3 Paper in design and architecture. Typology

The whisper of paper is deep
and when our feelings are intensive,
that voice cannot be heard.

Mitsuhiro Ban, 'Handbook on the Art of Washi' [1]

§ 3.1 Introduction

Paper base products such as corrugated cardboard, paper tubes, honeycomb panels and strong papers like Kraft and Washi can be successfully used for the production of interior design, products for everyday use, furniture, indoor partitions, pavilions and bigger architectural structures. Paper and its derivatives are often used for other purposes such as educational (origami) or social and artistic events.

Moreover, paper and cardboard are cheap and eco-friendly materials. Therefore, are they fit to be used in spatial structures for a limited lifespan. Fairs, exhibitions, major sporting events and other short-term events cost an enormous amount of money, and in many cases leave behind an ecological burden in the form of construction waste.

In 2008, under the EU's revised Waste Framework Directive, a new target for recycling rates was established. By the year 2020 50% of municipal waste, including at least 50% of paper, metal, plastics and glass, will have to be recyclable, as well as 70% of demolition waste. [2]

The projects presented in this chapter are characterised by different size, geometry, materials and properties, as well as by different connections between these aspects. The projects were created by various designers, including the author of this thesis.

In this chapter, the typology of paper and cardboard in design and architecture is described and depicted by means of realised examples. Smaller projects of the first two

types are described below, in this chapter. For their part, more complicated structures, such as large pavilions, houses and public buildings, will be described in Chapter 4. Emergency and relief projects will be presented in Chapter 5.

§ 3.2 Typology

The history of paper spans almost 2,000 years in Eastern civilisations. It has been almost 500 years since paper was first used in Europe for architectural applications, in the form of wallpaper, which was probably invented in Persia. [3] Cardboard and paper have been used as a structural material for about 150 years, which allows us to make certain observations about the specific features of the projects that have been realised. Five functional categories can be distinguished with regard to the level of complexity, size, material composition, budget and lifespan of the projects:

- **Furniture, interior design, industrial design, arts and crafts and products for everyday use**. Generally these products can only be used for about five years.
- **Exhibition pavilions, scenography, objects for temporary events** such as trade fairs, exhibitions, major sporting events, etc. Such structures are built for temporary use of up to one year.
- **Houses and buildings used by private clients**. The lifespan of such buildings is estimated to be between twenty years and fifty years.
- **Public buildings** such as schools, universities, sport clubs and galleries. Such structures are built to last for twenty years or permanently.
- **Emergency and relief architecture**, intended for people who have lost their houses due to poverty, social exclusion, natural disasters and human-made disasters. The lifespan of such buildings is supposed to be five years, but in practice, many of them are used for a longer period of time.

The projects in the aforementioned categories can be realised in different sizes. The sizes of S, M, L, XL were established by means of conducted research on the projects of art, industrial design, interior design and architecture, realised in the twentieth and twenty-first centuries. The aim of size categorisation is to systematise knowledge

of design and architecture made out of paper and cardboard. The size categories not only reflect the physical size of the project (measured in square metres) but also the complexity of the structures, the budget required, the expenses associated and the process of design, research and implementation.

- **Small (S)** – this category encompasses projects with low complexity, composed of a small number of materials. This category involves projects such as furniture and interior design elements, indoor partitions and screens, industrial design and art compositions. Usually, these products, or their elements in case of modular compositions, have a floor area of less than 5m^2. Products from the Small-size category tend to be mass produced.

- **Medium (M)** – these are structures made out of cardboard, whose complexity level can be managed by a small design team, without any need for advice from a specialist in the field of construction and production. This category encompasses housing structures, major art installations, exhibition pavilions, etc. Such structures are mainly composed of cardboard elements and the other materials used for connections between the elements. Important factors are impregnation and connection with the gound. These projects generally have a floor area of approximately 5-50m^2. The structures can be erected without special equipment or special building equipment like cranes. Projects included in the Medium-size category can be produced in small series or as one-off structures.

- **Large (L)** – these are projects of high complexity – structures made out of prefabricated elements and components mounted on the building site. The buildings in this category have a size between 50 and 450m^2. They require a large financial outlay for material research, experiments and tests, building the prototypes and expert consulting. Their assembly requires specialised workers. Cardboard elements are connected by specially designed and produced joints and connectors. In such buildings, other materials are used in addition to cardboard. Generally, these materials are timber, steel, plastics and glass. These are one-off projects.

- **Extra-Large (XL)** – this category encompasses the most complicated projects in terms of complexity, building material composition, technology and production, research and the tests that must be conducted. They require a large financial outlay and special research on materials, durability, strength and experiments. Research and development involve various fields of science and industry. Projects in this category cover an area greater than 450m^2. They can be realised as one-off projects designed for special occasions, or alternatively, they can be designed to be disassembled and re-assembled in the future.

The time required for research and development, design, production and implementation varies depending on the complexity and size of the project.

§ 3.3 Furniture, interior and industrial design, arts and crafts and products for everyday use

This section presents furniture, interior and design projects, arts and crafts, and products for everyday use. The objects presented in this section fall into the Small-size category.

The oldest products in this category are screens made out of paper stretched on a timber lattice, produced in ancient China, Korea and Japan (see Fig.3.1). The oldest remaining references to such products are from the eighth century AD. [4] Aside from screens, typical products made out of paper include decorative origami compositions, kusudama (spherical origami objects containing aromatic substances), lamps (see Fig. 3.2), umbrellas or clothes made of woven threads produced from twisted stripes of washi paper (see Fig.3.3).

FIGURE 3.1 Traditional Japanese screen, produced in Kyoto, 2013

FIGURE 3.2 Traditional Japanese paper lamp, Kyoto, 2013

FIGURE 3.3 Traditional cloth made out of washi paper, Echizen, Japan, 2013

These days, in addition to packaging, decorations and paper art, products in this category tend to be furniture and elements of interior design, industrial products and cloth made out of paper or viscose (chemically processed cellulose). [5]

§ 3.3.1 Arts and crafts; interior design elements

The products presented below are the smallest products from the interior and industrial design category.

In 2008, Japanese fashion designer Issey Miyake designed a collection called 'Pleated Paper Dresses'. The premise for the collection was the conviction that in approximately fifty years, the only accessible fibre will be cellulose fibre. After several months' worth of research on different materials and their processing, the designer and his team presented a collection of dresses made out of packaging material which was formed and folded into the desired shapes (see Fig.3.4). Issey Miyake's fashion designs are characterised by great attention to details and modesty of form and material, as well as accents, which is typical for Japanese design. [6]

Another Japanese company, SIWA, produces everyday objects made out of specially processed washi paper. Naoto Fukasawa designs bags, phone and laptop cases, wallets, etc. made out of paper made up of wood cellulose fibres and polyolefin, in accordance with the tradition of *washi-suki* paper. The material is tear-resistant and watertight. The ONAO company, which produces the paper from which the objects are made, has more than one thousand years' experience of paper production. One characteristic ingredient of the products is *wabi-sabi*, a Japanese philosophy of aesthetics that finds beauty in imperfect and ephemeral objects and beings (see Fig. 3.5). [7]

As part of the scientific students' organisation Humanisation of the Urban Environment, Aleksandra Omiotek, Mikolaj Romanowicz, Joanna Zyłowska and the author of this thesis in 2011 created the UL Lamp for commercial spaces, pubs and restaurants. The lamp was created in accordance with the tenet of the organization, i.e., human-environment-friendly design. The lamp was made of two honeycomb panels core with a thickness of 30mm, which were formed while being soaked and next dried and impregnated with timber varnish (see Fig. 3.6). The shape of the lamp was created by several pairs of hands shaping the panels. Thanks to the cell structure of the material, the lamp glows with soft light.

FIGURE 3.4 Pleated paper dress, author Issey Miyake, 2008

FIGURE 3.5 Business card case made out of processed washi paper, SIWA

FIGURE 3.6 UL Lamp designed by Jerzy Latka, Aleksandra Omiotek, Mikolaj Romanowicz and Joanna Zylowska, 2012

§ 3.3.2 Furniture

Furniture makes up the largest group of paper-based products on the market. The projects presented here were chosen on the basis of the diversity of the materials used and their composition and characteristics.

The most popular pieces of furniture made of cardboard are the chairs from the Easy Edges series, especially Wiggle Side Chair (see Fig. 3.7), designed around 1970 by American architect Frank O. Gehry. The series of chairs and lounges was made out of corrugated cardboard profiles laminated to each other with alternation of the corrugation at an angle of 90°, in order to make the composition more stable. The sides of the chairs were protected by hardboard. The Easy Edges chairs became a great success, especially at a time when paper and cardboard were increasingly being edged out by lightweight plastics. However, Gehry decided to discontinue his furniture designs and to focus on architecture instead. Since 1986, the Swiss company VITRA has produced selected models of the Easy Edges series.

