firstly, general material applications presented included various sources such as experience, testing and example products. Secondly, independent sources of use defined as databases, search engines, sample collections, books and exhibitions. The third category, materials on supply, included contacting the material's suppliers and representatives of manufacturers. The three groups of information sources include different levels of information and some aspects of materials might be more or less emphasized in one source than the other. For example, search engines might include various range of visuals and examples of different uses of the material but might lack information about technical properties in comparison to directly contacting manufacturers. Therefore, different information sources might have both advantages and limitations based on the information needed regarding the requirements of projects.

One issue mentioned about different information sources by Van Kesteren is that it is hard to predict how materials will react during the formation process and its life cycle, even though properties of materials are approved by the government specifications.[75] Therefore, the advantage of information sources in the general material applications category (such as experience) is that they allow product designers to anticipate materials behavior in design. However, selecting materials based on experience limits the discovery of new possibilities.

On the other hand, independent sources (databases, etc.) are beneficial to understand and enable users to follow new technologies and trends about materials. However, they do not include information that is required in the later stages of the

75. Ibid, 140.

design process such as availability, cost, etc. Van Kesteren states that materials are mostly chosen from an existing variety of materials from suppliers which refers to the third category: 'materials on supply.'[76] Normally, contacting suppliers and manufacturers of materials provide designers with the necessary information they require for specific products. Interviewees in Van Kesteren's study, however, mentioned a drawback of contacting representatives of manufacturers: these people have information only related to their commercial interests so they don't usually give advice on alternative materials. Nonetheless, designers start searching materials with different levels of information. If a designer already knows what type of materials he/she wants to use and inquires about detail specification, contacting representatives directly might be beneficial to get access to the right information in a timely manner.

Another study by Karana, Hekkert and Kandachar interviewed 20 professional designers in Turkey and asked them to complete a questionnaire about familiar databases and the sources and methods that are being used.[77] The results reported in the paper indicated that product designers mostly use a selection of similarity and inspiration methods. They visited fairs, exhibitions and stores to observe materials and products. They also found that most designers are using the Internet as an information source because updated information based on new materials and technologies can be found easily online.

There are an increasing number of online material sources available for designers and architects such as material libraries, books, information on

76. Ibid., 135.

77. Elvin Karana, Paul Hekkert and Prabhu Kandachar, "Material Considerations in Product Design: A Survey on Crucial Material Aspects Used by Product Designers," *Materials and Design* 26 (2008): 1082-1089.

consultancy firms, websites and blogs. Material consulting companies (for architects and designers) have emerged across the globe over the last decade.[78] Most of them offer consultancy, physical material samples and material browsing. Although designers collect numerous samples and catalogues from manufacturers to create their own material library, it is impossible to cover the vast and growing numbers of different materials produced all around the world. Therefore, current development of material consultancy and material library organizations/companies are highly influential and constitute not only a source of information but also a source of inspiration during material selection.

In the early 1990's George Beylerian could see a clear lack of material selection sources for the design industry and built one of the earliest material libraries: Material Connexion.[79] Today it aims to be a global platform for material solutions and innovations.[54] Another website is called "Materia": besides having collection of exciting materials, Materia also aims to connect different professions via exhibitions, conferences, etc.[80] Similarly, "Hello materials blog" aims to create a platform around the world to share knowledge and material innovation.[81]

Each of the websites has a different emphasis that affects the content and level of information offered. For example, sensorial properties and intangible characteristics of materials are very important during material selection. However, it is hard to find information about these aspects by using some of the online sources.

78. Ashby and Johnson. *Materials and Design: The Art and Science of Material Selection in Product Design,* 42.

79. "Material Connexion," A global materials consultancy and library of innovative and sustainable materials, www.materialconnexion.com (accessed: May 5, 2014).

80. "Materia," Materialize the Future, www.materia.nl (accessed: May5, 2014).

81. "Hello Materials Blog," Danish Design Centre, http://hellomaterialsblog.ddc.dk/ (accessed May 5, 2014).

Wastiels and Wouters, the writer of "Architects Considerations While Selecting Materials," argue that these sources mainly focus on technical information and therefore do not present information about the qualitative aspects of materials that we experience through our senses.[82] As a result, a clear and comprehensive overview, including both technical and sensorial aspects, might be advantageous to architects and designers.

We live in the Information Age and information as very easy to obtain. However, without considering the requirements of each project, it would be challenging to integrate and process the information received to develop innovative material solutions. Today, "it is known that more often the making of connections between data becomes more important than the data themselves."[83] There are different types and growing numbers of information sources about materials available for designers. Depending on the requirements of information and the designer's desire to innovate, several techniques can be combined.

1.4.3. Material Selection Criteria

In this section the objective is to give a brief overview of the literature detailing the key factors considered by architects and designers during the material selection process. The study conducted by Karana, Hekkert and Kandachar[84] in 2007 (with 20

82. Lisa Wastiels and Ine Wouters, "Architects Considerations While Selecting Materials" Materials and Design 34 (2012): 585.

83. Eekhout, 119.

84. Karana, Hekkert and Kandachar, "Material Considerations in Product Design: A Survey on Crucial Material Aspects Used by Product Designers," 1085.

professional product designers in Turkey) also includes a ranking of the materials' properties (technical, manufacturing, economic, ecological, sensorial and intangible properties) according to their importance during the selection process. The researchers discussed how product designers first look for data on sensorial properties of materials (such as vision, touch, sound, smell and taste). The selection process then considers intangible characteristics (such as associations, emotions, cultural meanings and trends) and technical properties (such as manufacturing process and cost). Although the results of this study represent the common opinion of 20 professional Turkish designers, information needed might change according the requirements of projects. For example, while working on a project with a limited budget, a designer might decide to analyze technical properties first in order to eliminate expensive materials. Then he/she might look for intangible characteristics.

In addition to intangible characteristics, Wastiels and Wouters aim to generate a schema based on basic material selection considerations for an architectural design project.[85] They suggest that understanding architects' considerations while choosing materials is important in order to identify what a 'best' material can be for a particular application. As a result of Wastiels' and Wouters' three studies regarding architects' materials selection process at different stages of the design process, they determined four categories: (1) context, (2) manufacturing, (3) material aspects, and (4) experience (see Figure 8). (1) Context is a group of considerations including physical context (project location, orientation, accessibility, etc.), context of use (the context in which the material is applied such as interior or exterior applications, and specific functions such as a concert hall or

85. Wastiels and Wouters, 586-592.

hospital) and cultural context (ethics, style, money etc.). (2) The manufacturing process is a set of aspects including production (moulding, casting, sheet forming, etc.), assembly (how different materials, components and elements are installed together) and finishing techniques (surface modifications: polishing, painting, coating etc.). (3) Material aspects consist of technical aspects (related to engineering such as strength, porosity, density, etc.) and sensory aspects ("qualities we experience through senses").[86] Finally (4) experience concerns the "perception of the (material) environment by an individual, and refer[s] to the intangible characteristics of a material or project."[87] Experience includes perceptual aspects, associative meaning and emotive aspects. Wastiels and Wouters argue that materials determine the character of a building, and therefore the experience factor plays a very important role during material selection. However, no comprehensive material information, including experiential, perceptual or systematic qualities, is available to the architect. Hence, this lack of information results in a knowledge gap.

Context	Manufacturing	Material Aspects	Experience
Physical context	Production	Technical aspects	Perception
Context of use	Assembly	Sensorial aspect	Association
Cultural context	Finishing		Emotion

Figure 8 Material Selection Criteria

In conclusion, the two main focus mentioned in this study are the desire to innovate and the material selection process of innovative materials application.

86. Ibid.

87. Ibid.

Characteristics of construction industry (such as immobility, complexity, durability, costliness, and high degree of social responsibility) have an important impact on designers and architects desire and ability to innovate. Secondly, the material selection process is a problem solving activity. In order to come up with more innovative solutions, the need to discover new and existing materials and to develop innovative configurations are essential aspects. Although different sources can be combined regarding various levels of information needs, several studies indicated that most of the sources do not include comprehensive information about intangible, sensorial qualities of materials. Therefore, two issues occur that can limit a firm's ability to use innovative materials application in the building industry: (1) characteristics of construction industry such as immobility, complexity, durability, costliness, and, high degree of social responsibility, and (2) lack of information sources that include comprehensive information about new and existing materials.

This thesis proposes that industrial design can help increase the use of innovative materials application in the building industry. The role of industrial design in new product development process is not only essential in achieving a competitive advantage, but also is crucial as a focus of communication between different people with various skills and backgrounds. Furthermore, by considering other designers' knowledge of new and existing materials, forming processes and production techniques, industrial designer can discover unforeseen configurations of materials as well as encourage new developments in the building industry. The study will explore and seek answer to this main question: how can the role of industrial design in new product development be applied to material selection process of architectural

projects that will help increase innovative materials application in the building industry?

PART 2: METHODOLOGY

> Research involves both analysis (the taking things apart) and synthesis (the putting things together). We gather data. We increase our experience. We look closely at the patches of collected data, the parts of our experience; that is, we analyze. And we put the parts together, often in different ways than before. We synthesize.[88]

The selection of materials has a significant impact on the performance and aesthetics of the built environment. In order to achieve more creative solutions, the initial step is to have a better understanding of possibilities and limitations of materials, and access to different levels of information about existing and new developments. In order to address this complexity, I conducted a study with designers, architects and manufacturers to investigate how well the process of development, selection and application of innovative materials is currently working in the building industry.

The first part of the research focuses on examining the sources that designers and architects use while working on building design. The aim is to explore how information about materials is being found. The second and the most important part of my research hinges on analyzing the barriers that prevent many architects and designers from producing innovative solutions more often.

88. Robert E. Stake, *Qualitative Research: Studying How Things Work* (New York: The Guilford Publications, 2010), 118.

2.1. Overview of Qualitative Methods

> Qualitative research is a research strategy that usually emphasizes words rather than quantification in the collection and analysis of data.[89]

This study used qualitative research in order to gain a better understanding of the relationship between design, material and building industries. According to Groat and Wang, the major strength of qualitative research follows from its capacity to take rich qualities of real-life circumstances and settings to address a research question.[90] The goal is to understand the experiences of designers, architects, manufacturers and suppliers regarding the use of materials for architectural projects. Therefore, I conducted semi-structured individual interviews to address and discover the fundamental problems considered as barriers to the industry's ability to use new materials more readily to build innovative design projects. The research places particular emphasis on finding differences, similarities and connections between different industries. Interviewing manufacturers, architects and designers is a significant method to improve my understanding of interlocking relationships between material, design and building industries.

2.1.1. Role of the Researcher and Ethical Considerations

> For qualitative research, the researcher him or herself is an instrument, observing action and contexts, often intentionally playing a subjective role in the study, using his or her own personal experience in making interpretations.[91]

89. Alan Bryman, *Social Research Methods*, 4th ed. (New York: Oxford University Press, 2012), 380.

90. Linda Groat and David Wang, *Architectural Research Methods* (New York: John Wiley & Sons, Inc., 2002), 199.

91. Stake, 20.

In this study, I was the research investigator who contacted potential participants, conducted interviews, collected, transcribed and analysed the data provided by designers, architects, and manufacturers. I explained the research study at the beginning of each interview and provided an information letter to the participants that include the background, purpose, study procedure, benefits, risk and confidentiality of the research.

A potential benefit of the research is that designers and architects can reflect and consider their design process throughout the interviews which will affect the possible outcome of the study. The information that is shared will contribute to the existing body of knowledge regarding material selection process in the design and architecture professions. Since the research was conducted in Edmonton and Calgary, a greater understanding of local material industries, design and architecture communities will be achieved. The risk of the research to participants is minimal and no greater than what may be expected during regular discussions around architecture, design and material industries.

Confidentiality is the important factor in terms of ethical considerations of the study. Collected data, including contact information and audio recordings used for transcribing data into written form, will be kept confidential. Participation in this study is voluntary and participants have the right to withdraw from the study and modify their answers at any time without consequence during the interview and up to three weeks after it is finished.

