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TEXTILE ARCHITECTURE:
EXPLORING THE POTENTIAL OF FIBER ASSEMBLIES AND THEIR APPLICATION IN ARCHITECTURE

A B S T R A C T

This paper explores the relationship between textile materials and architecture, and how this relationship changes through collaboration between textile engineers and architects. Rather than evanescent matter and structurally insufficient building material, textile may be observed as a large number of fibers organized into coherent and flexible structures which are permeable by air, water or adjustable to human body and its activities. Certain textile properties have always been a matter of interest for architects and have always offered both an intriguing metaphor and an operative device for architecture throughout its history. Today, textile materials in combination with software, robotics and sensorial devices provide for the renewed inters in adaptable form of architecture and the ability of the built environment to react according to contextual changes. This study examines structural characteristics at the material level and explores further into the constructions of fiber assemblies. The aim is to represent textile as a new material which application and implementation in architecture can influence development of new ideas in creating aesthetic and cultural context.

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SMART MATERIALS
TEXTILE ARCHITECTURE
ROBOTICS

INTRODUCTION

Textile materials may be observed as complex fiber assemblies, which do not represent material per se but an entire material system. In fact, the logic of "textile structure" may be related to a wide spectrum of materials. Any material system is comprised of a series of intrinsic relations which define the material structure. In that sense textile may be understood as a departing point for the exploration of a larger group of materials rather than any one and specific material. Various spatial effects may be created, depending on the fiber constitution and geometric principles which keep fibers together.

The relationship between textile and architecture exists on several levels. Often is textile, along with its interesting fabrication process, used as metaphor for conception of soft space. The other form of the connection relates to spatial environments whose structure is a pleated network of linear elements which structural logic reflects that of textile assemblies. The most obvious connection relates to the situations where textile was used as actual material in realized architectural objects.[1]

Textile materials have often been used by the architects and artists for materialization of the spatial effects such as flexibility and changeability, physical move of the spatial structure or its interaction with the user. Textile is used as means of space defining which can easily be transformed by the user or adjusted to various scenarios of use. The field of application in a given moment relates to the spatial installations and experiments in the form of prototype rather than use of textile in materialization of completed architectural objects.

The interest in textiles in these cases is based on the presumption that the material itself by its characteristics may meet increasingly growing requirements for adaptable and dynamic spaces whose configuration is changeable and depends on the events or processes which take place in them. In other words, the characteristics of textile materials are to a great extent reflected with desired spatial qualities and theoretical tendencies in a given moment.

The broader theme of the paper relates to exploration of the role of material in architecture, how technological facts of a material become mediators of effects on the level of the product or realized architectural object. Each material possesses certain characteristics on which its application and role in creation of the built environment depends. However, the spatial effects produced by materials often remain invisible or are overshadowed by the entire architectural strategy.

It is necessary to explore to which effect the characteristics of textile materials may affect their application in architecture and how much the technological development of textile, on the level of material itself, may on a higher level initiate the development of the new architecture which adapts itself to certain situations through physical alterations in real time and space.

The proposed exploration aims at presenting the potential of textile materials to transform and inform contemporary tendencies in architecture. In a broader sense the aim is to present architecture as material discipline in which the characteristics of material together with their technological innovations may influence the development of ideas in architecture in creating of the aesthetic and cultural context .

Throughout this paper different aspects of textile materials have been explored in terms of presenting potentials of textile materials for realization of novel forms of architecture. The exploration has been divided into several steps. The first is studying the textiles in the context of other materials which throughout history transformed architectural discipline. This historical viewpoint should help to point out the facts that correlate architecture and textile materials. The next step is to study the accelerated and complex technological development of textile materials through relationship of material structures and the new trends in fiber materialization. Central to this study is the development of synthetic fibers and their ability to meet the contemporary requirements of environmental protection.

IN-BETWEEN MATERIAL INNOVATIONS AND IDEAS ABOUT SPACE

There is a certain interspace that separates technological innovations and their application and implementation in architecture. This interspace has often been the topic of research of the historians of architecture with a presumption that innovations in the field of materials and their application and implementation in architecture is not a momentary event. Technological innovations have been developing gradually during a certain time period, where each next phase gradually influenced the aesthetics and cultural context. The gradual technological development of textile materials since the mid 20th century has made textiles widely represented materials the field of application of which increased with each technological innovation. This paper will present those technological innovations which bring textiles closer to the "new" architectural material, namely to the material whose field of application increasingly seeks into architectural discipline.