Another example of interior design created by a well-known architect is the Carta Collection designed by Japanese architect Shigeru Ban. The collection was initially designed in 1994 for the Miyake Design Studio Gallery in Shibuya, Tokyo. The collection was later expanded to include a chair, chaise longue, screen and table (see Fig. 3.8). The architect used impregnated paper tubes connected with timber elements. The pieces of furniture making up the Carta Collection are produced by Swiss company wb

form. [8, 9] Through his large number of projects from many categories and in many sizes, Shigeru Ban drew people's attention to paper and cardboard as a contemporary building material.

FIGURE 3.7 Wiggle Side Chair, Frank Gehry, 1972

FIGURE 3.8 Chair, Shigeru Ban, 1994

Apart from well-known architects, many other designers have tried to use paper and cardboard, especially recycled paper and cardboard, in order to create interior and industrial design products.

The American designer Zach Rotholz, an alumnus of the Faculty of Mechanical Engineering at Yale University and founder and CEO of Chairigami (the name is derived from 'chair' and 'origami'), designs and produces furniture composed of triple-wall corrugated cardboard. The material for his designs consists of 70% recycled fibres and 30% virgin fibres. Chairigami's collection includes chairs, tables and shelves. All its products consist of flat plates of cardboard which are folded by the customer. Their assembly does not require any additional materials, glue or joining elements (see Fig. 3.9). Chairgami's products are much more affordable than the pieces of furniture designed by the famous architects [10].

Australian company Karton Group [11] designs, produces and sells furniture made out of recycled cardboard. The company produces chairs, tables, shelves and beds, which can be folded into shape by users within five minutes. [12] The elements of the cardboard bed are pre-folded, then inserted into each other. Their ribbed structure is reminiscent of the lightweight structures used for the construction of aeroplanes. The carrying capacity of Karton's cardboard bed, made of mixed recycled and fresh fibres, is 2,000 kg (see Fig. 3.10).

Swiss architect and designer Nicola Stäubli created a non-profit line of furniture for children, intended to be built by the future users themselves. Free patterns can be downloaded from his website (www.foldschool.com) and used to cut the shape of the furniture, which can then be folded into the right form. The assembly of the furniture requires nothing but basic and readily available tools such as scissors, spray glue, cutting mats, etc. The concept of the foldschool is based on the sustainable play with recycled material. The original products were made out of 4mm corrugated cardboard (see Fig. 3.11). [13]

FIGURE 3.9 Lounge Chair, Zach Rotholz, 2011

FIGURE 3.10 The Paperpedic Bed, Karton Group

FIGURE 3.11 Foldschool, Nicola Stäubli, 2007

§ 3.3.3 Furniture by the Humanisation of the Urban Environment Design Team

This line of furniture made of paper-based materials was designed and produced by the author of this dissertation, in collaboration with students of the Humanisation of the Urban Environment Science Organisation from Wroclaw University of Science and Technology's Faculty of Architecture. The furniture was presented at the Home(less) ness exhibition at the Wroclaw Contemporary Museum in May 2012 (see Fig. 3.12). [14] The authors of the exhibited pieces were Jerzy Latka, Małgorzata Bienkowska, Mariusz Biernacki, Katarzyna Drapa, Anna Jakubinska, Aleksandra Omiotek, Karol

Madrecki, Alicja Sawicka, Justyna Sielska, Katarzyna Starzak, Mikołaj Romanowicz and Joanna Zyłowska.

FIGURE 3.12 Collection of chairs and lamps. Home(less)ness exhibition, Wroclaw Contemporary Museum, 2012

The materials used to construct the furniture were mostly corrugated cardboard, honeycomb panels and paper tubes. These products were combined with other materials, such as wood, metal and Plexiglas.

The MCT (Modern Christmas Tree) Lamp was made out of a paper tube with a length of 2000mm, diameter of 100mm and walls 4mm thick. Holes were drilled into the tube using differently-sized drills in order to allow the light from the bulbs or LED stripes placed inside the tube to shine outwards (see Fig. 3.13). The name of the lamp refers to the authors' idea that a pro-ecological material be used for lighting rather than a real Christmas tree that needs to be cut from the woods.

Another piece made out of paper tubes was the La-Ma Table. Connected tubes were put together and laminated in such a way that they would serve as a table while at the same time serving as a storage place for the paper cups used during the vernissage of the exhibition (see Fig. 3.14). Part of the table is covered with Plexiglas. The paper tubes used in the project were 70mm in diameter, and their walls were 4mm thick.

FIGURE 3.13 MCT Lamp and Muff Puff seats

FIGURE 3.14 La-Ma Table

The Muff Puff collection is a line of seats whose shape is reminiscent of muffins or cupcakes. The seats are made of paper tubes with a diameter of 470mm and wall thickness of 7mm produced by company Mawocores [15]. Cushions or poufs are placed at the top of the paper tube. The space inside the paper tube can be used for storage purposes (see Fig. 3.15). The same collection also contains a sofa that is a reference to a classical piece of design called the Marshmallow Sofa, designed in the 1950s by Irving Harper and George Nelson. [16] Unlike the original design, the parts of the Muff Puff Sofa (sliced paper tubes and cushions on the seat and at the back) were made out of recycled materials. The cushions are inserted into the sliced paper tubes. For this reason, the furniture can be customised colour-wise. The structure of the Muff Puff Sofa is made out of 72mm thick plywood and 3mm thick steel wire (see Fig. 3.16).

FIGURE 3.15 Muff Puff Seats

FIGURE 3.16 Muff Puff Seats

The Patchwork Armchair was made out of honeycomb panels with a thickness of 25mm and square cushions made out of recycled materials. The side case of the armchair can be used as a worktop and storage space for books, magazines or simply a cup of coffee. It also plays a structural role, enhancing the stability of the whole armchair (see Fig. 3.17).

The Rocking Chair Massager is a piece of furniture that combines paper tubes with timber. Horizontally placed paper tubes are attached to the sides of the chair, which are made of plywood. They serve as a seat, but at the same time they can be used as a shelf for books or newspapers, which can be reached from the back (see Fig. 3.18).

FIGURE 3.17 Patchwork Armchair

FIGURE 3.18 Rocking Chair Massager

Lounge L was an attempt to create a piece of furniture for temporary use. It consists of honeycomb panels that were inserted into one another by means of pre-cut slots. The Lounge was assembled within several seconds from elements taken from a box whose dimensions were 1.5x1.5m and which was 200mm thick. The idea behind the Lounge was to create a piece of furniture which can be easily stored and transported and quickly assembled and disassembled when necessary (see Fig. 3.19).

The exhibition also featured another seat made of honeycomb panels: Kart®on, a high-backed chair designed for a dining room. It was made of twenty honeycomb panels, each of which was 25mm thick. The panels were first cut into the desired shape, then laminated together (see Fig. 3.20).

FIGURE 3.19 Lounge L

FIGURE 3.20 Kart®on chair

§ 3.3.4 Work&Chill furniture

The participants of the 2017 Summer School of Architecture, Work&Chill, organised by the author of this thesis, were asked to draw up projects and later to build prototypes of multi-functional furniture made out of cardboard and other materials. The Summer School, organised at Wroclaw University of Science and Technology in association with TU Delft, was a course that went beyond the core of the curriculum at the two universities' Faculties of Architecture. During the Summer School, students were challenged to design and build multi-functional units that could serve as a place where people could relax, work and have meetings.

Open spaces, school corridors, universities, factories and other work places often lack social areas, where employees or students can meet, talk, relax or even work in groups or undertake other actions. Since we spend at least one-third of our lives in a work environment, we need spots that will turn this environment into something pleasant, close to its users, something that will make the workplace feel more like a home.

The theme of the 2017 Summer School of Architecture, 'Work&Chill', referred to innovative, mobile, usable, modular, comfortable and affordable solutions that will meet the demand for social spots in the workplace, thus making workplaces more homely and user-friendly.

Work&Chill refers to a spot where one can sit, lie, relax, talk with friends, work in groups or alone, study, read and engage in all the other activities that are expected in workplaces like offices, schools, universities and factories. Workshops were taught for 2.5 weeks, during which time 26 architecture students, supervised by Dr Marcel Bilow and Jerzy Latka, constructed five Work&Chill spots. Four groups used paper as the main building material, while one group mainly used timber. The projects realised during the workshops included the following:

Cardboard:ception (authors: Marcin Dudkowski, Monika Kalinowska, Piotr Panczyk, Natalia Rod and Agata Wycislok) is a project realised for Wroclaw Contemporary Museum. Cardboard:ception is a multi-functional installation, which was placed under the staircase in the Museum (see Fig. 3.21). The context posed some problems to the students. Wroclaw Contemporary Museum is situated in a former bunker and its functional lay-out is concentric, meaning that all the walls, corridors and rooms are curved. The project, in the form of a special grid, follows the wall's curvature and creates a cosy nook for book-crossing, reading and waiting. There are modular seats on cases next to the books, and the whole structure has empty spaces filled with cushions in which people can seat or lie.