2.2 Development of the Questionnaire

Two groups of questionnaires were developed for the study. The first part includes questions for interview participants who are architects and designers based in Edmonton and Calgary, while the second part is prepared for interviews with manufacturers and suppliers. Both groups were asked fundamentally similar questions with minor changes arranged according to the background of different participants. Some of the questions developed for interviews with architects and designers are focused on examining the sources that they use while working on architectural projects. The objective was to determine how the information about materials is found which will help understand whether or not architects and designers are experiencing any challenges while searching for materials. Two examples of questions asked to the participants are:

- What information sources do they use during materials selection?
- How satisfying and useful is the information provided (about materials) by the sources?*

Another important part of this study is based on exploring the line of communication between material industries, architects and designers. The aim is to gain a basic understanding of how to facilitate new ways of thinking about materials in the design process for architectural applications. Some examples of questions asked to the participants are:

* Question inspired from and based upon: Van Kesteren, "Product Designers' Information Needs in Materials Selection," 135.

- What kinds of aspects of materials are significant for you in your selections?**
- Can you tell me about your material selection process?
- What is the most important problem you encountered while selecting materials?
- What are the barriers to using innovative materials application?

After talking to five architects and designers, and analyzing the information provided by them, the following questions for interview participants who are professionals from manufacturing industry were developed. The questions were mainly prepared with the purpose of understanding the challenges and limitations of introducing new products to the market. A limitation experienced during the interviews with manufacturers was that they are not always willing to share the unsuccessful applications of their products. Although professionals from different companies mention various examples of successful applications, unsuccessful applications and failures were not discussed in depth. The list of questions developed for the interviews are indicated below:

- What aspects do you consider to allow architects and designers a certain level of confidence in your products?
- How do you reach architects and designers? What are the mediums you use?
- What is the most significant problem after market launch of the product?
- What are the risks/barriers of introducing new products to market? Please start with the most important problem based on your experience.

** Question inspired from and based upon: *Materials in Architecture: Glass, Stone, Concrete, Steel, Wood.* (Berkeley: Ginko Press; 2012).

- What sources do you use for research in different stages of product development such as idea creation, development/market research, market launch... ?
- How do you reach architects and designers? What mediums do you use?
- Can you give me some examples of innovative materials application suggested by (company name) and failed to be used by an architecture/design firm. What were some of the factors that convinced them to make that decision?
- Can you give me some examples of innovative materials application suggested by (company name) and agreed to be used by an architecture/design firm? What were some of the factors that convinced them to make that decision?

2.3. Data Analysis

2.3.1. Information Sources

List of aspects mentioned by participants about how information regarding materials is being found:

A. Experience

The dictionary definition of experience is: "The knowledge or skill acquired by a period of practical experience of something, especially that gained in a particular

profession."[92] Experience based on previous design projects and long-term feedback provided by clients and users generate a significant information source in different stages of the design process. A strategy to achieve expected results is possible by using common materials and collaborating with manufacturers of products with whom architects and designers are familiar. This strategy is preferred because it not only includes lower risk compared to trying a new material application, but also reduces the time dedicated for research. Through experience-based material selection, designer and architect can analyze possible applications, as well as estimate scheduling, long term performance, construction and cost aspects.

> Based on our experience of our firm and body of work that we do, we tend to use the materials we know that works, that are local, cost effective, tend to have a long term durability and easy maintenance.... The senior architects tend to pass along information to younger architects about what materials work well, what the cost is, and how those materials come together to achieve the design ideas we want. Shafraaz Kaba[93]

B. In-office Library

An in-office library consists of the architects' and designers' own collection of material catalogues, samples and prototypes. Although it can be beneficial to reach samples and colour schemes easily while designing, creation of an in-office library also depends on the availability of rooms to store large numbers of materials. In addition, frequently updating and organizing new and existing materials can be a time consuming activity for an architecture and design firm.

92. Oxford Dictionary, Definition of "Experience" in English, http://www.oxforddictionaries.com/definition/english/experience (accessed February 12, 2014)

93. Interview with Shafraaz Kaba, Manasc and Isaac Architects, February 21, 2014.

> Most of our suppliers are willing to give us samples which enable us to understand what we are getting. Our library includes physical samples of various materials such as tile and stone to brick, glass and window frames. Shafraaz Kaba

C. Contacting Manufacturers and Colleague

Contacting manufacturers is important to obtain more information that is not included in the data sheets or catalogues. Talking to colleagues and getting feedback regarding their experience with materials are also considered as a significant source for professional information.

> A practical way to learn about the actual performance of a material is talking to the professionals who have used it in the past to find out if they were pleased with the results of its application. Perhaps it is not that much different than asking a friend for advice: 'Do you have a good dentist? Did he/she do a good job? Was it good only for you or also for a hundred of other satisfied patients?' That is an imperfect/informal way of acquiring a useful and valid information. Christopher Filipowicz[94]

D. Search Engines

Search engines offer extensive information resources. Search engine results include a variety of information sources, therefore they provide beneficial information for following the new developments of building and material industries.

E. Books and Magazines

Local and international magazines and books contain valuable information about new developments and allow professionals to find examples of materials that have been used in different projects. However, a participant mentioned that a drawback

94. Interview with Christopher Filipowicz, HFKS Architects, July 17, 2014.

of these types of sources is the difficulty of finding information about the producing company, and of assembling products seen in magazines.

> If I see a product in the magazine that I like, it is hard to find the person that actually sells it locally. Then to find out examples of how it has been used and who has actually installed these products. Chet Domanski[95]

F. Tradeshows and Exhibitions

Tradeshows and exhibitions have a diverse range of visitors, so they constitute great places for networking and facilitating interaction between material and design industries. Tradeshows and exhibitions also provide beneficial information sources for architects and designers, and give professionals of material industries the opportunity to advertise and present their products.

G. Canadian Standards Association (CSA) and National Research Centre (NRC)

The Canadian Standards Association (CSA) is a standards organization that is "dedicated to promoting a better, safer, more sustainable world where standards work for people and business."[96] The National Research Council of Canada is a national Canadian research and technology organization that provides "innovation support, strategic research, scientific and technical services."[97] The majority of the participants stated that the CSA and NRC provide a significant source of information regarding materials.

95. Interview with Chet Domanski, July 15, 2014.

96. CSA Group, http://www.csagroup.org/us/en/home. (accessed June 28, 2014)

97. National Research Council Canada, last modified on July 21, 2014, http://www.nrc-cnrc.gc.ca/eng/ (accessed July 22, 2014).

To summarize, most of the participants agreed that the CSA, NRC, and manufacturers are a common source of information regarding materials. The physical samples of materials provided by suppliers help architects understand the properties of materials better. However, a disadvantage mentioned by one of the participants is that manufacturers are results-oriented and they can make different claims to sell their products. Therefore, in order to have a better understanding of materials, different sources are used by architects and designers.

Moreover, participants feel more comfortable using the products that meet the requirements of CSA standards. Therefore, as Gann, Wang and Hawkins state, government regulatory policies have a significant impact in shaping the direction of technological change and they should be approached strategically to achieve positive outcomes.[98] On the other hand, a progressive approach should be developed for regulations to encourage innovation. Gann, Wang and Hawkins argue that "regulations need to accommodate technical change at different levels in the production process, including new product development and systems integration."[99] The CSA and NRC provide significant and liable material information. However, to keep abreast with the vast development of materials and to allow a faster implementation process of new information, new strategies should be developed.

> If a material came through National Research Council or CSA, I could rely on it. I have 100% confidence. But often the innovation we look at is way ahead of and that's the place it's hard to embrace. Jan Pierzchajlo[100]

98. David M. Gann, Yusi Wang and Richard Hawkins, "Do regulations encourage innovation? - The Case of Energy Efficiency in Housing," *Building Research & Information* 26, no. 5 (1998): 280-296.

99. Ibid., 280.

100. Interview with Jan Pierzchajlo, Rockliff Pierzchajlo Architects & Planners, February 4, 2014.

The selection process of large numbers of materials, products and components requires different levels of information on cost, scheduling, technical and aesthetical properties. According to the participants' comments, most of the time, receiving necessary information is achieved by directly contacting different organizations such as builders, suppliers, contractors, etc. Finally, although a majority of interview participants mentioned that they don't experience any difficulty in finding information about materials, a participant mentioned the following issue:

> If we (architects) want to research a new material application we are on our own. In terms of materials, there is no central hub, no place to go to initiate research. We start with a product manufacturer, (such as doors, masonry, windows) or a subtrade. We have to create our own research and it is about becoming familiar with all of the products and trades. Wesley Sims[101]

Therefore, a lack of comprehensive information sources might result in selecting materials based on the ability to contact different professionals in the building and material industry.

2.3.2. Analyzing the Barriers

A. Complexity

Building design and construction are based on "temporary coalitions of different organizations that come together to attempt to achieve a task over a specific period."[102] According to Reichstein, Salter and Gann this complexity factor relates to the 'liability of projects' because for every stage of projects, starting with strategic definition to construction, working with different professionals and teams is

101. Interview with Wesley Sims, Sims and Shorten Architects, 2014.

102. Gann and Salter, 961.

required. [103] Construction includes architects, designers, engineers, consultants, as well as organizations responsible for on-site production, assembly and installation and integration of systems. The complexity of the construction industry significantly affects and limits innovative behaviour.

> I talk about buildings as an assembly of components which must adhere to Building Codes and technical requirements, the organization of different Engineering disciplines: electrical, mechanical, structural, project budgets, and schedule. If trades do not have the skills or experience TO build, you cannot be as innovative as you may want... Architects used to have a lot of control over the building process but now (especially in bigger projects), contractors and owners have more control over the whole project. They are less likely to try to be innovative (risk adverse), they want to build efficiently and get things done more quickly. Wesley Sims

> Architecture is the most conservative of arts, it has to satisfy certain kind of function. We have lots of rules that we have to follow, the building code, CSA standards for how some of the things come together, so those are often I won't say barriers because I think there are still ways to innovate... But still things that we have to work around. Jan Pierzchajlo

Another aspect that results in complexity is the number of materials, products and components used for building design and construction. Coordination of construction includes arrangement of various components, bringing together different systems and suppliers and installation of these on-site. That aspect is also called "liability of assembly."[104]Therefore analyzing how different materials, products and components perform together constitute a complex but significant aspect of building design. Hence, the complexity of the construction industry is a significant factor that limits innovative behaviour.

> Architectural solutions are all about how different materials come together from inside to the outside to create this whole package of assemblies. Shafraaz Kaba

103. Reichstein, Salter and Gann, 632.

104. Ibid.

> Sometimes, not the individual materials themselves but the assembly of those materials and how they perform together becomes a very important aspect determining factor. On their own and separately they may perform very well. However, in combination, their performance may significantly change. Christopher Filipowicz

B. High Degree of Social Responsibility

A high degree of social responsibility increases conservatism in building design. Knowles and Pitt argue that this conservatism is caused by the concern for public safety, health and environmentalism.[105] Also, new materials application depends on the clients' needs and requirements. Two research participants mentioned that the architects' responsibility to their clients and users results in less innovative materials application in the building industry.

> Part of the reluctance to try new things is that if you are experimenting you can take on tremendous risk, first for your client and also for yourself professionally, the liabilities you can be exposed to. Why would you experiment with a 42 million dollar building? Why would you need to do this extra stuff for little benefit and great great risk. Jan Pierzchajlo

> If we work with a new material without having sufficient comfort level or sufficient material performance testing and verifiable results, then we could expose our client to a risk of having their building built with components not meeting the necessary specifications. Christopher Filipowicz

C. Durability / Long-Term Performance

The majority of participants mentioned that the long-term performance of products is the most crucial aspect during the material selection process, and also a barrier to using innovative applications. Although most participants feel more liberated using traditional materials in new ways, depending on the context of use and longevity of the building, it might be considered risky as well.