The first step in the exploration relates to defining the context within which textile materials will be explored by referring to the specific role which certain materials had in the history of architecture. The use of the new materials often signified the emergence of the new ideas about space. In other words, the development of the architectural discipline can be followed through the appearance and application of new building materials. The presumption that textile materials possess the potential to transform architecture in the identical manner in which steel and concrete used to starting from the arguments of Sigfried Giedion in the book *Building in France, Building in Iron, Building in Ferroconcrete* (1928), and further on pointing out to the historical significance and appearance of materials such as glass and plastics.

Giedion presents the modern architecture from the beginning of the 20th century as full implementation of that which the industrial revolution produced in the mid 19th century. The 20th century modernism strived to define its architectural expression through specific selection of the group of materials – reinforced concrete, steel and glass. The specific relationship of the development of architectural discipline and the materials used is seen by Giedion as a type of synthesis in architectural design – the integration of the development of the architectural ideas with the technological development of material systems.

Glass and plastics: from transparency to flexibility

The integration between architectural concepts and innovations in the field of materials can first be observed through emergence of materials such as glass and plastics. These materials have first of all brought up the new ides about space whereas their final implementation and technological application came with a certain delay. It is presumed that textile materials with the same force can transform the way the architects contemplate about space.

The historian Detlef Mertins in the essay *Glass Architecture* makes his argument that glass, behind its characteristics as material, bears more profound significance in architecture. According to what Mertins writes: „it can be said that glass is still glass because it never was just glass."[2] The essay refers to the work of Bruno Taut from the beginning of the 20th century when glass was presented as a new step forward in technological development promising integration of man with nature. The first design studied by Detlef Mertins is the *Glass House* design for the glass industry at the 1924 Koln exhibition. Inside the house, like crystal, a new living environment was created which offered a new experience of space. The second design actually is the theoretical debate which was initiated by Taut through the "Crystal Chain" group which in chain-like manner exchanged the ideas by letters in the period from November 1919 till December 1920. The group was formed by thirteen architects of the German expressionism, who in their letters offered fantasies on glass cities and towers integrated with the Alps mountain chain – the group offered the new living environment made of glass intended for the inhabitants of the industrial cities such as Berlin, the glass in versatile colors and tones would refract the nuances from the natural environment and thus influence the psychological conditions of the inhabitants and general improvement of the quality of life.

Plastics also brought up the new ideas about space in the middle of the last century. The historian of architecture Beatriz Colomnia makes her argument that fascination with plastics, as the dream material of that time, offered a "new dream" in architecture and in the life style. The *House of the Future* design by the architects Alison and Peter Smithson dating from 1956., represents a series of cast shapes which can be inter-connected only in a single form or the unique shape which, like any other consumer product, would be deserted as soon as the new model has appeared.[3]

That which the designs *Glass House,* which glorified glass as new material, and *House of the Future,* which introduced plastics, have in common is that they have never been fully made of glass, namely plastics. The structure of the Glass House was completely a concrete one which was only lined with glass, and also none of the surfaces were transparent.[4] The plastic house (House of the Future) was actually built form plywood which was lined with a thin plastic layer. It concerns a simulation, the projected scenography in which material effects and significance of material went ahead of their technological and practical implementation in architecture.[5]

Textile: metaphor, assembly, building material

The relationship between textile and architecture may be perceived on several levels: it is often that textile or textile design process has been used in architecture as a metaphor in conceptual phase or in the design process, the other type of connection relates to spatial assemblies whose structure made of linear elements possesses the textile characteristics as a system of fibers and the third, the most evident connection, relates to the situations in which textile is used as actual material in realized architectural objects.

The above listed situations have a long and unexplored history. The Austrian – American architect Frederick Kiesler used textile as metaphor in his *Endless House design* (1958). Kiesler explained the house walls as clothes made of textile which is in correlation with human body.[6] The illustration presents the work of Kiesler on the physical model of the house which was exhibited in the Museum of Modern Art in New York in 1959. (Figures 1 and 2). Besides *Endless House* design Kiesler is known for his manifest of correalism which dealt with the ideas on continual space and the relationships between the man and the architectural object. The use of textile as metaphor to explain these ideas can be considered as the beginning of contemplation about textile environments which are adaptable and changeable in relation to the event taking place in them.