FIGURE 3.21 Cardboard:ception

FIGURE 3.22 Landscape bench

Landscape Bench (authors: Gabriela Barlik, Bartlomiej Bienkiewicz, Jozefina Furmanczyk, Dominika Piecuch, Margareta Sztejkowska, Paulina Urbanik, Przemyslaw Wdowiak and Paula Werblicka) is a bench and seat inspired the landform with canyon. The product was made from layered honeycomb panels and finished with wood. It was designed to serve as a reception desk or space for relaxation and work in open spaces such as offices or library lobbies (see Fig. 3.22).

Work&Roll (authors: Szymon Ciupinski, Anna Domagala, Andrzej Kaczmarek and Paulina Lechowska) is a mobile, revolving module whose multi-functionality is achieved by rolling the module into a different position. This octagon-shaped piece of furniture has an empty interior in the form of soft and organic planes which, depending on the position, can serve as a lounge, seat with table or chair. Work&Roll can be used for both work and relaxation, in a dozen different positions. Paper makes up about 90% of the product. Thirty-two layers of honeycomb panels were laminated together and protected from the outside with plywood (see Figs. 3.23 and 3.24).

FIGURE 3.23 Work&Roll

FIGURE 3.24 Work&Roll – detail

§ 3.3.5 Space dividers and partition walls

Today there are many products on the market that function as interior partition walls, screens or space dividers. Many of these products are made of paper, cardboard and other materials, including textiles.

The prototype of Paper Miracle, a third-prize-winning competition project, was presented at the Home(less)ness exhibition at the Wroclaw Contemporary Museum. The competition challenge was to design a space for creative meetings within office spaces. The Paper Miracle was designed by the members of the Humanisation of the Urban Environment Scientific Organisation: Anna Jakubinska, Katarzyna Laskowska and Jerzy Latka. The aim of the design was to create a system consisting of one type of main module and one supportive module. By combining the modular elements together like 3D puzzles, the division of the space and room for creative activities was created. To get office workers' creative juices flowing, the employees were obliged to build the structure themselves, which could be done according to patterns and manuals provided, or in any way the employees themselves came up with (see Fig. 3.25). The other important factor was team work, which was required both in the visionary stage and at the execution stage. The modular elements were made out of honeycomb panels with a thickness of 30mm and dimensions of 450x450mm (main element) or 450x270mm (secondary element). The panels were made of recycled material and were able to be recycled after the lifespan of the piece of furniture. The proposed system was relatively cheap and therefore affordable to almost everyone. Because the modular elements were so cheap, they could be used in different ways. They could be covered in notes, painted and replaced. New parts could be built and existing structures could be expanded, thus creating simple furniture. The destruction of the elements could even get people's creative juices flowing (see Figs. 3.26-3.28).

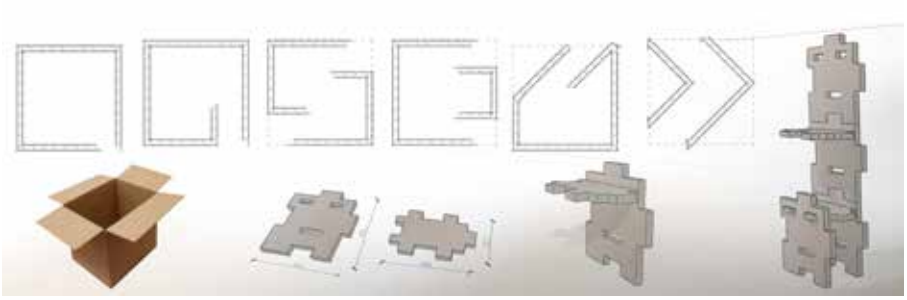

FIGURE 3.25 Paper Miracle – proposed patterns of the space and single modular elements, 2011

FIGURE 3.26 Creating Paper Miracle, 2011

FIGURE 3.27 Paper Miracle structure in the office space, 2011

FIGURE 3.28 Paper Miracle, 1:1 prototype exhibited at Wroclaw Contemporary Museum, 2011

Nomad System Room Dividers was created by American designers Jaimy Salm and Roger Allen. The company's room dividers consist of modular elements cut from corrugated cardboard. The material used is craft paper, 30% of whose fibres are recycled. Rounded rectangles with incisions can be covered with patterns or colors printed on their surface (see Fig. 3.29). Each of the modules has a dimension of 530x355mm and a thickness of 5mm. The demountable lightweight structure of the partition wall is assembled by inserting elements into the incisions of the adjacent elements. The Nomad System is produced by a company called MIO. Apart from the Nomad System, MIO offers a variety of products made of cardboard and paper, including partitions, acoustic tiles and decors. [17]

Bloxes is a concept that uses the art of folding flat cardboard into three-dimensional elements. The name of this cardboard-based modular system is derived from the combination of two words: 'block' and 'boxes'. The basic material is corrugated cardboard. Each folded module has a side dimension of 240mm. The project can be compared to Lego blocks. Each of the folded modules is shaped like a small cube with flaps which allow it to be connected to the next module (see Fig. 3.30). The Bloxes can be used to create partition walls and simple pieces of furniture like seats or tables. Bloxes were invented by American Jef Raskin in the late 19060s. In 2008 his son, Aza Raskin, patented the Bloxes. He is currently working on their development in association with Andrew Wilson. [18]

BIA Systeemwanden is a Dutch producer of prefabricated partition walls consisting of three layers. Depending on the model, the outer layers can be made of gypsum, Farmacell boards (a mixture of gypsum and cellulose fibres) or 4mm paperboard. The inner layer is made of corrugated cardboard which fills the gap between the outer layers in a zig-zag-like pattern. Due to the use of the corrugated cardboard infill, the lightweight partitions become more stable. The prefabricated elements are assembled on wooden slats and if necessary are caped form the top with a U-shaped bar. The two adjacent panels are held together by clips made of metal or cardboard (see Fig. 3.31). In order to make T-like or corner connections, BIA Systeemwanden created special

corner elements filled with honeycomb panels. BIA Systeemwanden can be used in both residential and commercial spaces. [19]

FIGURE 3.29 Nomad System Room Dividers, 2016

FIGURE 3.30 Bloxes – prototype from the 1960s

FIGURE 3.31 BIA Systeemwanden, 2015

The Canadian design company Molo created a line of elastic space dividers called the softwall + softblock modular system. The collection, designed by Stephanie Forsythe and Todd MacAllen, also includes seating (soft seating) and tables (a cantilevered table) (see Fig. 3.32). All the products have one thing in common: they are made of material that has a honeycomb-like structure, so it is elastic and can be stretched, shortened and formed according to one's own idea (see Fig. 3.33). Some of Molo's products are made of Kraft paper, 50% of whose material was recycled, with the remaining 50% being virgin cellulose fibres. The products are fire-retardant. However, after being used, they can still be recycled. The softwall in folded state has a thickness of 50mm, so it can be easily transported and stored. Once unfolded, the softwall can be extended several dozen times, to a length of 4.5m. The width of the softwall is 305mm. The maximum load on the 305mm softwall section is 15.5 kg. At the ends of the partitions there are panels with magnets, which can be used to attach the sections of the walls to the next module of the partition. Furthermore, the package contains hooks which can be mounted to an existing wall so that the folded softwall or softblock can be hung from them. The maximum height of the partition is 3m. Since 2008 the soft collection has been part of a permanent exhibition at the Museum of Modern Art in New York. [20-22]

FIGURE 3.32 softblock and softseating, molo, 2003

FIGURE 3.33 The honeycomb structure of the softwall, molo, 2003

Interior partitioning was one of the themes explored by the Cardboard in Architecture scientific design team, which was established at TU Delft's Faculty of Architecture and the Built Environment in the years 2003-2008. [23] One of the challenges faced by the members of the team was to create and research a system of partition walls made out of cardboard. Taco van Iersel and Elise van Dooren conducted the research and analyses of three types of partition walls made out of cardboard whose structure corresponded to that used in traditional building techniques. The technical specifications were influenced by three types of associated factors: legislation (fire-retardant cover, thermal insulation, acoustics), user demands (transportation, assembly and disassembly) and economics (the market). Having researched various commercially available forms of partition walls and building materials, the group distinguished three basic archetypes of internal partition systems:

– **Hollow wall system** – consists of posts and cross beams with plating (see Fig. 3.34). In this system, the cavity inside the wall can be used as a space for electrical wiring and acoustic and thermal insulation materials. In the solution proposed by the researchers, a wooden frame was covered with material used for the production of packaging for liquids such as Tetra Pack boxes. The packaging for liquids consists of layers of paperboard, polyethylene and aluminium. The air cavity was 20mm, creating air thermal insulation, and the aluminium in the packaging layer reflected heat from radiation. However, in order to achieve the same kinds of results as hollow wall systems currently available in the market, many layers of packaging material would need to be applied, which would result in additional work and high costs.

– **Stacking system** – which can be sub-divided into two types of systems: load-bearing (sand-lime blocks) and not load-bearing (i.e., aerated concrete). The alternative

solution the team came up with was cardboard bricks connected to each other and to the layer underneath by means of flaps and glue (see Fig. 3.35). This solution is a modern take on good old-fashioned masonry, but at the same time, it is much lighter and less durable. The main problem was the need for glue to connect the cardboard bricks, which significantly increased the time needed for construction.