105. C. C. Knowles and P.H. Pitt, *The History of Building Regulation in London 1189-1972* (London: Architectural Press, 1972).

> Depending on the required longevity of the building, you want to use the materials and technologies that are proven. Otherwise, we risk not knowing if these are going to stand the test of time. Also, using a material we are familiar with but in a way that has never been used before may create a risk. This may result in a poorer long-term performance, which will be impacting maintenance and repairs for the life of the building. Christopher Filipowicz

> What are the things that I would like to try and like to see is to use proven materials in new ways. That's different than taking a new membrane or plastic material. Although salesmen say that it should be able to do something, you don't know really how it will perform until you try it for 10-20 years. Jan Pierzchajlo

D. Costliness

Costliness is definitely a factor that affects material selection. However, most of the participants mentioned the impact of the cost regarding long term performance of products. In other words, the maintenance cost that ensues, when a product fails or its performance decreases in the long term is considered as a limitation due to unexpected expense including price of the material, transportation and installation.

> I think liability is the first one and outcome is cost. Your own personal liability and your client's investment in that building you have to consider it and treat it respectfully. Jan Pierzchajlo

E. Life Cycle of Buildings

Building life cycle is an important consideration during the design development that affects future maintenance and operational requirements. Depending on the expected life cycle of a building, architects' and designers' ability and desire to innovate might vary. For example, the World's Fair, also called the World Expo, is a large public exhibition held every five years to facilitate exchange of innovation. The duration of the World Expo is between six weeks and six months which accelerates the development of most outstanding and innovative temporary building applications

that will satisfy short-term performance requirements.[106] As such, World Expo construction have traditionally been a source of innovative building ideas. However, because they are usually taken down after the event ends, the ability to monitor how new building materials age is limited. It would be interesting to research buildings that have not been demolished after such exhibition to examine the aging process and longevity of these structures.

> A facility to last for six months carries different requirements than one constructed to perform well for many years. Christopher Filipowicz

F. Scale and Context of Use

Context of use refers to the context which materials are applied. The challenges and limitations of innovative materials application might differ according to the materials context of use. For example, the application of an innovative material to a large scale building facade, in comparison to a smaller scale interior application, constitutes a higher level of risk regarding the long term performance of the building. Therefore the scale and materials context of use are important factors during the material selection process that affect architects' and designers' desire and ability to innovate.

> Probably the most important part of the building design for me is the envelope and the materials that make it up, because it has such a fundamental role in making of architecture and, if the envelope doesn't work, you are in a big trouble. I feel much more liberated in trying new materials as finishes. Jan Pierzchajlo

106. "World's Fair," Wikipedia, http://en.wikipedia.org/wiki/World's_fair (accessed September 9, 2014).

G. Physical Context

Physical context such as project location, orientation and accessibility etc. is a driving factor for designers and architects in building design. Especially in Alberta, which has warm summer and extremely cold winter conditions, the assessment of climate is crucial for successful design solutions. Since it is typical for local manufacturers to take climate conditions into consideration while introducing new products, the majority of participants mentioned that they prefer using local materials.

> I rely a lot on the people that carry the products. They'll come and show you the new products that they think it can be beneficial to you. The problem is that they are often manufactured in a different location. For example, if it is manufactured in Texas where the weather conditions are very different than ours, I am always nervous that the product may not perform as well here as it does in warmer climates. Chet Domanski

> For the most part because of our buildings are mostly built for this region, climate, we look at local materials and how they respond climatically to the environment. Shafraaz Kaba

H. Cultural Context

Context including environmental, cultural and historical factors not only affect how we perceive a space but also has significant impact on innovation. Cultural context is one of the significant factors in contemporary building design. Some countries provide more "innovation-friendly environment" than others.[107] Bruno Lanvin, author of the Global Innovation Index 2013, describes three key elements of innovative countries: "They have generally fostered education, they have attracted talents and

107. Bruce Einhorn, The 30 Most Innovation-Friendly Countries, http://images.businessweek.com/ss/09/03/0312_innovative_countries/1.htm (accessed July 9, 2014)

created talents for innovation; second they have also nurtured the climate of investment around innovation, they have created a culture of venture and risk capital which has helped local investors; and last but not least they have also built strong and dynamic structures of innovation, that is the institutional part of it which should not be neglected."[108]All of these aspects determine innovativeness of countries as well as encourage companies to come up with more innovative solutions.

> A local tradition or specific cultural context may also impact decisions on selection of materials and the willingness to experiment with those, costs aside. I would not be surprised if there are some communities, or societies that are more open to the idea of using new materials or applying traditional materials in an innovative way. Sometimes it is as simple as the necessity to address the environmental change, economic circumstances or disappearing skills. Christopher Filipowicz

The data collected from the interview participants has been organized under eight groups, which are complexity, high degree of social responsibility, durability or long-term performance, costliness, life cycle of buildings, scale and context of use, physical context, and cultural context. Although one of the characteristics of the construction industry is immobility, none of the participants mentioned this factor as a barrier to using innovative materials application.

108. Bruno Lanvin, The World's Most Innovative Countries: The Global Innovation Index 2013, INSEAF Knowledge, last modified July 1, 2013, http://knowledge.insead.edu/innovation/the-worlds-most-innovative-countries-the-global-innovation-index-2013-2525 (accessed July 11, 2014).

2.3.3. The Material Selection Map

Figure 9 The Material Selection Process

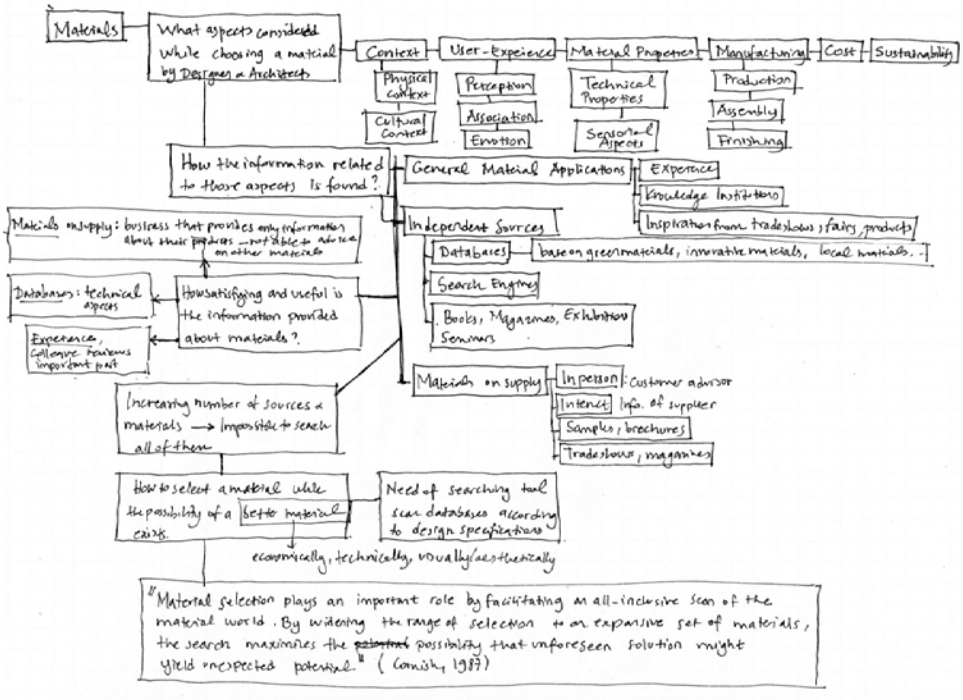

Figure 10 Thought Process Map 1

The material selection process map was designed as a summary of both interviews and literature review in order to give a brief overview of the phases considered by designers and architects while choosing materials (see Figure 9). However, material selection is a complex and integrated process that is an essential part of the design

development. This linear structured map aims to summarize and pull together major stages of material selection that can make the analysis easier to practice. The map focuses on analyzing the challenges of each stages but does not necessarily aims to optimize the sequence of them. In other words, the map is a representation of a single material selection cycle that is organized to convey a complex thought process to identify what the next steps that architects and designers might consider (see Figure 10). The mapping process identified seven steps: desire, finding information, project requirements, evaluation of possibilities and analysis of risks and benefits.

The first stage consists of the issue which is addressed in the first part of the report in detail: the desire and ability to innovate and experiment. The second part includes the information sources that designers and architects have been using throughout the material selection process: experience, in-office library, contacts with manufacturers and colleagues, search engines, books and magazines, tradeshows and exhibitions, and the Canadian Standards association and National Research Centre.

The third part of the material selection process map covers the criteria or the requirements of material selection process, such as performance, aesthetics, cost and scheduling aspects. After initial research, finding materials and identifying options in relation to project requirements, the fourth stage takes place: evaluation of possibilities. The options mentioned in the category are application of (1) traditional/common materials, (2) traditional materials in new contexts, and (3) newly developed or improved materials.

The fifth part of the material selection process map is based on an analysis of risks and benefits of materials application options. Different liabilities can result in less innovative materials application. However, efficient analysis of the benefits and risks of using innovative materials application can be a determinant to reduce these barriers.

Figure 11 Core Issues

After mapping the material selection process, I listed four key issues based on the following question: Why does an innovative material application fail to be used by architects and designers? Figure 11 summarizes these issues:

1. Desire: Architects and designers might prefer developing conservative design solutions, and not be interested in using new materials application.

2. Research: Architects and designers might fail to research materials efficiently. This might be because of a variety of issues such as time limitations, effective sources, difficulties finding information regarding project requirements, etc.

3. Key indicators: Selected materials might not satisfy key requirements of projects and end up not being used.

4. Communication: During material selection, the manufacturer's ability to communicate how the product or system addresses the design solution might affect the architects' analysis of benefits and risks of a prospective materials application.

In order to have a better understanding of the challenges of introducing new material applications and to analyze how well the issue of liability is currently addressed, I have decided to interview professionals in the material industries. Some of my questions are based on comprehending the main challenges of new product development in the building industry, as well as on how these professionals manage risk and commercialize their products. My questions also concern the types of communication channels manufacturers use to present materials and to allow architects and designers a certain level of confidence to use their products. The responses to these questions constitute a significant part of my research.

After data analysis of the first part, the central research question evolved as follows: If innovative materials application in architectural projects depends on the liability risk, how can industrial design act as a bridge/facilitator to assist in reducing the challenges of introducing and using new materials in the building industry?

2.3.4. Level of Long-term Performance Risk and Innovation

One of the important liability issues of using the innovative materials application mentioned by interview participants is the uncertainty of their long-term performance. Such uncertainty of long-term performance can also has a huge impact on other factors, such as maintenance cost or professional and legal

responsibility to customers in the long-term. Different products of the building industry constitute different levels of risks according to their context of use. Therefore, I analyzed building products/materials according to two main categories: higher and lower levels of performance risk regarding materials context of use. Each category includes three sub-categories based on the level of innovativeness of products, materials and components (see Figure 12). In other words, in the second part of the research the intention is to analyze materials based on their level of long-term performance risk and innovation.