If Kiesler's metaphor was related to the effect of materiality which textiles may produce in space, his contemporary Konrad Wachsmann sees textiles as potential constructive system whose structural logics is actually the assembly of textile materials. Wachsmann has been experimenting with spatial structures of great span, the structures were intended for aircrafts housing and were made of great number of bars. The author has never directly associated his structures with textile structures however the analogy is evident – Wachsmann's structure required greater number of connections and joints between the bars which presented greater problem than bridging the large span (Figure 3). The problem of great number of connections Wachsmann tried to overcome by structural logics in the new structural design *Experimental Structural web* dating from 1953., (Figure 4). The proposed solution was not based on jointing a great number of bars but the structure was based on (interweaving) interference of continual bars in the form of fibers in order to achieve construction logics - that is exactly the logics which makes the structure of textile materials. Textile materials are made of fibers which are kept together by interweaving

Figure 1, Figure 2. *Endless House* (1958), Frederick Kiesler and in that way friction is achieved between the fibers. Wachsmann's design actually is the textile structure which overcomes the problem of great number of complex details, namely joints, and thus offers an economical solution for the problem assigned.

TEXTILES AS MATERIAL SYSTEM

The common property for all textile materials is that they consist of fibers, their characteristics and technological development is based on fibers characteristics and their mutual relationship within material. The second step in the exploration relates to the structure of material and understanding textiles as fiber assemblies.

During the past two decades textiles and materials based on fibers underwent dramatic development. A rapid technological development has made textiles unavailable and made it difficult for the architects and artists to comprehend the new spectrum of possibilities which the textiles offered. In other words, the complexity of the new textiles and their continuous development requires collaboration between the architects and textile engineers in order to expand the application of textile materials to the architectural discipline as well. The aim in this chapter is to present the basic information and adopt the principles which represent the basis for understanding the potential and new tendencies in the development and application of textiles.

The chapter is divided into two segments which are related to definition and structure of textiles, namely fibers materialization. The exploration has been initiated on the basis of the two lectures held at the seminar titled *„Textiles and Fibre-based Materials in Architectural Construction"* which took place at the School of Design in Kolding in August, 2011.[7] Textile engineer Joy Boutrup gave the lecture titled *„Scales of Performance, Fibres, Yarns and Textiles"*

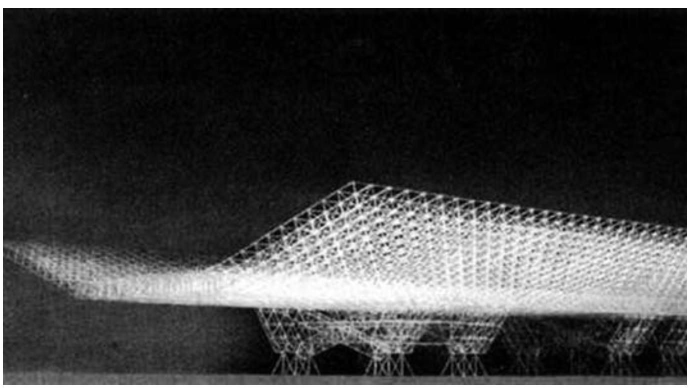


Figure 3. Aircraft hangar (1950), Konrad Wachsmann.

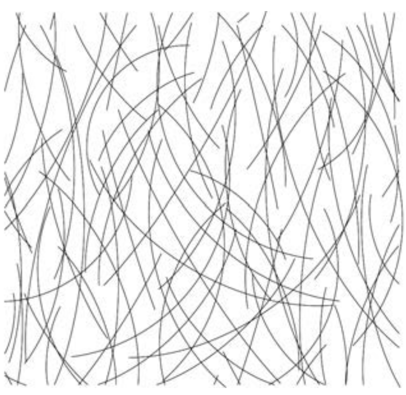
Figure 4. *Experimental Structural web* (1953), Konrad Wachsmann.

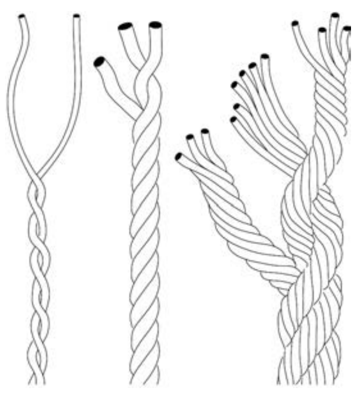
in which she presented the key exploration questions which concerned the potential, scale and chemical properties of the structure of the material. The second lecture was given by the architect and researcher Johan Bettum which was titled *„The Material Geometry of Fibre – Reinforced Polymer Matrix Compposities“* in which the exploration of the potential of fiber-based material systems was presented. Bettum's previous researches in the field of fiber assemblies, particularly his doctoral thesis *The Material Geometry of Fibre – Reinforced Polymer Matrix Composites and Architectural Tectonics*, will serve to accentuate the key facts for understanding the textile structure as material system.