– **Panel system** – consists of prefabricated wall panels which were connected to each other (see Fig. 3.36). This system is characterised by the limited time required to build it, the minimal number of actions required on the building site and high flexibility. However, there is a limiting factor, which is the weight of the panels. According to the Dutch building code, the maximum weight which can be carried by one person is 25 kg. The cardboard alternative to this system consisted of honeycomb panels with a liner made of paperboard. The profiled edges were H-shaped. The assembly process was dry, which means it did not require any adhesives. The panels could be recycled after demolition.

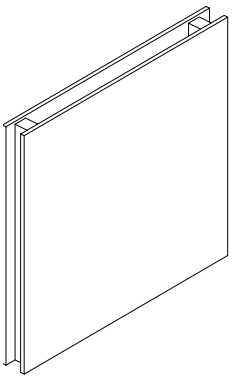

FIGURE 3.34 hollow partition system

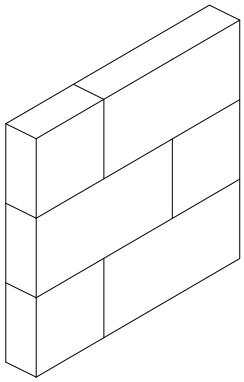

FIGURE 3.35 stacking partition system

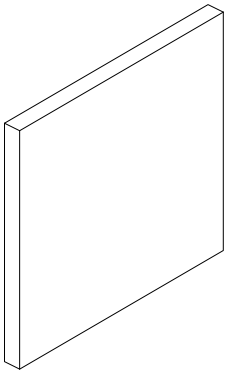

FIGURE 3.36 panel partition system

The scientists from TU Delft compared three types of material (cardboard, wood and sand limestone) used for the production of one metre square of partition wall with regard to environmental burdens, resources, amount of energy and water used for production, weight and potential for disassembly and recycling. Please find the results of the comparison below (see Tab.3.1):

SUBJECT	MATERIAL	POSITIVE → NEGATIVE
weight	cardboard	
	wood	
	sand-limestone	
exhaution	cardboard	
	wood	
	sand-limestone	
energy content	cardboard	
	wood	
	sand-limestone	
emissions	cardboard	
	wood	
	sand-limestone	
use of water	cardboard	
	wood	
	sand-limestone	
recycling	cardboard	
	wood	
	sand-limestone	
disassembly	cardboard	
	wood	
	sand-limestone	
waste	cardboard	
	wood	
	sand-limestone	

TABLE 3.1 Comparison of cardboard, wood and sand limestone in partitions per m²

The author of this thesis conducted further research comparing different types of partition walls as part of his doctoral research. The most popular type of partitioning in Poland was compared with a potential new product on the building market: cardboard panel walls. The wall was designed as a pre-fabricated partition wall consisting of several layers of honeycomb panels installed into a cardboard structural frame. Basic features such as assembly time, thickness, weight and price were compared (see Tab. 3.2). The values were then calculated for one square metre's worth of wall without any finishing layers.

WALL TYPE / FEATURE	CARDBOARD PANEL WALL	BRICK WALL (FULL CERAMIC BRICKS)	POROUS CONCRETE BLOCKS WITH LIME-CEMENT MORTAR (800) 150MM	SILKA CS BLOCKS	PLASTERBOARD WALL	GLASS BRICK WALL
Thickness	150mm	150mm	150mm	120mm	150mm	80mm
Weight	12-20 kg	220 kg	85-130 kg	195-225 kg	50-90 kg	70-90 kg
Acoustic insulation (Rw)	45 dB	46 dB	36 dB	50-56 dB	55 dB	38-45 dB
U-value (m^2K/W)	0.8 – 0.5	5.13	2.53	2.13	0.60-0.35	2.34-2.97
Fire resistance (minutes)	30	120	120	180	30-120	30-60
Connection type	Screws	Mortar	mortar	mortar	screws	Reinforcement, mortar or glue
Price* per m^2 (including work-load, exclusive of finishing)	PLN 90-120 (€21-28)	120-150 PLN (€28-35)	120-140 PLN (€28-33)	120-130 PLN (€28-30)	90-200 PLN (€21-47)	250-400 PLN (€58-93)

TABLE 3.2 Comparison of the cardboard panel wall with other traditional types of partitioning, per m^2

It can be observed that partitions made out of cardboard are lighter, cheaper and more quickly assembled. However, their acoustic insulation and fire resistance levels are lower. The price of traditional partitions were checked at the Polish building market in April 2017 by local research. The properties and price of cardboard partition walls were estimated based on available data (price per element, computer simulation for U-value, references to similar products with regard to acoustic insulation and fire resistance).

§ 3.3.6 Art and performance

Paper and cardboard are also used for artistic activities and performances. Founded in Russia in 2007, Cardboardia – a cardboard utopia, where the ideas and dreams of its creators are being realised by means of cardboard – is a socio-political manifesto as well as a cultural and artistic project, whose members have a *child's freedom* to express their needs, dreams and convictions. [24] Once a year, during the Cardboardia *materialisation* event, the imaginary state of Cardboardia with its cardboard cities is created (see Figs. 3.37 and 3.38). All residents, citizens and tourists can participate

in Cardboardian society. Every year the state is built from scratch. The cardboard utopia is a place where, according to the idea stated by its creator, Sergiej Korsakov, personal expression is celebrated. It is a project that connects international societies and allows their members to bring to life their ideas and artistic visions by using cheap and available material. The most active members of Cardboardia come from Russia, the USA, England and the Netherlands. The current population of Cardboard consists of tens of thousands of people. Cardboardia is also the biggest exporter of decorations, arts and crafts and furniture made out of cardboard, which can be purchased from its website. In July 2015, the Cardbordia event took place in Lublin, Poland. [6,11]

FIGURE 3.37 Mobile Embassy of Cardboardia in the city of Lublin, Poland, 2015

FIGURE 3.38 Cardboardia in the city of Lublin, Poland, 2015

§ 3.3.7 Production costs and market prices

One of the great advantages of cardboard as a material is its low cost of production, despite the high prices of some of the furniture created with it. Because its designer is a famous architect, and also because it is a high-quality product, Frank Gehry's Wiggle Chair costs €750, although the costs of the material do not exceed €20. Shigeru Ban's Lounge costs a whopping €900. On the other hand, Chairigami's Lounge Chair costs €95 and the Paperpedic bed produced by Karton Group costs €165 for a basic version and €450 for the whole bedroom furniture set.

The Paper Miracle proposed by the Humanisation of the Urban Environment group – a space for creative meetings in the office – costs €135 for a set dividing a room measuring 4x4m, with a height of 2.25m.

One package of Nomad System Room Dividers, which allow one to assemble a partition measuring 2.74mx0.9m, costs €53.5. The cheapest partition produced by BIA Systeemwanden, which consists of a gypsum liner and a corrugated cardboard core, costs €19.39 per square metre. The more exclusive softwall product costs €880 per segment. The aforementioned prices are correct of as year-end 2016.

The fact that some of the products are so expensive despite the fact that their materials and production are so cheap can be attributed to different marketing strategies and different target groups. While the products designed by Gehry and Ban are geared towards wealthy individuals, the products designed by Chairigami and Karton Group suit almost any budget. The Foldschool project is an open-source pattern that can be downloaded and used free of charge.

§ 3.4 Exhibition pavilions, stage sets, structures for temporary events

This category encompasses structures built for special occasions like exhibitions, trade fairs, festivals, major sporting events and other temporary events. Many structures built for such purposes only last a few weeks or months. After demolition they generate a lot of waste, especially when they are built out of traditional materials, such as concrete, steel or wood. Cardboard and paper-based materials can be used to construct the venues for such occasions, and after being used, such structures can be dismantled and the material can be recycled or utilised, resulting in a smaller burden on the environment than would be the case if traditional materials had been used. Sometimes these structures seem to be abandoned after the event. Naturally, not all structures can be built out of cardboard, but in some cases the use of recyclable materials can result in positive outcomes.

A good example of such a situation is the city of Sochi in southwest Russia, which hosted the 2014 Winter Olympics – the most expensive Olympic Games in history, which cost the Russian Federation about $50 billion. One year after the Olympics, this city with a population of 300,000 and with an incredible number of new and unfinished buildings, looked like a ghost town. [25, 26] The question will always remain how to manage places that were used intensively for a short period of time. It seems host cities often lack a strategy for the future. An example of the opposite is the Olympic Park in London, where after the 2012 Summer Olympics, the venues built in east London (historically the poorest part of the city) resulted in new public spaces for cultural and sporting events and for everyday activities. The discussion about the sense

of spending £9.3 billion on a temporary event like that is still ongoing. For instance, the former mayor of London, Ken Livingstone, characterised the investment as 'the only way to get billions of pounds out of the government to develop the East End'. [27] The case of London is a good example to follow, on the condition that such a venue is built next or within a big city or agglomeration and can serve later as a place for leisure and culture, filled with housing estates. However, many venues, not only for the Olympics but for all sorts of events, bring degradation and waste, unless they are designed and built in a way that allows the materials to be re-used or recycled. Such problems can be solved by using degradable materials, which can be recycled after the lifespan of the structures with minimal impact on the cultural landscape and the environment. An example of such a structure would have to be the Pappedern, i.e., small utility units, made out of cardboard, designed by 3h design for the 1972 Munich Olympics (see also Section 4.1: The history of paper in architecture).