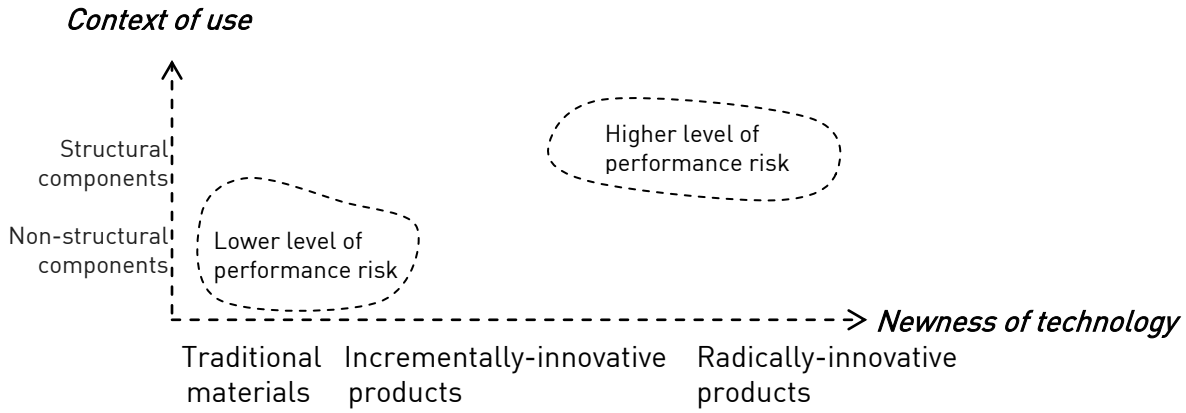

Figure 12 Level of Performance Risk - Innovation

The higher level of long-term performance risk consists of the structural components of buildings such as wall, floor/slab, stair and roof, etc. applications. These components carry higher performance risk compared to non-structural components in any innovative materials application since they directly affect the

performance of the building. In terms of newness of technology of materials and products, three measures indicated are as follows:

(1) manufacturing firms that have produced traditional building materials such as brick, stone, concrete, masonry, etc.
(2) manufacturing firms that have introduced incrementally-innovative products .
(3) manufacturing firms that have introduced radically-innovative products.

The lower level of long-term performance risk includes interior or non-structural products that do not affect the performance of the building in a crucial way, such as, floor and wall finishes, partitions and fixtures. Similar to the higher performance risk, depending on the newness of product technology, this factor can be divided into three categories:

(1) manufacturing firms producing the same products for the past 10+ years.
(2) manufacturing firms introducing incrementally-innovative products.
(3) manufacturing firms introducing radically-introduced innovative products.

I have contacted three professionals in the manufacturing industry based on the level of innovation and long-term performance risk of their products application that they have successfully managed (See Figure 13):

Level of Managed Long-term Performance Risk	Level of Innovation	Company Name
Management of higher performance risk	Radically and incrementally-innovative products	TTS (Tekle Technical Services)
Management of both higher and lower performance risk	Incrementally-innovative products	Green over Grey
Management of lower performance risk	Incrementally-innovative system	DIRTT environmental solutions

Figure 13 Participants Based on Level of Risk and Innovation Management

A. Incrementally and Radically-innovative Products: TTS (Tekle Technical Services)

The first participant is the CEO of the TTS research and development facility, which is focused on designing sustainable bio-fibre based building products. TTS is also specialized in product testing, process and technology enhancement.[109] Tamrat Tekle, the interview participant, explains that TTS is a corporation started in 1998 with the primary vision of developing sustainable construction materials and maximizing the utilization of natural fibres. TTS is developing and introducing both radically and incrementally innovative building materials. Some examples of their products are BioFibre cement and structural insulating panels. BioFibre cement is a unique and versatile bio-composite line of products that combine biofibres with ordinary Portland cement to improve structure performance (see Figure 14).[110]

109. Tamrat Tekle Services, http://www.ttsfpl.com/ (accessed July 6, 2014).

110. Tamrat Tekle Services, http://www.ttsfpl.com/green-building-products (accessed July 6, 2014).

Figure 14 TTS BioFibre Cement. Source: http://www.ttsfpl.com/green-building products/biofibre-cement

Structural insulating panels (SIPs) are high-performance building panels that save energy and allow better control over indoor air quality. These panels also help "decrease carbon emissions, water pollution and deforestation" and can be used for exterior wall, roof, floor applications and foundation systems. [111]

Since TTS' products include structural components, architects and designers might consider that they carry a higher level of long-term performance risk (compared to non-structural applications). Mr. Tekle articulates the challenges of commercializing their products and the solution that they have decided to apply:

> People seem to be shy about these products. We know the products work so... we push on. We know we strongly believe they work and make environmental sense, makes social sense. It makes economical sense. How can we make it work? In order to pre-commercialize these materials, we made a strategic decision and evolved TTS from an applied products development facility to a bio-composite incubator.

TTS provides consultancy, education and training as well as quality control programs for the industry.[112] In other words, their experience in product development and understanding of new possibilities with natural fibre addresses a gap in the industry and helps companies develop new technologies and products. In order to produce products in limited quantities, TTS has been developing pilot plants

111. Ibid.

112. Tamrat Tekle Services, http://www.ttsfpl.com/ (accessed July 6, 2014).

to provide limited quantities of their products for designers and architects. Mr. Tekle mentioned some of the advantages of building pilot plants while commercializing their products: (1) they are relatively cheaper than commercial plants and (2) they allow companies the time to calculate the market and bear out the technology. Hence, producing small quantities also helps them to become known and familiar with the market and convince architects and engineers about their products. Once a certain product succeeds in piloting, which means that there is more pool in the market than their pilot capacity can handle, then that is a good indication of the feasibility to build a commercial plant.

In order to allow architects and designers to have a certain level of confidence to use their products, this company pays attention to different aspects, such as, performance, safety, availability and affordability. To demonstrate the long-term performance of a product, TTS is capable of conducting testing over 100 specific test protocols, such as, gluing, nailing, screwing, bending strength, compressive strength, etc. Depending on clients' requests, they provide Canadian Construction Materials Center (CCMC) reports, which are a part of the National Research Council (NRC) of Canada. The CCMC "offers the construction industry a national evaluation service for innovative non-standardized materials, products, systems and services in all types of construction"[113]. However, some challenges to receiving the evaluation report and meeting product certification standards in Canada are based on the fact that this extensive process is very expensive and takes time.

113. "About the CCMC," National Research Council Canada. last modified July 9, 2013, http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/ccmc/about_ccmc.html (accessed July 11, 2014).

B. Incrementally Innovative Products: Green over Grey

The next participant is one of the founders and chief designers of the Vancouver based company Green over Grey. They design and install living walls, and their goal is "to create living works of art that purify the air you breathe, make life more sustainable and add some green to the grey of our cities."[114] Various applications consist of both architectural exteriors and residential, modern interiors. Therefore, depending on the context of use this type of project can be associated by architects and designers with categories of both lower and higher long term performance risk.

> For developing our living wall system we actually travelled to various tropical rainforests and studied how the plants grew vertically in nature. From that knowledge we created our system out of 100% post-consumer recycled and non-toxic materials. It provides the plants with everything they need to grow, therefore reaching their full and exquisite potential.

The Green over Grey system is ten times lighter than modular green wall applications and allows thousands of plant species to grow vertically without soil. They explain how their system works on their website: "The material that we use retains moisture and nutrients allowing the plants to thrive. Therefore over time the strength of the system actually increases. This allows us to design living walls with larger plants, such as bushes, shrubs and small trees."[115] The green wall system reduces limitations of modular green wall solutions and creates more opportunities for designers and architects (see Figure 15).

114. Green over Grey - Living Walls and Design Inc., http://www.greenovergrey.com/living-walls/overview.php (accessed July 10, 2014).

115. Green over Grey - Living Walls and Design Inc., http://www.greenovergrey.com/living-walls/what-are-living-walls.php (accessed July 10, 2014).

Figure 15 Green over Grey Living Walls. Source: http://www.greenovergrey.com/photo-gallery/photo-gallery.php

The interview participant mentions that they meet in person with architects and designers, and explain exactly how the system works. The best way to demonstrate long-term performance of their products is to provide a list of references, and show an example of the components. Also, they arrange a tour of their projects in order to allow prospective clients have a better understanding of their products.

> The best way to make them have confidence is to provide a list of references and then bring them on a guided tour of some of our installations; including some that have been around for years and are still thriving. Our most popular tour is starting at Vancouver Tourism, then heading past ING Direct, to Perkins & Will Architect's atrium and ending at Lululemon's Headquarters.

Since the Green over Grey team is dealing with living plants that need to be taken care of, they include maintenance packages to guarantee clients that their wall/investment is going to always look appealing. According to this participant, the main challenge of introducing new products to market is educating people about what actually is possible.

> For every single installation that we do, there are people commenting that they have never seen anything like this before. Once they see our installations in person, they are sold on the idea.

C. Incrementally Innovative Solutions: DIRTT

DIRTT provides environmentally responsible prefabricated solutions by manufacturing movable, modular architectural walls (see Figure 16). They customize their products according to different needs of customers and spaces dimensionally, functionally and aesthetically.[116] DIRTT's modular and reusable solutions include interior walls, doors, floor and power, etc. They aim is to reduce construction cost, energy, refuse and time while designing a building.

Figure 16 DIRTT Healthcare Design Solutions. Source: http://www.dirtt.net/public/products/applications.php?cat=healthcare

DIRTT solutions can be considered in the lower or minimal risk category since their application basically consists of interior and non-structural components.

The company utilizes ICE software, which is developed for modular workspace design. This software delivers the design as a "barcode directly to the factory floor" regardless of location.[117] In other words, DIRTT solutions are driven by the ICE software that not only allows 3D visualization of spaces but also gives information about engineering and price aspects at the same time. After designing a

116. DIRTT Environmental Solutions, http://www.dirtt.net/ (accessed July 9, 2014).

117. DIRTT Environmental Solutions,http://www.dirtt.net/public/resources/company_2013.php (accessed July 9, 2014)

space that fits the particular customer's needs, the solution automatically goes to their factory where the project is being built and arrives on site few weeks later. Therefore, DIRTT provides architects and designers the flexibility to create unique environments visually, accurately and faster.[118] While using ICE software they eliminate a variety of risks, particularly by allowing project managers to visit the sites to check if the project is proceeding properly and will work as expected.

> Our walls are made of aluminium and it is a very structurally sound material. Our CEO says if they are not standing in 150 years, then we did something wrong. Let's say a client needs an update after 10 years, he/she can move the wall to a different location. If they want different colours, they can pop out the panels and change them out and there is no need to change the structure.

Another technology that DIRTT has been using is 'Spider Agile Technology.' It constitutes pre-fabricated modular and conventional power solutions that can be adjusted according to the needs of customers. This technology allows having modular electrical on a grid to help designers rearrange spaces faster and easily. Currently the company has a limited ability to come up with design proposals based on what their software can deliver. This asset, which reduces their time-to-market and financial risk, also has the effect of limiting the company's ability to introduce new materials into their designs.

They have been using different types of communication channels such as "lunch and learns" in Edmonton but one to one conversations have been the most important way to communicate with architects and designers. Among the four aspects (desire, research, key indicators, communication) that are identified based on the material selection map, the participant from DIRTT stated the communication aspect as the most important issue that they have experienced:

118. Andree Iffrig, DIRTT University, http://www.dirtt.net/public/resources/_docs/dirttU/DIRTTUniversityBackToSchool_v1-2.pdf (accessed July 9, 2014).

> Clients can come and visit our factory but sometimes they call me later and ask 'what system was it that you used in this application?' We don't have systems, we don't have products, we make solutions, we design everything custom. Communicating that I would say has been the biggest issue. The designers and architects who understand DIRTT use it all the time. I would say communication and the way we deliver our message is the most important issue.

To summarize this field of research so far, the three research participants represented very different companies and articulated different strategies practiced in the building industry profession while introducing innovative applications depending on the level of managed risk and innovation. In addition, in order to communicate efficiently with clients and instil architects with confidence about offered solutions, participant stipulated five aspects as crucial:

1. One to one conversation with designers and architects. All three interview participants mentioned that they prefer to meet in person to explain how their products/systems work. Also, different firms organize different events to make potential clients familiar with their solutions such as lunch & learns, tradeshows, etc.

2. Lunch & learns, tradeshows, exhibitions and company websites. To become market familiar with the feasibility of their solutions, professionals emphasize that lunch & learn, tradeshows, exhibitions and company websites are great opportunities for increasing knowledge in the material industry.

> As our product and design process is very unique and completely a niche concept, forward thinking architects and designers tend to find us online. We also provide Lunch & Learns. Green over Grey

3. Previous examples of their work/product application. Depending on the previous projects and clients, architects and designers might feel more liberated to use innovative applications. For example, if the Government of Alberta had previously used their company's solutions, then clients are more confident to follow. As well, project visibility builds prospective client and professional community awareness.