Basic and Advanced fiber assemblies

The basic division of fiber assemblies is according to the manner in which the fibers are kept together, namely according to the techniques of achieving friction between fibers. The division of fiber assemblies according to the techniques of friction achieving affects the chemical and mechanical properties of fiber materials to a great extent, and is particularly important because it separates textile materials from other fiber assemblies whose properties and applications differ significantly. The division into basic and advanced fiber assemblies can be considered as one of the definitions of textile materials.

In basic fiber assemblies the friction between the fibers has been achieved by simple overlapping of randomly orientated fibers (Figure 5). These assemblies [*non – woven*] were obtained without any special techniques of friction stimulation such as weaving, and are mainly used for reinforcement works. This group incorporates also those fiber assemblies in which only lateral friction between the fibers is stimulated. By techniques of folding in and torsion the basic fiber assemblies were obtained such as threads and yarns which make the basis for forming advanced fiber assemblies, namely textiles (Figure 6).





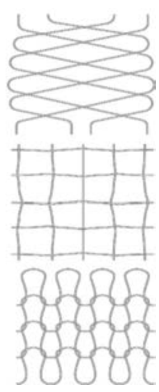


Figure 5. Basic fiber assemblies. With randomly distributed fibers / Figure 6. Basic fiber assemblies. Created by wrapping up. / Figure 7. Advanced fiber assemblies: braided,woven and knitted fibers

Advanced fiber assemblies or textiles are divided into several sub-types (Figure 7). In other words, textiles may be classified into several typologies according to different geometry principles which can be applied in their production: *braided*, *woven*, *knitted and looping*.[8]

Since textiles are made of fibers, the definition of fibers to a great extent constitutes the definition of textile materials. The definition of fibers is based on geometry principles and material molecular structure. Fibers are linear filaments of the material with relatively small cross section (having the diameter less than 100µm) in relation to its length, where the ratio between the length and cross section thickness is greater than 100. In other words, fibers are not a material by itself, but represent a certain form of material which meets these proportional characteristics.[9] However, not all materials can take the form of the fibers, the other part of the definition is related to the molecular structure which enables bending of fibers which is their intrinsic property.

The fibers within the fiber assembles are mutually connected only by friction. Textiles are classified among the advanced fiber assemblies in which this friction has been stimulated by different techniques and geometry principles of fibers braiding. On the other part, in basic fiber assemblies friction is achieved only by overlapping and diverse orientation of a great number of fibers.

Basic characteristics of textile materials have resulted directly from the fibers and their correlation. The basics characteristics are porosity, flexibility and great tension strength. Porosity of textile materials is caused by the space between the fibers and depends on their thickness or friction strength. Porosity means that textiles absorb sound, heat and water – they possess capillary properties. The resulting effect of porosity and capillary properties is that material can change its characteristics depending on the environment it finds itself in. Another significant characteristic relates to flexibility of materials and thus textiles can be folded in different directions depending on their assemblies and in its basic form textiles are formed only by gravity. Great tension strength is an essential characteristic which makes textiles suitable for reinforcement in composite materials.

Materialization of fibers

Materialization, namely the origin of fibers, to a great extent determines characteristics of textile materials. This is a segment in development of textiles which in terms of technology has advanced the most and represents the field for further innovations. The basic division of fibers relates to the natural and synthetic fibers which can yet be of organic and inorganic origin. The natural fibers of organic origin comprise wool and silk which are of animal origin, namely cotton and flax, of plant origin. Synthetic fibers of organic origin are nylon and PET whereas those of inorganic origin are silicone and glass fibers. The key innovations in development of fiber materialization concern the synthetic fibers, where the period of accelerated development has been marked by the appearance of nylon in the 1930s and was rounded up by the appearance of Kevlar in the 1970s.