The size of the structures included in this category can vary from Medium to Extra-Large, while their lifespan is several weeks or months; it rarely exceeds one year.

In general, the structures included in this category can be divided into two types: indoor and outdoor.

§ 3.4.1 Indoor pavilions, exhibitions, stage sets

Indoor pavilions are created from different paper-based materials, but mainly from corrugated cardboard, honeycomb panels and paper tubes. They are realised to serve as venues for different types of activities, e.g. fairs or exhibitions. Alternatively, they can be works of art.

In 2001 architect Daniel Libeskind was awarded the Hiroshima Peace Prize for his projects that promote international understanding and peace. Following the award ceremony, an exhibition entitled 'Four Utopias of the Six Stages of Existence' of the architect's works was opened in the Hiroshima Museum of Modern Art in July 2002. The exhibition presented four projects in the form of 1:5 scale models of the buildings and the author's drawings: the Felix Nussbaum House in Osnabrück, the Jewish Museum in Berlin, the Imperial War Museum North in Manchester, and the plans for his extension to the Denver Art Museum. Since the exhibition would later be moved to the ICC Museum in Tokyo, it was decided to create the exhibition in the form of a travelling show. In order to construct four mock-ups of the buildings, which were approximately 30m in plan and up to 10m high, 20mm honeycomb panels were used.

The honeycomb panels were connected to each other by means of cardboard angles glued and screwed to the honeycomb panels (see Fig. 3.39). [23, 28]

An example of an indoor art structure made of cardboard was the Rip Curl Canyon, an installation designed by Benjamin Ball and Gatson Nogues in 2006 for the Rice Gallery in Houston, USA. The installation consisted of 20,000 individually prepared components made of corrugated cardboard laminated into a wooden framework. It weighed approximately eight tonnes. The designers, who were inspired by Frank Gehry's Easy Edges furniture, expanded the knowledge of the material by means of parametric digital interface and by making full-scale mock-ups. Later they used industrially die-cut stripes of cardboard, which were then laminated together, and with the help of plywood armatures formed the three-dimensional shape of a cardboard canyon (see Fig. 3.40). The composition was a reference to the mythical Rip Curl Canyon, located in the western USA, where land and water collide. The structure, whose sizes were calculated in association with ARUP Los Angeles, was strong enough to support visitors climbing, snoozing and sliding down the installation. The Rip Curl Canyon was not the only cardboard art installation designed by the Ball-Nogues Studio. In the same year they also designed the Tiffany & Company Gehry Jewelry Launch, to mark the occasion on which Tiffany & Company launched Frank O. Gehry's jewellery line. This temporary structure was composed of 4,000 pieces of corrugated cardboard laminated together to form a human body, with display windows. The corrugated cardboard external wall was supported by 24 ottomans, also with organic shapes. Yet another project of the Ball-Nogues Studio was the Sculptural Cardboard Workspace, which fits into the furniture category. [6, 29]

FIGURE 3.39 Model of Denver Museum, Libeskind Studio, 2001

FIGURE 3.40 Rip Curl Canyon, Ball-Nogues Studio, 2006

In 2008 Shigeru Ban designed a Paper Tea House for Phillips de Pury & Company, an auction house in London. The structure, whose dimensions were 2x5.38x2.6m, consisted of square paper tubes laminated together to form the components of a house. The wall components were connected to each other by steel rods, and the

roof was made of folded paper. The floor and the furniture were also made of square paper tube, except for the table, which was made of honeycomb panels (see Fig. 3.41 and 3.42). As mentioned in the auctioneer's catalogue, the house was an *ephemeral building, a shelter for poetic feelings. It is also the "House of Emptiness," for it is free of all ornament, except for what little is necessary to satisfy the aesthetic aspiration of the moment. Finally, it is the "House of Asymmetry" in that it is destined for the cult of the incomplete, and some small detail is always left unfinished, so that it may be completed by the play of the imagination*. The estimated cost of the house was £40,000-60,000. [30, 31]

FIGURE 3.41 Paper Tea House, Shigeru Ban, 2013

FIGURE 3.42 Interior of the Paper Tea House, Shigeru Ban, 2013

In 2010, a team from Wroclaw University of Science and Technology's Humanisation of the Urban Environment scientific organisation designed and built a pavilion to mark the occasion of the 100th anniversary of the technical universities in the city of Wroclaw and the 65th anniversary of WUST. The pavilion, called 'Memory Mailbox', was designed and built by Michal Antos, Kamil Bocian, Jerzy Latka, Malgorzata Los and Anna Weber. The pavilion consisted of corrugated cardboard boxes and was shaped like a 5m long tunnel in which selected boxes were used as postboxes for alumni from different years of WUST's 65-year history (see Figs. 3.43, 3.44). Visiting alumni could use specially prepared stationery and write down their personal memories of their student days. The boxes were connected to each other without any additional material or glue, by inserting the flaps of folded boxes into the spaces between the flaps of adjacent boxes. Only at the bottom part of the ceiling of the pavilion staples were used to keep together the boxes next to it. The bottom boxes, which served as the foundation, were filled with weights. The pavilion was exhibited at one of the university buildings for about two weeks.

FIGURE 3.43 Memory Mailbox, Humanisation of the Urban Environment group, 2010

FIGURE 3.44 Memory Mailbox, Humanisation of the Urban Environment group – view from above, 2010

The Swiss artist and musician Zimoun creates 'architecturally-minded platforms of sound'. [32] In his art installations, cardboard boxes are used as both a dividing wall and the membranes of drums. By means of electrical engines and balls made of cotton or cork and attached to the engines, Zimoun creates spaces filled with rhythmic constructions that surround the audience (see Figs. 3.45-3.47). The balls driven by the engines rhythmically patter the boxes, but at different intervals. All the cardboard boxes are the same size, and all the engines are the same, as well, but the wires connecting the balls with the engines have different lengths and are attached at slightly different angles, which results in them each having their own rhythm. The internationally appreciated artist creates compositions that are reminiscent of natural constellations without imitating nature.

FIGURE 3.45 Zimoun's installation at Dutch Design Week, Eindhoven, 2014

FIGURE 3.46 Interior of Zimoun's installation, Eindhoven, 2014

FIGURE 3.47 Close on Zimoun's installation, Eindhoven, 2014

Founded in 2012, Austrian company Papertown realises stages, pavilions, trade stand, fair booths, furniture and art installations made out of cardboard (see Figs. 3.46 and 3.47). The company's portfolio contains over one hundred cardboard products and

structures to be used indoors. The projects are designed, transported, installed and maintained by the company itself.

Cardboard was a material of choice for the designers for several reasons: the material is light and easily shaped, which means that the finished objects can be easily changed if necessary. It is also cheap and will most probably remain cheap due to the increasing amount of recycled paper and cardboard. The production process is easy, especially when using machine-driven manufacturing methods. After preparation, elements can be easily transported and stored in the form of unfolded flat boards. The material can be painted and printed, and ongoing research conducted by the industry and scientific units is improving its qualities. Last but not least, cardboard is a sustainable material. The Papertown team mainly uses corrugated cardboard in its projects. Cardboard amounts to at least 90% of the materials used in the products, which makes the products eco-friendly. Eighty-five percent of the cardboard used is recycled and can be further processed after use. [33] Philipp Blume, the founder and CEO of Papertown, was honoured with an iF Design Award in the Interior Architecture/Exhibition Space Design category in 2016.

FIGURE 3.48 Cardboard Art House, Papertown, 2016

FIGURE 3.49 Konica Booth, Papertown, 2016

A group of TU Delft students under the supervision of Friso Gouwetor, Mark van Erk and the author of this thesis designed and built the Tree D Papervilion (see Fig. 3.50). The pavilion was the result of a Design Informatics course taught as part of the Building Technology curriculum at the Faculty of Architecture. Twenty-one students (Tim Neeskens, Eline de Vries, Marit de Groot, Rosanne Berkhout, Ákos Szabó, Bahareh Miri, Veerle van Es, Finn Dahlke, Dora Vancso, Jerry Pollux, Pim Buskermolen, Alex Kouwenhoven, Michael Cobb, Nikki Fung, Paul Johan van Berkel, Anne de Schepper, Tarik Alboustani, Alvaro Rodriguez Garcia, Congrui Zha, Antigoni Karaiskou and Lia Tramontini) divided into smaller sub-groups designed and developed the free form interactive info pavilion.