> We also have many projects that are physically in high traffic areas, (e.g. our three story project at Edmonton International Airport has 6 million people passing by each year), and many of those include architects, designers and property developers. Green over Grey

4. Product certification. Product certification is "a process by which products are assessed and confirmed as conforming with applicable standards. This evaluation results in the issuing of a statement or certificate of conformity and approval to apply a mark to the product."[119] Although time and cost factors can be considered as the challenges of meeting the applicable standards, product certification can be a very important consideration during material selection process.

5. Maintenance packages. Maintenance and ability to replace the products in the long term should be considered by manufacturers while introducing innovative products to market. For example, Green over Grey provides maintenance packages to assure clients that their wall will continue to look and perform well in the long term clients. Also, DIRTT solutions are designed to allow users to easily replace or remove the components if necessary.

According to the information provided by the three interview participants, the main challenge of introducing new products to market is communicating the

119. Peter Clark, "Standards in Focus," (workshop presentation, A Safer World for Customers - How Can Standards Help?, Standards Council of Canada, Toronto, May 24, 2005) http://www.iso.org/iso/livelinkgetfile?llNodeId=22144&llVolId=-2000 (accessed June 17, 2014).

innovative solution efficiently and educating people about the new products, systems and possibilities. Participants also mentioned that when architects and designers have a better understanding of advantages, they are willing to involve with these innovative applications. Therefore, in the next part of the report, the question asked is "how can industrial designers' experience and knowledge of introducing and using innovative materials application help overcome a lack of communication between different industries?"

PART 3: COMMUNICATION

> A central puzzle that people face, from a design perspective, is how to make communication possible that was once difficult, impossible or unimagined.[120]

3.1. Material, Design and Building Industries

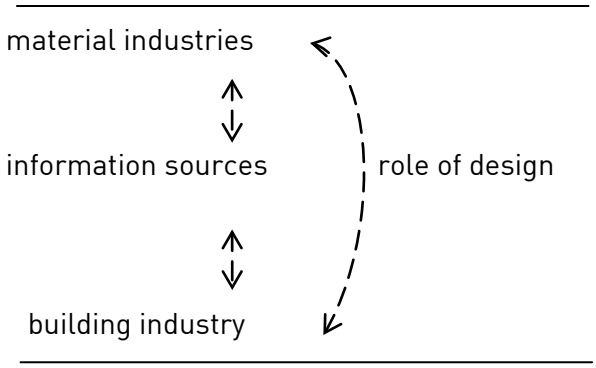

Figure 17 Material, Architectural and Design Industries

120. Mark Aakhus, "Communication as Design," *Communication Monographs* 74, no. 1 (2007): 112.

Material selection includes different disciplines and industries, and communication among them is essential to achieve innovative solutions. Manufacturers and suppliers can either communicate directly with designers or via using information sources (see Figure 17). Either way, product data should be introduced in an efficient way by considering "how architects and designers think, what information is relevant and how they want it communicated to them:"[121]

> Manufacturers traditionally communicate the features of their product to architects and often neglect to mention the benefits. The manufacturers process information in a logical way — first they look at details, and then pieces together the whole.... For architects a Manufacturer's product is only as relevant as the design problem it solves. Architects receive and process information simultaneously, in an intuitive and emotive manner — seeing the whole first, and then the details.[122]

Ashby and Johnson discuss how manufacturers and suppliers communicate information about their products through advertising, press releases, profiles and datasheets.[51] They highlight two main factors necessary for successful communication that encourage designers to use materials in creative ways: (1) having information addressing both technical and sensorial aspects of materials, (2) using language that is meaningful for both designers and developers and including vocabulary to express both design requirements and material behavior.

These two factors constitute the basis of successful material selection. However, understanding project requirements and possibilities of materials in detail is also a significant aspect of successful communication. The challenge is that what designers need changes according to differing projects. Therefore, information

121. Epiphany studio. Manufacturers are from Mars, architects are from Venus, July 25, 2013, http://www.epiphany-studio.com/2013/07/manufacturers-are-from-mars-architects-are-from-venus/ (accessed May 9, 2014).

122. Ibid.

about benefits and disadvantages of materials must vary as well. An example given by Ashby and Johnson is the concept of a child's car seat:

> The seat must hold and protect the child when subjected to decelerations of up to 10g; it must be strong enough to withstand the inertial forces that this demands yet not damage the child while doing so. Its dimensions must allow it to pass through a car door easily. It must be light, yet able to withstand mishandling and impact, and it must be easy to clean. If you think of products for children, you think of robustness and tolerance of misuse, of high standards of safety, non-toxic materials, simple, bold forms and bright colors.[123]

On the other hand, some of these requirements of child seats might not be as important while developing a regular car seat design. Although projects and demands change, material information provided by manufacturers mostly remains the same. Thus, rather than presenting and communicating material information through the same product data sheet, manufacturers should consider more engaging and efficient ways of educating their clients in order to succeed in the current competitive environment.

What this thesis suggests is that, first a designer can help increase the manufacturers' understanding of what is needed by guiding them through effective interactions in relation to specific requirements of architectural projects. Secondly, the industrial designer could take on a new and more evolved role through providing analysis of possibilities regarding materials application. This analysis will allow architects to spend less time on research while at the same time analyze risks and benefits more effectively. In other words, in order to facilitate more connections and accelerate the use of innovative materials application in the building industry, a new role for design is proposed in this paper that can help in two crucial ways: (1) communicating and stipulating the competitive advantage of materials/products,

123. Ashby and Johnson, 127.

especially newer ones, and (2) analyzing the risks and rewards of new material applications in relation to the requirements of projects.

3.2. Role of Industrial Design

3.2.1. Define: Designer as a Translator

> Design is an activity of transforming something given into something preferred through intervention and invention.[124]

The *Business Dictionary* defines industrial design as "creation and development of concepts and specifications aimed at optimizing the functions, value, and appearance of products, structures and systems."[125] Popadiuka and Choob, the authors of "Innovation and Knowledge Creation, How These Concepts are Related?" state that, because of the effect of globalization on the competitive environment, the search for strategies that will provide business organizations with a sustainable competitive advantage has increased.[126] However, there are two more factors which are as important for gaining competitive advantage: That is (1) creating an engaging platform to communicate this competitive advantage and (2) educating clients about benefits and risks of innovative materials application.

> The designer can be seen as an actor playing a key role as translator in one or more networks of people (inside and outside the firm, all with different knowledge, information, skills and desires), and of ideas, artifacts,

124. Aakhus, 112.

125. Business Dictionary, "Industrial Design," http://www.businessdictionary.com/definition/industrial-design.html (accessed July 5, 2014).

126. Sivio Popadiuk and Chun Wei Choo, "Innovation and Knowledge Creation, How are These Concepts Related?" *International Journal of Information Management* 26 (2006): 302.

> instructions, cost constraints, machinery, blueprints, prototypes and so on.[127]

Understanding what customers want and need constitutes the basis of the design process. A designer constantly thinks about what the fundamental problem might be regarding a system, product and/or environment etc. and what can be further developed. Walsh states that the designer stands between the user and the producer.[128] Walsh also discusses the integrative role of design that is crucial to innovation: design is the domain of creativity where ideas are devised but is also where the 'coupling' occurs between technical possibilities and market demands or opportunities.[129] In addition to finding the fit between market intensions and technical opportunities, industrial design as a profession covers aspect of aesthetics, ergonomics, finance and production techniques during the development of a solution. During interviews, one of the research participants, Wesley Sims, stated that:

> Architects are usually not the first ones out there to experiment with materials. In most cases it would be an industrial designer or even artist. For example, we could say that a flow form counter top would be really great in a space but we don't necessarily explore how to make that product. From my understanding industrial designers are more interested in exploring the potentials of each material. We are more interested of getting a proven material or product and applying it in an innovative way to our building assemblies.

According to Eekhout, compared to manufacturers, architects lack knowledge of the contemporary production techniques of industrial and prefabricated building

127. Michel Callon, John Law and Arie Rip, *Mapping the dynamics of science and technology* (Basingstoke: Palgrave Macmillan, 1986), quoted in Vivien Walsh, "Design, Innovation and the Boundaries of the Firm," *Research Policy* 25 (1996): 515.

128. Walsh, "Design, Innovation and the Boundaries of the Firm," 514.

129. Ibid.

products.[130] On the other hand, the manufacturers' approaches to products are typically result-oriented as they are focused on the long-term survival chances of their company. Thus, manufacturers lack knowledge and insight regarding architecture and their market. Designers should always be alert to new developments and keep abreast of innovative materials, processes and technologies to find new possibilities. When that is the case, the designer's understanding of various aspects, as well as a focus on intervention, invention and customers' demands can play an important role in translating standard material information according to project requirements.

3.2.2. Compare: Designer as an analyzer

> Innovation consists of new ideas that have been transformed or implemented as products, processes or services, generating value for the firm. Ideas are formed through a deep interaction among people in environments that have the conditions to enable knowledge creation.[131]

Knowledge has been defined as "awareness, understanding, or information that has been obtained by experience or study."[132]According to Popadiuka and Choob, knowledge consists of two dimensions: exploration and exploitation. Knowledge exploration involves discovery and experimentation of new concepts or technologies as well as developing new capabilities. Nevertheless, exploitation is based on

130. Eekhout, 222.

131. Popadiuk and Choo, 308-309.

132. Cambridge Dictionaries, "Knowledge" http://dictionary.cambridge.org/dictionary/americanenglish/knowledge?q=knowledge (accessed June 25, 2014).

experience or the aspects that are already known by an organization. Exploitation is achieved through repetition of an activity and formalization of knowledge.[133]

How then, can industrial design help generate this systematic knowledge regarding materials to achieve innovative solutions? After the recognition of project requirements based on understanding what different clients want and need, exploration of the range of available materials plays an important part during the design process. Ashby and Johnson identify that design is comprised of decisions; it is a "choice from [a] tremendous range of ideas and data-among them, the choice of materials and processes."[134] A synthesis of designers' experiences (exploitation) and new developments in technology (exploration) can provide a key contribution to the material selection process by helping the analysis of potential solutions that will meet the design requirements. Hence, an industrial designer's ability to translate, analyze, compare and classify can guide architects through material selection and help them assess the risks and benefits of innovative materials application in the building design.

The role of an industrial designer both as a translator and analyzer of material information can help achieve a direct dialogue between architects and manufacturers. It can support manufacturers in communicating the competitive advantages of their products as well as provide necessary information for architects that will guide them through the analysis of risks and benefits of new materials application. In other words, industrial design can facilitate the formation of a new interactive platform through translating general material information to a personalized data package based on project requirements.

133. Popadiuk and Choo, 309-310.

134. Ashby and Johnson, 124.

Case Study: Materials Council

> The key is to present the information in a way that is engaging so people want to read it. Then all the information has to be there and presented in a way that allows designers to make an informed decision. Ian Hunter, Materials Council

Materials Council specializes in the exploration, comparison and selection of materials for architectural applications. The two founding partners are industrial designers and researchers who have a deep understanding of design process, materials in architectural applications.[135] They provide consultancy support for manufacturers and educators, as well as architects and designers to help them achieve their creative visions. Their services bridge the gap between manufacturers and architectural industries to facilitate communication, application and improvement of materials and new technologies. The new Apple campus in Cupertino, California, expected to be completed by 2016, and the Masdar Institute of Technology in Abu Dhabi, completed in 2010, are two examples of some prestigious international projects Materials Councillors have worked on.

> Materials Council bridges the manufacturing and architectural industries, translating technical data, material performance and constraints, and communicates them to designers in clear, visual and immediate terms.[136]

Furthermore, the Materials Council also assists creatives in organization of their own office sample libraries. Their website states that office material collections are significant sources that allow professionals to analyze the options faster and more effectively during idea generation. The exhibitions and events they curate are based on current architectural themes, innovations and materials applications. Two

135. "Meet the Councillors, "Materials Council: Independent Material Consultants Limited, http://www.materialscouncil.com/about/team/ (accessed July 6, 2014).