It is often that in textile industry natural and synthetic fibers are combined in order to achieve certain characteristic of the material. The subject of further exploration are synthetic fibers which from the technological aspect possess many advantages: synthetic fibers may be produced (designed) with a designated intention according to the desired textile performances, with synthetic fibers it is possible to achieve an even cross section of the fibers which results in equal quality and mechanical characteristics in all parts of a certain textile.

The significant changes in textile industry occurred with the appearance of nylon in 1930. These changes significantly influenced the origination of the new textile fabrics whose fibers are synthetic polymers. Finally, after 30 years since their appearance, the explorations of the synthetic polymers fibers produced significant innovations which have made textile materials desirable even beyond the textile industry, and thus textile materials continued with their parallel development in various other industries. The new synthetic fibers, better known as High performance fibers have offered new textiles of desirable mechanical characteristics. Carbon fibers (1969) and Aramid fibers or Kevlar (1968).

THE TENDENCIES IN FIBER MATERIALIZATION: MATERIAL HYBRIDIZATION

If the innovations in the field of synthetic fibers from the 1970s, first of all the discovery of carbon and aramid fibers, made textiles interesting outside textile industry and initiated their further development on various levels, what are the current tendencies in textile development?

The significant factor in the development is the collaboration between textile engineers and designers, namely hybridization of creative industry and production. The architects and designers, besides pure application of material, influence to a great extent the transformation of textile processes and products. The collaboration between designers and scientist is the concept of the research project named *Nobel Textiles.* That project, besides leading textile and fashion designers, has included also five scientists with an aim to produce a concept based on scientific discovery.[10]

Several exhibitions and seminars strived to place the innovative textile materials within the context of creating new spatial environments. Matilda McQuaid is a curator of the first exhibition under the name *Extreme textiles: designing for high performance* held in New York in 2005., after which there followed a series of seminars and individual explorations related to the collaboration of textile engineers and architects. The purpose of this exhibition was to present a wide spectrum of fields in which textiles are used as well as to inspire the new approaches in materialization of the living environment of textiles.

Hybrid textiles and nanotextiles

The development of hybrid materials consequentially results in textiles which present the combination of different fibers. From the initial combining of the natural and synthetic fibers, hybridization today relates to combining textile and nanotextile.[11]

Nano technology operates on molecular level and combines the principles of molecular chemistry and physics with engineering principles.[12] Most often the innovations relate to combining the fibers with ceramics and metal. Textiles whose fibers are on molecular level coated with ceramics may withstand high temperatures without deformations and effects on their mechanical properties. On the other part conductive textiles have been made in combination of carbon and silver fibers which enable the textile components to be integrated in computerized systems or to act as sensors.

The development of technologies such as conductive textiles, nanotechnology and biotechnology have enabled the development of textiles and getting closer to the group of smart materials. That which makes materials „smart“ is the possibility to alter their characteristics, the ability to exchange energy and possibility to exchange the substance, namely to absorb or collect gases or water.[13]

Interactive textiles

Interactive textiles originated by application of smart textile materials as mediators between the user and the environment. Philip Beesley in his work uses interactive textiles and calls them „transitional objects" between the user's personal felling about himself and the broader feeling of the surrounding space."[14] The similar role of textiles can be seen in the work of the architect and researcher Mette Ramsgard Thomsen, who in her work combines textiles with software, robotics and sensors. She uses conductive textiles which become integrated with digital information from the environment and as a result achieves the spaces which are in continuous interaction with the events in the environment. Textile is used for integration of impalpable information with tactile physical material.

A significant theme which this authoress opens up is consideration of the borderline between the machine and material: „The robot and the textile seem like a contradiction in terms – the robot standing for everything that is automated and mechanical, and the textile for sensual materiality. Can it be possible to reconcile the two?"[15] Through the two projects under the common name of *Robotic Membranes* the authoress explores the behavior of textiles and attempt to use the advanced textiles at the same time both as material and as technology. In *Robotic Membranes* the integrated conductive fibers such as steel threads and carbon fibers make the stream of information through the braided assembly possible, while at the same time using the flexible characteristics of textiles for obtaining physicals moves and reactions. The resulting membrane integrates the structural properties of the architectural membrane with varying information from the environment, and with one connection established and its control we can propose programmed and dynamic architecture. *Vivisection* is the first prototype of robotics membrane dating 2006 – it represents a „live"