The Tree D Papervilion consisted of two elements. One was a paper tree, which was made out of paper tubes, connected to each other by means of 3D-printed joints. The joints were made out of translucent PLA (polylactide), which allowed the students to light the joints with LEDs from the inside. The wiring was connected to controllers that allowed users to change the intensity of the light. The second element was a bench made of honeycomb panels that was connected with a doubly-curved screen. The screen was made out of honeycomb panels 5cm thick. The panels were first stripped of their outer layers of paper, then placed onto a special mould, which enabled the creation of the double curvature. The new top and bottom layers of the paper were then laminated. The doubly-curved panels were connected to each other by means of specially designed flexible joints, made out of laser-cut plywood (see Fig.3.51). The Tree D Papervilion was built in Alicante, in association with Alicante University. A group of designers and students from Alicante University and York University in Canada then copied the Tree structure and further developed the lighting and robotic movement of the branches. In the end, both structures (one in Elche, Spain, and another in Toronto, Canada) were exhibited on 7 July 2017.

FIGURE 3.50 The Tree D Papervilion

FIGURE 3.51 The Tree D Papervilion, flexible connection between double-curved plates, 2017

In 2017 Marcel Bilow, Dina Cheliadina, Karolina Dyjach, Olga Gumienna, Ewa Hejducka and Jerzy Latka created a pavilion called the Paper Cave. The Paper Cave was a project designed for the exhibition pavilion for the 2017 European Paper Week. The Pavilion was 590cm long, 220cm wide and 250cm high. The Paper Cave consisted of 118 layered cardboard honeycomb panels (5cm thick) laminated into prefabricated components (see Fig. 3.52). The components' size allows them to be transported

(120x250x90cm). The components were easily put together, by screwing the bracing board to the wooden battens hidden in the structure.

The Paper Cave was designed in order to showcase a different and contradictory perception of paper. From the outside the pavilion had straight walls, in which layers of honeycomb panels alternated with translucent Plexiglas stripes illuminated with cold blue LED light. This exterior showed off the ordered structure of paper in the form of stacked cardboard sheets, while at the same time showing its plasticity. The Plexiglas stripes dimmed the light emitted by the LEDs that were installed in between the layers of honeycomb panels.

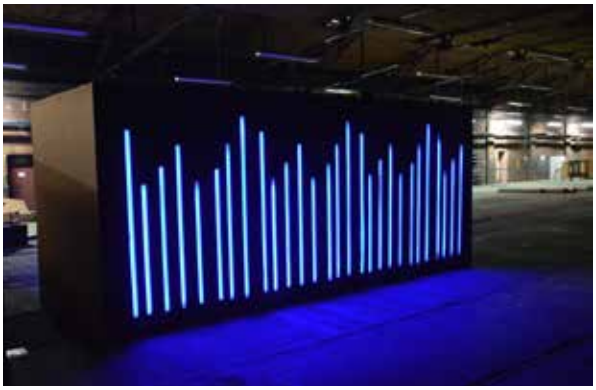

FIGURE 3.52 Paper Cave exhibition pavilion, archi-tektura.eu, 2017

FIGURE 3.53 Paper Cave interior lit by LED lights, 2017

The interior of the pavilion was an organic and chaotic space, even if it was made out of 10 repetitive elements. This interior of the structure was meant to remind visitors of the natural and organic origins of paper (see Fig. 3.53). Five special niches (width 70cm, depth 50cm and height 100cm) were incorporated into the interior, where five innovative paper products were displayed. The interior of the pavilion was illuminated by blue LED light. This cold light complemented and balanced out the warmth of the natural colour of the honeycomb panels. The tension thus created between the interior and exterior of the Paper Cave was a reference to the high technology involved in paper production and the low-tech and natural composition of paper.

§ 3.4.2 Outdoor pavilions

The main difference between indoor and outdoor installations made out of paper-based materials is the need to impregnate the latter against water and moisture. In addition, external climatic conditions like wind force have to be taken into account during the design process and calculations.

Students from the Department of Architecture at the University of Cambridge designed and built a Cardboard Banquette Pavilion in 2009. The pavilion was built to mark the start of a new term at the university. The structure was created by third-year students, who designed and built the pavilion. Its furniture was created by first-year students. The students were supervised by Tom Emerson, Ingrid Schröder, Max Beckenbauer and Rentaro Nishimura, a designer and specialist in architectural folding techniques. Fourteen students built the structure, which was based on a Yoshimura origami pattern and consisted entirely of corrugated cardboard. The folded plates were connected to each other by ropes. The pavilion was produced in three days and erected in several hours. It hosted eighty people during a party held on 23 October 2009 (see Figs. 3.54 and 3.55).

FIGURE 3.54 Cardboard Banquette Pavilion, Cambridge, 2009

FIGURE 3.55 interior of Cardboard Banquette Pavilion, Cambridge, 2009

Assistant professor Olivier Fritz, his assistant Tom Pawlofsky and students of the University of Liechtenstein built a 60m^2 Model-Making Pavilion in 2007. The pavilion was constructed from CNC-cut and machine-folded corrugated cardboard, covered with a PVC membrane. The curved pavilion was the result of computer-aided design and production research. Prof. Fritz and Tom Pawlofsky developed a new formwork

system for free forms. This patented system is made of corrugated cardboard and can replace mass-produced, expensive and labour-intensive available solutions. [6, 34]

Tom Pawlofsky supervised a group of students from the Master Advanced Study group at the Department of Computer-Aided Architectural Design (CAAD) at ETH Zurich in Switzerland. Michele Leidi, Min-Chieh Chen and Dominik Zausinger, with the help of Jeannette Kuo, designed and prefabricated a cardboard pavilion called Packed, which was then shipped to Shanghai and built. Packed, which was part of the final exhibition of Shanghai Expo, was exhibited at the '3D Paper Art' exhibition at the Shanghai Museum of Arts and Crafts and at Shanghai's Fudan University in October and November 2010. The pavilion consisted of 409 truncated cones. Each of the cones was made of 28 layers of corrugated cardboard which were cut and laminated with a computer-controlled machine (see Figs. 3.56 and 3.57). The radius of the cones was calculated in such a way as to allow the cones to fit into one another to reduce the amount of material needed and to decrease the volume for transportation. The cones touched each other in one tangent point and were connected to each other by means of zip ties. The bottom cones had thicker walls but were smaller in diameter than the top ones to ensure the most heavily loaded part was stable, and also to allow more light to enter through the lighter cones at the top. The cones were covered with shrink foil to protect them against the weather. Production took place at ETH in Switzerland and the prefabricated elements were then sent to China. [35, 36]

FIGURE 3.56 Packed: cardboard pavilion, Shanghai, 2010

FIGURE 3.57 Corrugated cardboard cones

Public Farm 1 was a submission to the Young Architects' Program of courtyard installations organised by the PS1 Contemporary Art Center in New York. The New-York-based WORK Architecture Company designed the Urban Farm, which was created from paper tubes normally used as a formwork for underground concrete pillars (see Fig. 3.58). Public Farm 1 was built in the courtyard of the PS1 Gallery in 2008. The farm had two hills meeting at the lowest point. The paper tubes were organised in a daisy-shaped arrangement and were used as pots for 51 species of herbs, fruits and

vegetables (see Fig.3.59). Six paper tubes were dedicated to one single species of plant, and the centre tube was used as a structural column or as picking station for harvesting the plants. Each of the structural columns had another function, as well, depending on the programme for the area. Some served as solar-powered juicers, periscopes or water-splashing columns, while others served as towel columns or solar phone-charging stations. Each paper tube had six wooden supports bolted to the cylinder from the inside, which provided structural stability and also held wooden discs. The discs were used as a base for the installation of the soil and plants. The paper tubes were impregnated, and the cut ends of the tubes were protected by steel rings. [6, 36]

FIGURE 3.58 Public Farm One, WORK AC, 2008

FIGURE 3.59 Public Farm One, view from above, WORK AC, 2008

In the words of its designers, the structure of Public Farm 1 was *Channeling the last utopian architectural projects about the City that examined its potential, represented its promises of liberation, and captured its pleasures — from Superstudio's Continuous Monument to Koolhaas's Exodus — Public Farm 1 (P.F.1) is an architectural and urban manifesto to engage play and reinvent our cities, and our world, once again*. [36]

The projects outlined in this section showcase the broad variety in temporary structures and compositions in which paper is used as a primary material. Regardless of whether the project was basic and small or rather a large pavilion or installation, cardboard and other paper-based materials were applied successfully. The projects realised indicate the high economical potential of using paper and cardboard in mass-produced elements for commercial applications. The fact that the material is recyclable and environment-friendly is one of the important factors in the market.

Other examples of cardboard structures for temporary use, such as the Japanese Pavilion for Expo 2000 in Hannover, the Apeldoorn Cardboard Theatre or the exhibition pavilion for Wroclaw University of Science and Technology realised by the author of this thesis are described in Chapter 4. The above examples were used to describe the range of possibilities and applications. The structures discussed in Chapter 4 will be categorised more specifically based on the structural system, connections between elements, impregnation methods and materials used, their connections with the ground, etc.