136. "Consultancy for Creatives," Materials Council: Independent Material Consultants Limited, http://www.materialscouncil.com/consultancy/for-creatives/ (accessed July 6, 2014).

such examples are, 'In the Scale of Carbon,' which is focused on sustainability issue and 'explores the carbon footprints of materials used in built environment,' and 'Whiter than White,' which explores the theme of 'whiteness' and, includes a selection of architectural materials and finishes.[137]

Since Materials Council aims to bridge material and architecture industries and accelerate innovation with their consultancy services and exhibitions, they set a great example of the focus of my thesis. Since they are based in London, I contacted and interviewed them via email. Ian Hunter, one of the founders of Materials Council, provided detailed answers to my four questions.

The case study interview (see Appendix B) summarizes most of the aspects discussed in the review of literature and research data analysis. The common problems Hunter mentioned that lead an innovative materials application not being used by architects and designers are: (1) characteristics inherent in the building industry, such as complexity, costliness, durability, and high degree of responsibility to the clients, (2) limitations of product certification (3) lack of awareness and understanding of new materials and products, where to find them, how to use them, what are the real benefits of a product. Hunter agreed on the information sources mentioned by other interview participants and presented in the material selection map. Furthermore, this interview participant emphasized the importance of networking and talking to experts, staying curious and being open to learning new perspectives about materials, design and architecture. One of the most important parts of the interview is that Hunter mentioned the key importance of presenting the materials' information. They work closely with their clients in order to help them

137. "Exhibitions & Events," Materials Council: Independent Material Consultants Limited, http://www.materialscouncil.com/exhibitions-events/ (accessed July 6, 2014).

comprehend the hierarchy of their design requirements so that clients can determine what aspects are more significant. After priorities are specified, they prefer using a combination of data, logic and reason and past precedents. As a result, three key aspects, identified below, could be helpful for designers in terms of creating dialogue between architects and manufacturers through personalized material information. This role of industrial design in the building industry can achieve improved knowledge transfer and increased awareness regarding innovative materials application (see Figure 18).

Analyze the project

Identifying key requirements of the projects, such as scheduling, cost, and performance, can help specify the order of precedence of material information that will be communicated to the architect.

Explore the key indicators

Having a better understanding of primary requirements and important considerations allows manufacturers to communicate the competitive advantage of their products in a more effective way. It also provides architects with the necessary data to analyze and compare products in a time-efficient way.

Find the relevant references

The performance factor includes very important sub categories such as, sustainability, durability, context, manufacturing and technical aspects. According to the results of interviews with manufacturers, one of the most effective ways to inform architects and raise the awareness about their products is to show past examples of their work. Exploring previous clients who have used these materials

and project type, a selection of relevant examples can be made. For example, selecting a material that has been used by the Government of Alberta can be considered by architects less risky in terms of performance. Furthermore, in order to help with the analysis and comparison of appropriate options, both benefits and drawbacks of materials should be examined. Since manufacturers are not always willing to share their unsuccessful applications, talking to clients, experts and colleagues can be a useful source during the selection of materials application that satisfies the project requirements.

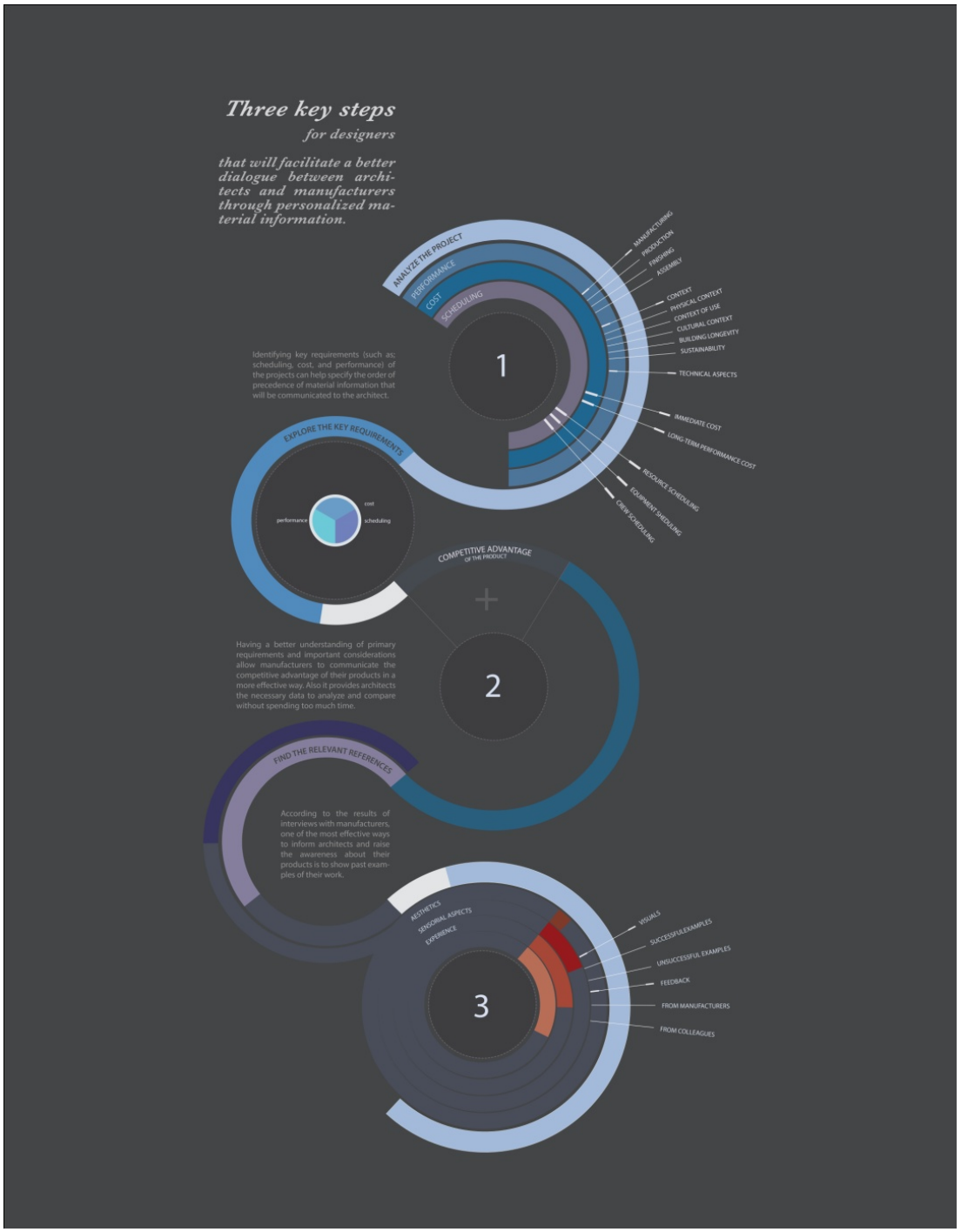

Figure 18 Three Key Steps

PART 4: CONCLUSIONS

This research aimed to improve the understanding of new material development in material industries as well as the material selection process for architectural projects. The main argument is that industrial design can help increase use of innovative materials application in the building industry.

Two issues were identified in the first part of the report that can limit a firm's ability to use innovative materials application: (1) inherent characteristics of the construction industry such as immobility, complexity, durability, costliness, high degree of social responsibility, and (2) lack of information sources that include comprehensive information about new and existing materials.

In the second part on methodology, interviews were conducted with architects and designers to discover the information sources they use, and the aspects that are important during their material selection process. Additionally, an important part of the research was receiving information about the challenges and limitations of using new materials application in the building industry. Information sources mentioned by participants include: experience, in-office library, contacting manufacturers and colleagues, search engines, books, magazines, tradeshows, exhibitions, CSA and NRC. The barriers to using new materials application have also been identified as complexity, high degree of social responsibility, durability and long-term performance, costliness, physical context and cultural context.

As a result of the interviews with architects, I designed a map that includes the stages of material selection and analyzed why an innovative material application may fail to be used by architects and designers. Four factors identified from this map

are: (1) lack of desire and interest to be innovate in the use of materials, (2) failure to research effectively, (3) materials unsatisfactory in relation to key requirements, and (4) inability to communicate the competitive advantage of their products.

Since one of the most important liabilities of using innovative material applications mentioned by architects and designers during the interviews is the uncertainty of long-term performance, I sought out research participants that are material industry professionals based on their experience managing long-term performance risk and innovation. Participants who are representatives of different organizations mentioned various strategies applied after the market launch of products. Interview results can be summarized in five points to clarify the information channels that manufacturers use in order to inform and give architects and designers a certain level of confidence in their products. These are: (1) one-on-one conversations with designers and architects, (2) lunch & learns, tradeshows, exhibitions and company websites, (3) previous examples of their application, (4) product certification, and (5) maintenance packages. The main challenges of introducing new products to market are indicated as communicating the innovative solution efficiently and educating people about new products.

Having an industrial design component within a company during new product development could be not only essential in achieving competitive advantage, but also crucial in focusing communication between different people with various skills and backgrounds. Therefore, this thesis asserts that the role of the industrial designer both as a translator and analyzer of materials in the building industry can help achieve a direct dialogue between architects and manufacturers. First, industrial designers can help increase the manufacturers' understanding of what is

needed by guiding them through ways of effective communication in relation to specific requirements of architectural projects. Secondly, they can provide necessary information for architects that will guide them through the analysis of risks and benefits of new materials application. As a summary, industrial designers can facilitate a new engaging platform through translating general material information to a personalized data package based on project requirements.

4.1. Limitations and Recommendations for Future Research

The first limitation of this study is that its primary focus of understanding the relationship between industrial design, architecture and material industries is a complex issue and involves various aspects and professions besides architects, industrial designers and manufacturers. Although the purpose was not to analyze all the factors that have an influence on the material selection process, a researcher must understand the limitations of using and introducing new materials application based solely on the experiences of manufacturers, designers and architects, since their experience may be to significant degree shaped by aspects and professional interactions beyond the scope of this thesis. Secondly, since most of the interview participants are based in Edmonton and Calgary, other projects in different contexts, countries and settings may have a different understanding and experience of innovative materials application that might include different determinants.

The final limitation is that the data analysis attempts to provide detailed descriptions of interview results and notes on how industrial design can facilitate dialogue between different industries. Results have not yet been tested in Edmonton

and/or Calgary. Materials Council, based in London, is a successful example of bridging the gap between material, design and architecture industries while working on international and prestigious projects. Further research could be conducted to determine limitations and barriers of introducing and using new materials application based on comparisons among different contexts and countries.

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APPENDIX-A: MOTION GRAPHICS VIDEO

> A relatively new medium for communication, motion graphics utilizes the element of time to its fullest potential in order to communicate its message through visual and audio storytelling.[138]

Since one of the most powerful and engaging medium of communication is through videos, I have decided to design a motion graphics video for the Master of Design exhibition. I have designed a video to give the viewer a clear idea of this research and my main assertion in result of reading a couple of sources about the issue of effective communication and storytelling. I have decided to apply the ideas and guidelines introduced in the book *Made to Stick: Why Some Ideas Survive and Others Die* by Chip Health and Dan Health. Basically, the writers indicated six key qualities to successfully communicating a concept that actually sticks to people's minds. [139] These are simplicity, unexpectedness, concreteness, credibility, emotion and stories.

1. Simplicity

Finding the core is eliminating many ideas to find out the most important concept. Health and Health explains this concept as "stripping an idea down to its most critical essence."[140] In this book one key component is the method of how news reporters tell their stories. The first sentence, called the lead, aims to communicate the most important information of the story to the audience. For example, the

138. Dominic Flask, Motion Graphics, Design is History, http://www.designishistory.com/design/motion-graphics/ (accessed: August 2, 2014).