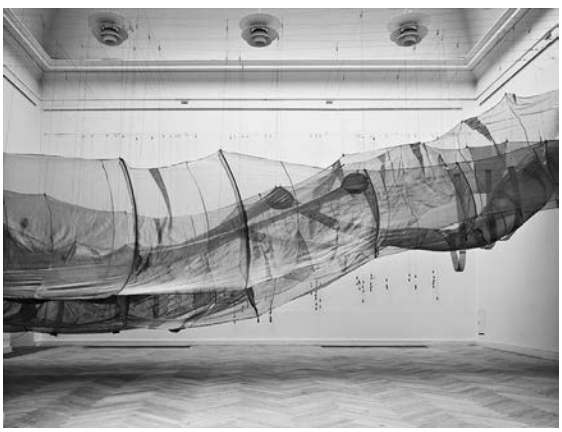


Figure 8. *Vivisection* (2006), Mette Ramsgard Thomsen

Figure 9. *Strange Metabolisms* (2007), Mette Ramsgard Thomsen

membrane which acts and reacts depending on space occupation. As a spatial experiment, this installation first of all explores the significance of integrating the possibilities for reception of the stimuli and reactions in tectonic surface (Figure 8). Another prototype, named *Strange Metabolisms* dating 2007., explores how a certain manner of weaving, namely the technique applied for achieving friction in the fabric, suggest and determine the character of movement or folding of the fabric, how weaving as the principle of achieving the structure and diverse fiber materializations may lead to the new formal language and behavior of material. The prototype combines synthetic and natural fibers such as silk, wool, plastics and steel. (Figure 9).[16]

Ecological textiles

Textile industry has been one of the biggest pollutants since the industrial revolution to date, and according to the analysts William McDonough and Michael Braungart, one half of the world waste waters may be associated with textiles manufacturing as majority of chemicals used for final treatment and textile dyeing is toxic.[17] In this segment of the paper the basic tendencies in development of textiles as environmentally proper material will be defined and the examples of innovative textiles belonging to this group will be mentioned. The effect upon the environment will be observed from the aspect of pollution and energy consumption during manufacturing process and the possibilities of material recycling.

The presumption that environmental propriety of a material may simply be associated with the origin of the material, i,e, with the natural material, is especially dangerous in textile materials. The use of natural fibers, first of all those of plant origin such as cotton, in its final form gives an impression of environmentally proper material, however, the very process of its manufacturing cannot be considered as environmentally valid – as only for cotton growing one fourth of the world pesticide production is used. The basic tendency in manufacturing environmentally proper materials is shifting the focus form the natural fibers to synthetic ones, another alternative is redesigning of the very process of manufacturing, namely the entire ecological cycle. The researcher Carole Collet provides several examples: *Bio Steel* is one of the examples where the achievements in biotechnologies were used for obtaining the new fibers through genetic modifications, the second example relates the *Fox Fibre* or *Tencel* – the fibers which were produced through controlled production process. In this way the issues of air pollution with pesticides have been overcome when growing cotton as well as waste waters from textile industries when dyeing textiles. In this case the textiles are naturally colored and cotton is grown in the controlled environment; the examples of fibers originating from food processing industry are *Soy Silk* fibers obtained by soya treatment; *Ingeo* textile fibers are the first fibers produced from yearly renewable resources.[18]

CONCLUSIVE CONSIDERATIONS

The development of textile materials in architecture is based on synchronized textile exploration on two levels: the first level relates to the very structure of material whereas the second level of the exploration concerns the architectural form as a result of implementation of textile materials. Throughout the history of architecture the development of textiles on two levels was actually the development and study of textiles in two scales. In Frederick Kiesler's design of the *Endless House* from 1958., textiles were studied on the level of the effects which the application of such material could have on architectural form. The design was presented through a mock model in large scale whose oval walls by bending and distortion define the „endless" space, namely the continuous space without clearly defined zones in which the walls do not divide the space into smaller sub-units but connect them. On the other part in Konrad Wachsmann's design, *Experimental Structural web* from 1953., textile was studied on the level of structure. Konrad's design and structural logics proposed fully represent the logics of the textile materials as fiber sets organized in an assembly by mutual braiding and torsion. That which is common for both designs, *Endless House and Experimental Structural web,* is that textiles were studied on the level of metaphors without a clear intention to use textiles as building material. However, the manners of textiles study on the level of spatial effect and structure, applied in these designs, define the framework of the exploration of textiles in architecture which is topical nowadays as well.