§ 3.5 Housing and buildings used by private clients

Contemporary architecture, or rather the contemporary world, is facing new and ever-changing challenges. Several of these challenges seem to be significant and will greatly affect future life conditions on earth.

The first issue is sustainable development, which may be understood as a physical development of a human environment, which should not cause harm to nature and our living environment, so that future generations will be able to use earth's resources as much as we do at present. But sustainable development means also an equal development of societies and their living conditions.

The condition of contemporary humans seems to be more and more unstable. People increasingly live in urbanised spaces. More than 54% of the world's population lives in cities [37]. Humans have become an element of a dynamically changing social and legal systems. The contemporary era, also called 'liquid modernity', was described by sociologist and philosopher Zygmunt Bauman as a modern time in which we are no longer connected to the places or concrete activities that were characteristic of the generations that preceded us. [38] Our traditional understanding of countries and nations has been replaced by international connections and social networks. Bauman shows that people are more connected to, say, international companies than to nation states. Humanity is in constant flux, and thanks to electronic media, where everyone can be a receiver as well as a provider of information, the traditional structure of society has changed completely. Humans have always believed in some perfect world with its own order. Several attempts have been made to create one – nearly always in vain.

Ever since Thomas More first described it, Utopia, being a better place to live in, has always been connected with an actual place. The name *Utopia* is derived from the Greek

word topos, meaning *place*. In the sedentary stage of modernity, space and power were linked. Power was always related to a certain territory that was held by a powerful person or family. This territory was ruled, either by a royal family or by a government. As Bauman said (2003): *In the transgressive imagination of 'liquid modernity' the place (physical or social) has been replaced by sequences of new beginnings*. [39]

Local governments and nations are becoming less important. Authority is now held by international corporations, whose homeland is economy, and therefore money, and which are not attached to any one place. Young people nowadays are increasingly likely to travel a lot and to move from one place to the next in order to gain new experiences or to find a satisfactory job. [40]

People no longer plan their entire life. They only plan few years ahead. Our need for space changes, too, over the years. Our lives can be divided into chapter of up to twenty years: childhood, adolescence, young adulthood, adulthood and retirement. Each of these stages comes with different spatial needs. People use their homes for a relatively short time before moving on to a different home. Homes are tailored to their inhabitants' individual needs. After a period of residence, houses should be processed, reconstructed, used again in a new configuration or recycled.

Bauman's observations on fluid modernity are reflected by Eurostat statistics on migration. In the year 2010, 5.1 million people migrated in the European Union, which means that in this one year 5.1 million people either emigrated from or immigrated to an EU country. By the year 2013, this number had increased to 6.2 million and in 2014 the number rose to 6.6 million. [41, 42] The year 2015 presented new challenges in terms of migration. This time the influx of immigrants and refugees from the Middle East and Africa was caused by the Arab Spring, which started in 2011. The International Organization for Migration said that a million immigrants and refugees came to the European Union in 2015. Globally, the number of immigrants and refugees reached 244 million in 2015, which was 74 million more than in to 2007. [37]

Researchers have predicted that the level of migration in the EU will continue to grow, given the current plans for cooperation and the fact that Eastern European countries like Macedonia, Montenegro and Serbia, which currently have candidate status, will likely join the EU, Furthermore, the EU initiated a programme of intensified cooperation called the Eastern Partnership (EaP) in 2009. The Eastern Partnership consists of six former Soviet countries, namely Ukraine, Belarus, Moldova, Azerbaijan, Armenia and Georgia. [43] This will probably result in more migration to the EU. Moreover, the EU will have to import foreign labour in response to various social challenges, in view of its ageing population, low birth rates and the prospects of its

social security system. [44] Furthermore, many immigrants are arriving from India and the Middle East. Most of these migrants are young twenty- or thirty-somethings.

As stated in Statistical Books of Eurostat:

Immigrants into EU Member States in 2013 were, on average, much younger than the population already resident in their country of destination. On 1 January 2014, the median age of the EU-28 population was 42 years. By contrast, the median age of immigrants to the EU-28 in 2013 was 28 years [41].

Economists and politicians have noted that today's young people are the first since World War II to start their independent lives in worse conditions than their parents. The lack of suitable housing and increasing unemployment in many European countries are resulting in frustration and confusion.

In this ever-changing reality, the humans less and less need a physical link to the territory or to the cultural codes that go with it. The *global village* lifestyle requires people to continually adapt to new, changing conditions and situations. Moving has never been so easy. Travel and a change of scenery, either because one needs a job or for training and education purposes, are becoming commonplace.

Therefore, it is reasonable to ask whether we still need houses built to last fifty to one hundred years, as previous generations did. The concept of a home has become more ephemeral. We hardly see multi-generational homes any more in which three generations of one family grew up.

The answer to the question asked above is a new generation of materials and structures. New solutions should involve sustainable, easily produced, low-cost materials with a limited lifespan which can be re-used, reset or recycled. Paper is such a sustainable, easily produced low-cost material with a limited lifespan.

Ozlem Ayan proved in her PhD dissertation that Swiss society, especially its younger citizens, would be willing to live in houses built to last ten to fifteen years if they were financially affordable and eco-friendly. [45] The project described in the work is called CATSE (Cardboard in Architectural Technology and Structural Engineering). Ayan and Pohl proposed a concept of Cardboard Housing in which a group conducted research together connecting architectural, social and structural approaches (described in a dissertation entitled *Strengthened Corrugated Paper Honeycomb for Application in Structural Elements* by Almut Pohl). [46]

Ayan describes in her dissertation the issue of high energy consumption in the Swiss building industry and increasing ecological awareness in society, which encouraged her to introduce a new sustainable and low-energy material to the market. Analyses of the lifecycle of cardboard, SWOT and PEST as well as a comprehensive questionnaire were used to position cardboard housing in the Swiss market. As Ayan noted in her dissertation, structural factors and a changing demography may affect the implementation of CATSE. In an ageing population, increased levels of immigration will decrease the median age of the population. CASTE is geared towards the lower age segment and may prove popular with first-time home buyers in Switzerland.

Ayan found that the three main themes that determined the adoption of CATSE in the building market were:

- **Cost**: the government can use its tax policy to give people an incentive to purchase eco-conscious homes.

- **Trends**: Swiss society is eco-conscious, it has introduced environmental construction standards. As Ayan mentioned: *By Minergie (*quality label for buildings that combines high comfort of living and low energy demand), *houses have an energy consumption which is 70% to 85% lower than the consumption of traditional houses built prior to 1970's or 50% lower of the standard of today's new buildings*. The CATSE houses are intended to stay on site for ten to fifteen years. Afterwards they will be reconstructed to meet new environmental and energy-efficient standards. Swiss houses that have the Minergie label tends to be 9% more expensive.
  According to Swiss Federal Office Statistics, more than two million of the country's seven million residents regularly move house. CASTE may make the move easier and may help people adjust their new homes so as to suit their changing spatial needs. As the family grows and grows smaller again.

- **Quality**:

  - Space
  - Easy access
  - Interior services and hygiene
  - Interior environment and health
  - Safety
  - Neighbourhood
  - Architectural expression
  - Technical aspects of construction

A survey of two hundred respondents measured Swiss people's level of acceptance of cardboard houses. Ayan stated two reasons that have brought attention:

- **Unconventionally short lifespan** (ten to fifteen years)
- **Cardboard as a building material**

The survey provided information on the following matters:

- **Relocation**: 80% of respondents moved house at least once in their lives; 1% moved house more than eight times; 30% moved house five to seven times; 40% moved house two to four times.

- **Consumer preferences** in new dwellings (independent categories and CATSE-related).

- **Negative experiences** with new dwellings.

- **Associations with cardboard as a building material**. Positive associations 17%: universal, modular, disposable, easy installation, good insulation, strong, stable, useful, creative, environmentally friendly, foldable, light, efficient, flexible. Negative associations 11%: flimsy, temporary, unstable, strange smell, glue, useless when wet, humidity, buckling, noise, weak, ugly, flammable, uncomfortable to the touch.

- **Associations with cardboard buildings**: 47% structural problems, 49% structural integrity under bad weather conditions, problems related to joints, sealing and friction, stability in strong winds, overall security, 50% water/humidity, 10% durability. Personal comments: there is a stigma attached to cardboard, as it is a material used by homeless people.

- **Increasing the acceptance rate of cardboard buildings**: 32% require further scientific test results and proof that cardboard is stable, waterproof, fireproof and secure; 22% would accept cardboard buildings if they had a chance to experience a finished product at an exhibition fair; 27% had heard positive stories about experiences with cardboard houses from colleagues and friends; 10% had come across positive reports in the media; 2% felt commercial advertisements would be an effective way to persuade them.
  In the Swiss building industry, one-third of investments in the private sector and 55% of investments in the public sector can be attributed to attempts to upgrade Switzerland's ageing buildings. Since these high rates of renewal/refurbishing play a prominent role in the amount of construction work being carried out, and since

reports confirm that people are moving house more often, a system that requires reconstruction every ten to fifteen years may prove to be regarded as an advantage. The CATSE model initially attracted interest from the government and private entities. The product needs to be trusted by the market.