139. Chip Health and Dan Health, *Made to Stick: Why Some Ideas Survive and Others Die* (New York: Random House, 2007).

140. Ibid., 28.

essence of a story can be described as: "A healthy 17 years-old heart pumped the gift of life through 34-year-old Bruce Murray Friday, following a four-hour transplant operation that doctors said went without a hitch."[141] This can attract a reader for further develop information and keep them engaged.

> If news stories were written like mysteries, with a dramatic payoff at the end, then readers who broke off in mid-story would miss the point. Imagine waiting until the last sentence of a story to find out who won the presidential election.[142]

Creating my own lead, I have decided to start the video by focusing on the importance of communication among different disciplines in the building industry. My lead is: "Communication among different disciplines is essential during material selection in order to achieve innovative solutions in the building industry."

2. Unexpectedness

Unexpectedness focuses on how to get people's attention and keep it. Chip Health and Dan Health argue that surprise gets attention and interest keeps it. To achieve unexpectedness I used a research result that indicates the surprisingly low percentage of sales of innovative products and the low percentage of companies with research and development departments. My unexpected information is that, "According to a survey of Swiss companies, the proportion of sales of innovative products in the building sector is just 10.7%, while only 24% of the companies carry out research and development work."

141. Ibid., 31.

142. Ibid.

To keep viewers' interest after mentioning barriers to innovation (concreteness part), I also added the following line: “However, reducing these barriers and managing innovation are possible through better communication.”

3. Concreteness

The purpose of concreteness is to "help people understand and remember."[143] In order to make it easy to understand what my thesis suggests, I mentioned several characteristics regarding construction industry to let people imagine a new system that might play an important role in facilitating more communication between architecture and material industries. I indicated that there are different factors that can limit innovative behaviour such as immobility, complexity, durability, costliness and high degree of social responsibility.

Making a connection between existing knowledge and a new system of communication can generate a simple, easier and effective introduction. In other words, it enables both simplicity and concreteness. An example given in the Health and Health book claims that, by using the knowledge of grapefruit, it is possible to teach people the concept of pomelo much faster than if all the properties such as color, taste and other attributes had been listed.

The book’s authors suggest that, after six months, people are more likely to remember pomelo as a grapefruit-like fruit than memorizing its attributes. Since most architects and designers are familiar with material libraries like Material Connexion, I explained the statement of personalized material information as an advanced material library-like application. I thus added to my video: “Imagine a

143. Ibid., 106.

system like an advanced material library that knows/understands the requirements of projects, and personalizes material information accordingly."

4. Credibility

This quality is based on exploring a vivid detail of the concept that will make the statement credible or "help people believe."[144] I explained the benefits of my new proposed system to increase credibility. I included the statement "This system will help manufacturers communicate competitive advantage of materials. Rather than presenting the same properties through product data sheet, manufacturers need to understand the whole image: what architects need and how they want it to be communicated to them. With personalized data architects and designers can spend less time on research, analyze risks and benefits of materials and find new possibilities of materials that will work with the requirements."

5. Emotional

The emotional aspect is focused on "how to make people care about the idea."[145] In my video, I mentioned the long-term benefits of innovative materials application in the building industry and by focusing on the connection between building industry and environment, the intention was to raise the interest in the concept. The following sentence is an example from the script based on this aspect. "Innovative materials application foster growth in building industry, but most importantly innovations can

144. Ibid., 163.

145. Ibid., 171.

improve the environment we live in and with communication through personalized data we will progress much further."

6. Stories

Stories are associated with entertainment and therefore have an huge impact on how to get people to act on the idea. The way I approached this factor is that I designed visuals of the video based on a story. I included changing seasons and other visual elements that symbolize the keywords of design, architecture, building industry, environment and communication (see Figure 19, 20, 21 & 22).

Figure 19 Motion Graphics Video Visual 1

Figure 20 Motion Graphics Video Visual 2

Figure 21 Motion Graphics Video Visual 3

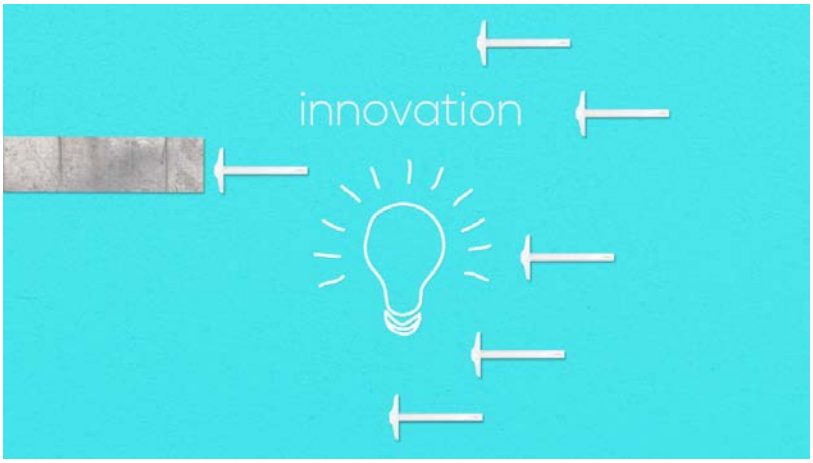

Figure 22 Motion Graphics Video Visual 4

APPENDIX-B: INTERVIEW WITH IAN HUNTER OF MATERIALS COUNCIL

1. According to your experience, what are the most common problems after market launch of an innovative material that leads to its failure or it not being selected by architects and designers?

There is always a race to be the first to use a new material in architecture and design. Typically this is driven by the desire to produce something innovative, new or different combined with a push from the material developer to have a realized project that demonstrates the possibilities of their product. The material will no doubt be supplied at a very preferential price in order to secure a prestigious project.

Once the first application has been realized the opportunity to be first is lost, removing one of the motivating factors, the manufacturer will need to start making some money so the material will be priced properly going forwards. Looking at the bigger picture, architecture is a conservative industry with many parties involved in the design of a building. Due to the scale of projects in size, complexity and cost people will err on the side of caution, whether it's the designers or the clients. This is accentuated by the fact that buildings are occupied by a number of people over their lifetimes. Most of the time buildings are developed by someone who won't occupy them, or the occupant will consider a resale eventually - so again this causes a tendency to play safe in material selection, what I like to call the magnolia effect.

New materials often don't have a lot of the tests and standards (fire standards, slip resistance etc.) that are needed for any large scale use of a material. These tests are expensive to undertake, and many different variations are needed for different countries. Small innovative companies are squeezed by having to compete with large multinationals who can afford to have all of the testing carried out and compete on the global market.

Last but not least, there is simply a lack of awareness of new materials and products, where to find them, how to use them and a limited understanding of what the real benefits are of a given product. This understanding and knowledge takes a great deal of time - it's what we at Materials Council do all day everyday and we struggle to keep up!

2.1. Can you give me some examples of an innovative materials application agreed to be used by an architecture/design firm and what were some of the factors that convinced them to make that decision?

> An innovative material application that I have been involved with was in the design of the new Apple campus while at Foster + Partners. Here we developed the facade that pushed the use of glass to its boundaries. A traditional material stretched to its limits, the largest curved glass sheet in the world, and there were over 600 of them. There were huge challenges in manufacturing, transportation - balancing high performance solar control while maintaining visibility was a huge challenge. The decision was driven and really only made possible by a client with a strong commitment to high quality design...and a very large bank balance.

2.2. Can you give me some examples of an innovative materials application failed to be used by an architecture/design firm and what were some of the factors that affected them to make that decision?

> A quick example I can think of was when we worked with a firm to undertake a feasibility study for the use of 'knuckle bone' flooring in a retail environment. This is literally as it sounds, a medieval technique of using the bones of cattle and dear as a mosaic. Not surprisingly everyone involved panicked and there were just problems at every corner from finding the supply, controlling the aesthetic, safety, maintenance etc. Basically there wasn't a real benefit to taking this idea forward to justify the additional effort.

3. What are the challenges of translating technical data and presenting research reports to architects and designers? Can you give me some information about research reports you are working on?

> One of the reports we are working on is a report to detail materials suitable for a swimming pool environment. Quite an aggressive environment, but a common challenge faced by many practices.
>
> The key is to present the information in a way that is engaging so people want to read it. Then all the information has to be there and presented in a way that allows designers to make an informed decision. A real challenge is

comparing multiple attributes/properties of materials. We work hard with our clients to make them define and understand the hierarchy of their design requirements so they can prioritize which aspects of a material are important or not.

When this is done successfully then it promotes a better understanding of the issues and allows these decisions to be discussed and justified amongst co-workers and most importantly with the client.

Ideally long term benefits should be clear. This is part of understanding what the overall design strategy and requirements are. Then once the principal aims or functions of a design are understood it is possible to suggest which material attributes will be important in achieving these aims. We would use a combination of data, logic and reason and past precedents.

4. What mediums do you use to keep abreast with the latest developments in

material industries?

I'd say mostly curiosity and enthusiasm. Again nothing magic here, your map sums up the information points well. Books, magazines, designs all around us, trade fairs, Internet, talks, lectures, material libraries. The most important thing that we have is our network - we speak to a lot of people who are experts in a number of fields. That's always the best way to learn.