Technological development of textiles in the last two decades significantly made the field of material application broader. Textiles are integral parts of various disciplines which further generate and stimulate their development. The majority of technological innovations relate to the fibers materialization and to understanding textiles as fiber assemblies and the development and innovations on the level of fibers have contributed to adaptation and creation of desired textile performances. In the work of the architect and researcher Johan Bettum, one can see the complexity which this process of gradual development of material has in architectural discipline. Bettum's research is based also on studying textiles in two scales. The basis for understanding the textile potential lies in understanding the very structure of the material, namely the techniques of achieving friction between the fibers and the development of fibers materialization, whereas on the other part the desired effects and theoretical tendencies within architectural discipline direct the explorations towards the structure of material.

Textile materials do not represent one material but they present the platform for exploration of diverse fiber assemblies. The potential of textiles for architecture directly lies in this property of textiles as material system whose structure is based on the relationships among the fibers and not on the concrete selection of one material. The development of textiles since the emergence of nylon and carbon fibers has had an aim to make textiles more available and having more tensile strength as possible. The tendencies in textiles development in architecture can be described as material hybridization based on combining various fibers. From the initial combining of the natural and synthetic fibers, today hybridization relates to combining textiles and nanotextiles. The example for materials hybridizations are conductive textiles whose fibers may act as sensors which in combination with software makes these fibers „live" and textiles as interactive material.

The work of the architect and researcher Mette Ramsgard Thomsen characterizes on one part the exploration of architectural form as flexible textile structures, whereas on the other part erases the borderline between the material itself and the machine. In *Robotic Membranes* design the author uses conductive fibers such as steel threads and carbon fibers which enable textiles to become the surfaces through which the information stream from the environment. By using textiles at the same time as architectural membrane and the sensor for registering the changes in the environment, the author create a structure which is interactive and depends on the events taking place in that environment. The development of textiles in architecture form metaphor to robotic membranes represents a certain technological development but also simultaneously the development within the very architectural discipline. That which characterizes this development and gradual implementation of textiles in architectural discipline is that innovations on the level of fibers cannot be clearly separated from the innovations on the level of entire architectural strategy and theoretical tendencies in the given time and cultural context.

NOTES

1 See Mark Garcia, *AD Architextiles* Vol76 No6 (London:Wiley, 2006).

2 Detlef Mertins, "Glass Architecture" in *Modernity Unbound: Other Histories of Modernity* (London: AA Publications, 2011), p. 16

3 Beatriz Colomnia, "Friends of the Future: A conversation with Peter Smithson." October Vol 94 (2000): pp. 3-30.

4 Ibid. 2, p. 17

5 Ibid. 3, p. 24

6 See Frederick J. Kiesler, *Inside the Endless House* (New York: Simon and Schuster, 1966).

7 See „Textiles and Fibre-based Materials in Architectural Construction," http://www.digitalcrafting.dk.

8 See Johan Bettum, "The Material Geometry of Fibre – Reinforced Polymer Matrix Composites and Architectural Tectonics" (PhD diss., Oslo School of Architecture and Design, 2009), pp. 237-247.

9 Ibid., p. 215

10 Carole Collet, "The Next Textile Revolution" in *Responsive Textile Environments* (Canada: Tuns Press, 2007), pp. 14-25.

11 Ibid.

12 Philip J. Brown and Kate Stevens, *Nanofibres and Nanotechnology in Textiles* (Cambridge: The Textile Institute of Woodhead Publishing, 2007).

13 Axel Ritter, *Smart Materials* (Basel: Birkhauser, 2007).

14 Sarah Bonneimaison and Christine Macy, *Responsive Textile Environments* (Canada: Tuns Press, 2007), p.12

15 Mette R. Thomsen, "Robotic Membranes: Exploring a Textile Architecture of Behaviour" in *AD Protoarchitecture* Vol78 No4, (London: Wiley, 2008), p. 94

16 Ibid.

17 Ibid. 10, p. 17

18 Ibid.

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Figure 1. http://art-being.blogspot.com
Figure 2. http://art-being.blogspot.com
Figure 3. http://www.rndrd.com/, first published in *Architecture D'Aujourd'Hui* 91, September 1960:185
Figure 4. http://www.axxio.net
Figure 5. drawing by the authora
Figure 6. drawing by the author
Figure 7. drawing by the author
Figure 8. „CITA: Center for Information Technology and Architecture," http://cita.karch.dk/
Figure 9. „CITA: Center for Information Technology and Architecture," http://cita.karch.dk/