APPENDIX-C: THE THOUGHT PROCESS MAPS

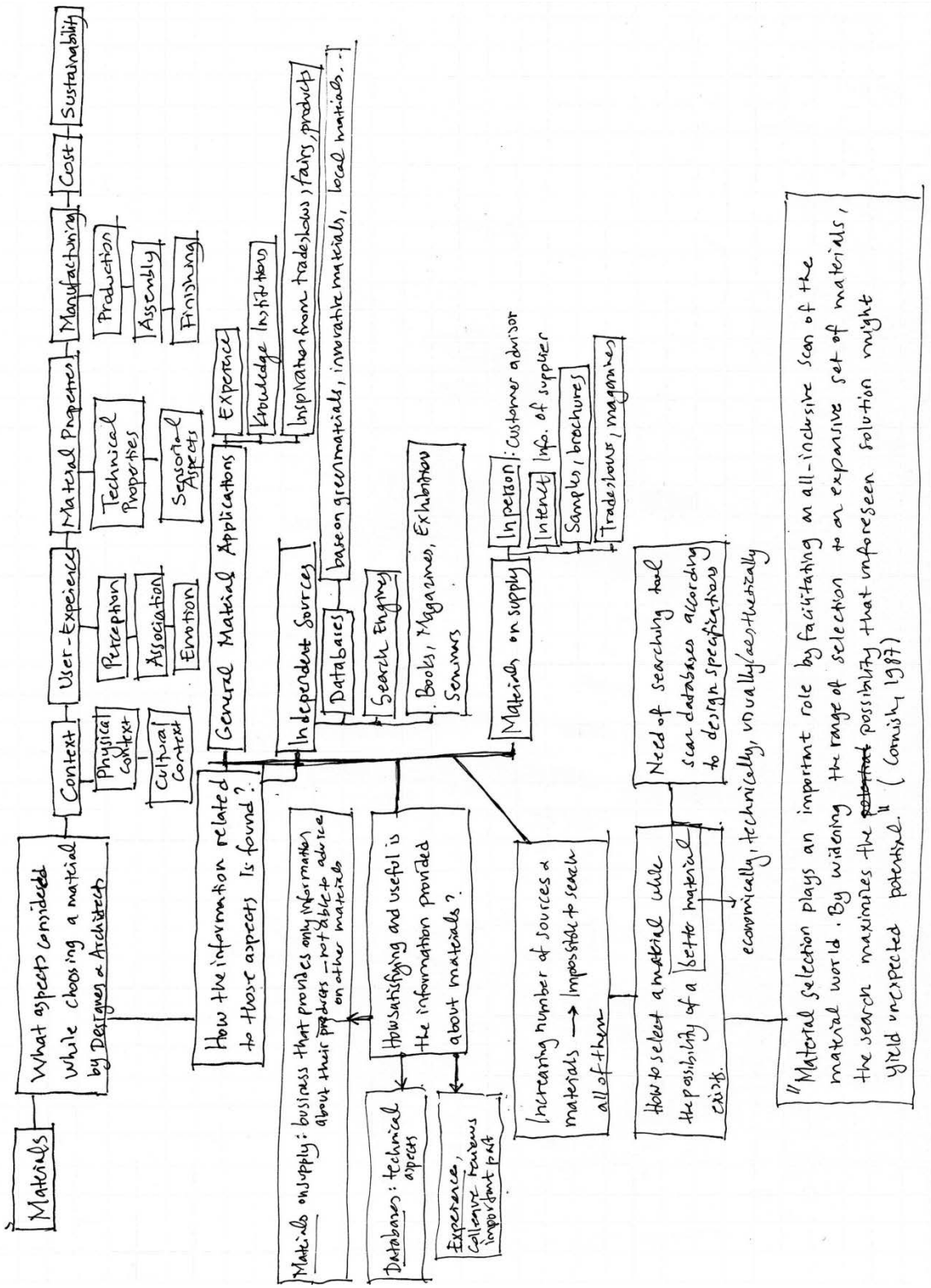

Figure 23 Thought Process 1

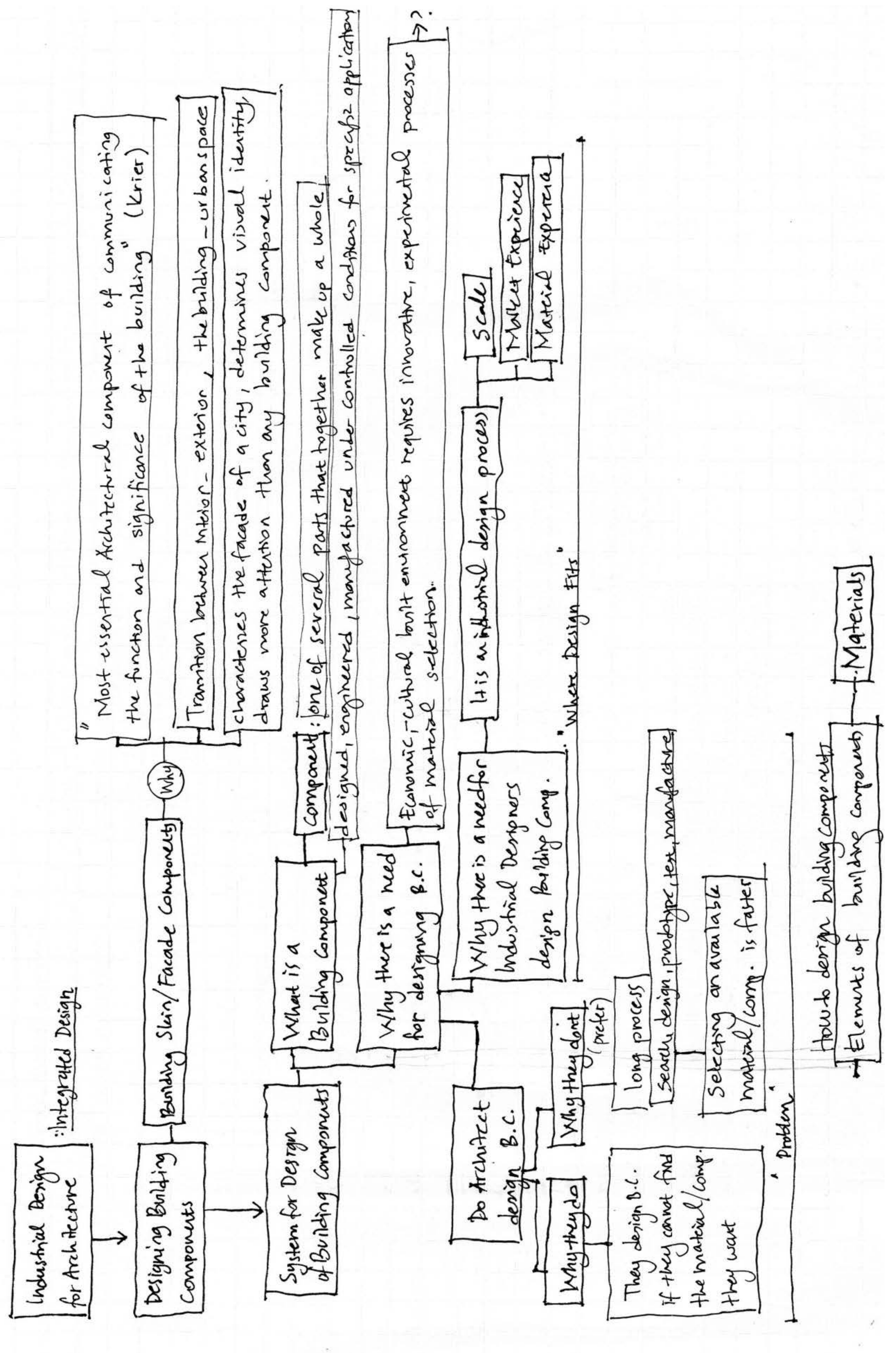

Figure 24 Thought Process 2

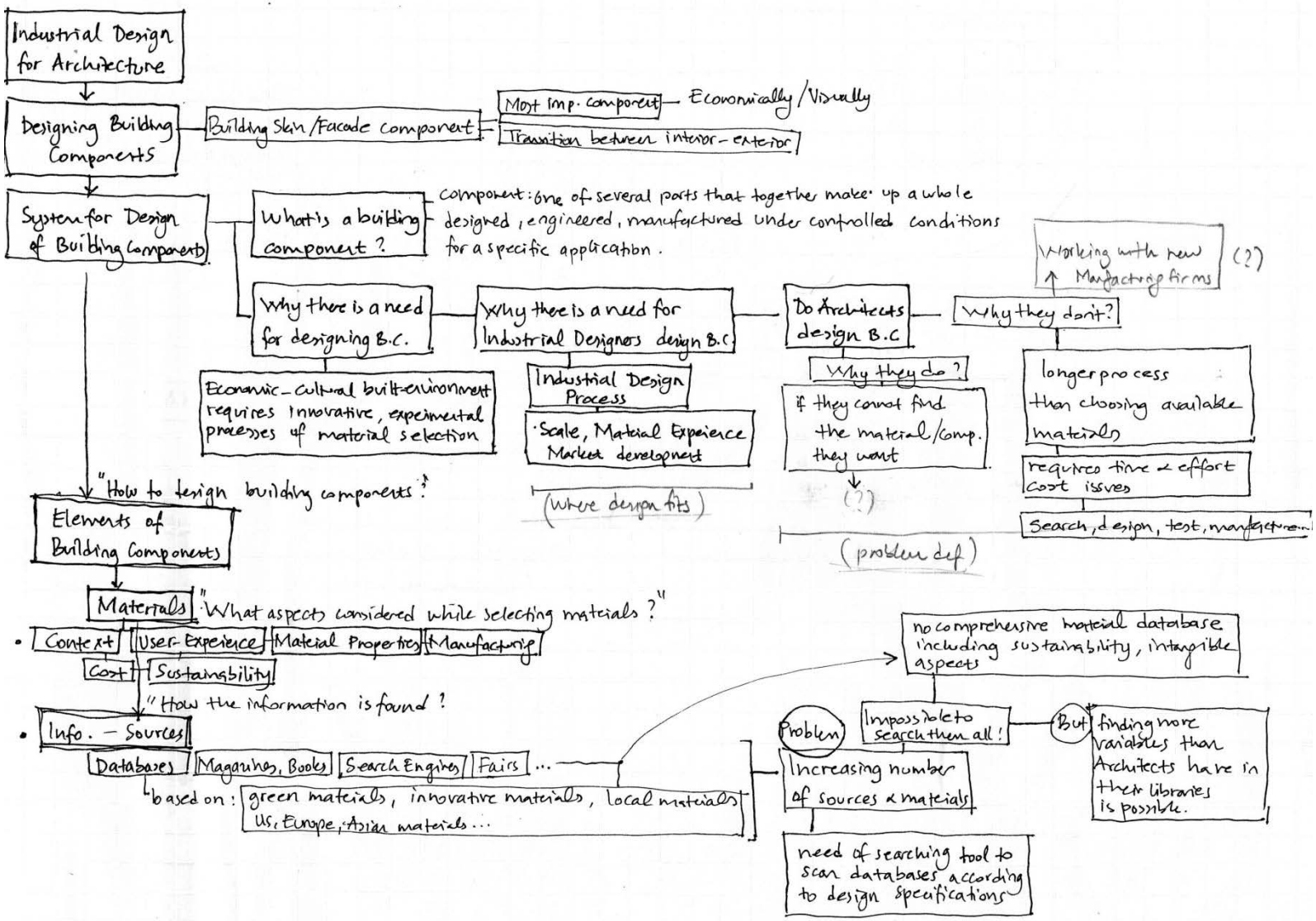

Figure 25 Thought Process 3

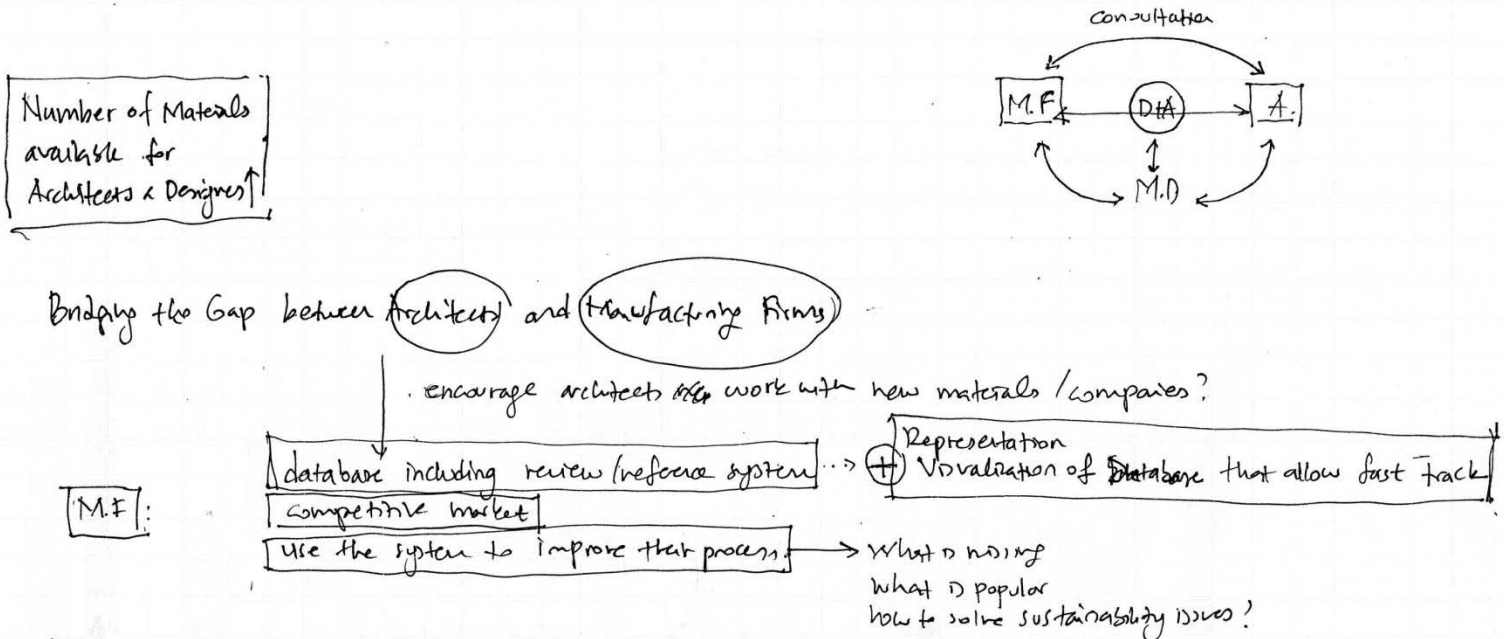

Figure 26 Thought Process 4