With regard to the societal approach to cardboard housing Ayan concluded that development strategy for CATSE should follow three lines:

- Positioning of CATSE – Swiss people are highly conscious of the quality of their housing and are becoming increasingly environmentally conscious. Corrugated cardboard will satisfy the ecological and economic demands of cardboard housing. The short lifecycle of cardboard houses will not necessarily put users off, because the rate of refurbishment, renovation and removal in the Swiss building market is relatively high at present. In addition, renovation and refurbishment are quite expensive, meaning that people may welcome the opportunity to discard their houses after few years and move into a cheap new homes.
- Positioning of the Swiss construction industry, which is currently experiencing a boom.
- The trend of innovative environmentally friendly housing and its impact on cardboard housing.

Ayan and Pohl proposed a certain solution for a cardboard house, which was a corrugated honeycomb wall panel used both as a construction wall and as a partition wall. The proposal for the cardboard house involved various types constructed on the same spatial scheme. Unfortunately, the cardboard house was not built, so the research and thesis remain as a theoretical approach.

Actually realised examples of cardboard houses are presented in Chapter 4. They include projects like Shigeru Ban's Paper House (see Section 4.3.3) and the mass-produceable Wikkel House, which represents the private market of residential buildings (see Section 4.3.15).

§ 3.5.1 Paper houses for the elderly - unbilt

The author's own proposal for a paper house was a design prepared in cooperation with Prof. Zbigniew Bac from Wroclaw University of Science and Technology. The conceptual

project involving experimental houses for elderly people is scheduled to be built in near Zielona Gora city in Poland.

The project is an experimental housing estate which will consist of nine segments. Each individual segment will consist of two small ground-floor apartments (see Fig. 3.60). The segments will be able to be built independently in a multi-phase realisation process. The apartments, which measure 46m^2, will be located on either side of a pathway on a north-south axis. This arrangement will allow light to enter the houses from the south west and south east during the day. Bedrooms will receive light from the east or west, depending on the segment.

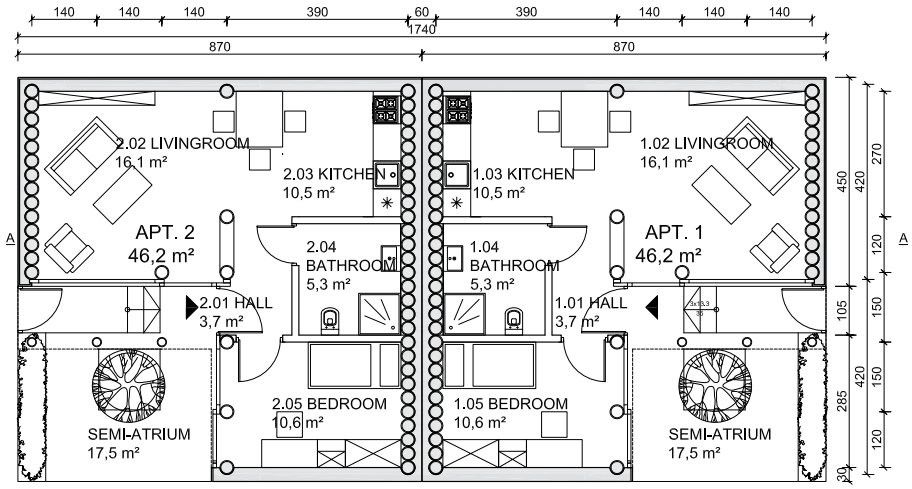

FIGURE 3.60 Houses for elderly people: cardboard segment, floor plan, 2012

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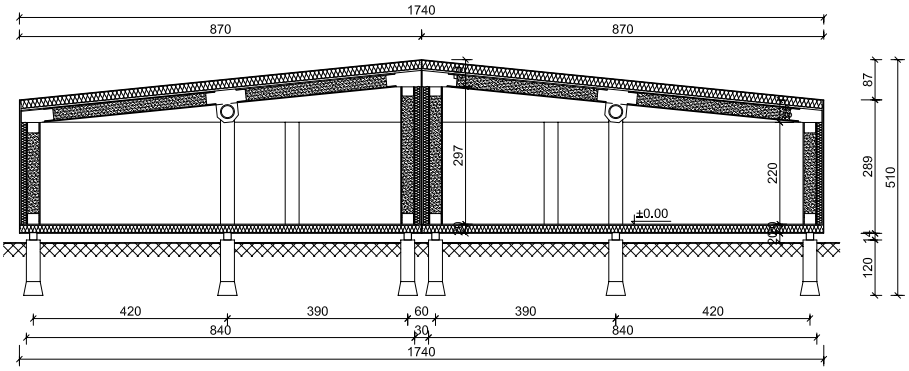

FIGURE 3.61 Houses for elderly people: cardboard segment, section A-A, 2012

Each apartment consists of:

- Entrance hall 3.7m^2
- Living room 16.1m^2
- Kitchen with dining room 10.5m^2
- Bathroom 5.3m^2
- Bedroom 10.6m^2

Furthermore, each apartment has an semi-atrium of 17.5m^2.

The rooms are lit by light entering through the semi-atrium, which also serves as a small garden and entrance area. The atrium can be reached from both the living room and the bedroom.

The building was designed as an experimental structure made out of cardboard components. Structural walls on the sides and in the middle of the building transfer the load from the roof. They were designed as rows of columns made of paper tubes whose diameter was 300mm and whose walls were 20mm thick. In order to improve their thermal insulation properties they were filled up with Styrofoam granulate. The paper tube walls were covered from the outside by an insulating layer made of the cellulose fibres (Warmcel Excel), and lightweight HPL (High Pressure Laminate) elevation panels or a mixture of straw and clay. The partition walls were designed as lightweight cardboard panels, framed and filled with acoustic insulation material. The paper tubes were connected to each other by wooden joints fastened by screws and bolts. In accordance with the 'light-touch-of-the-ground' idea, the foundations of the entire segment were made out of fourteen reinforced concrete pillars with dimensions of 30x30cm and a height of 100cm. The roof structure consisted of rows of paper tubes

connected to each other by means of spongy tape. The tubes were connected with the walls by means of wooden joints which were slid into the roof and wall tubes. The roof structure was supported in the middle by the horizontal paper tube beams lying on the load-bearing inner walls (see Fig.3.61). The paper tubes that formed the roof were covered from above with thermal insulation material and a metal finishing layer. The external walls, which did not transfer any loads, consisted of honeycomb panels covered from the outside with HPL panels or attached to the adjacent building.

The experimental paper house for an elderly person is part of a bigger project led by Prof. Zbigniew Bac, in association with the University of Zielona Gora and the Arka Foundation. Nine segments are scheduled to be constructed. Each of these segments will consist of two apartments based on the same layout. According to Prof. Bac, the idea is that each segment will be built using a different technology and different materials (bales of straw, wood, bricks, clay, etc.). [47]

§ 3.6 3.6. Public buildings

Public buildings which have been made of paper-based elements so far include schools, university buildings, sport clubs, galleries, meeting spaces, etc. These structures are built to last for twenty years. However, there are several examples of paper buildings that have been recognised as permanent structures, such as the Nemunoki Children's Art Museum by Shigeru Ban (see Section 4.3.6) or the Ring Pass Field Hockey Club by Nils Eekhout (see Section 4.3.12). On the other hand, there have also been some public buildings made out of paper with a lifespan of just a few weeks or months. The most common reason to use paper as a building material in public buildings is the desire to overcome structural or architectural boundaries by architects and engineers and the promising environment-friendliness of the material. However, the ecological issue is in many cases not yet improved and elaborated. A good example of such ecological motivations is a building owned by the Westborough Primary School, designed by Cottrell & Vermeulen Architecture and BuroHappold Engineering (see Section 4.3.8). The structure of the building is made out of cardboard and wood, but the foundations are concrete, and their weight makes up approximately 80% of the weight of the entire building. One would think that buildings made of paper, a material that can be cheaply mass-produced, would not cost very much. However, this is not the case with public buildings. As they are built only once and generally are spectacular in terms of structural or architectural solutions, tests and experiments have to be

conducted for almost every building. Therefore, it is common for revolutionary and innovative designs to be at least twice as expensive as traditional solutions.

§ 3.6.1 Bije(e)nkorf – unbuilt

Authors: Jerzy Latka, Julia Schonwalder
Year: 2017
Location: Dakpark, Rotterdam, the Netherlands
Area: 65.4m^2 (size: L)
Lifespan: Permanent (twenty-year lifespan)
Type: Public building

Bije(e)nkorf is the author's own proposition for a public building made out of prefabricated cardboard elements. Designed together with the engineer Julia Schonwalder, Bije(e)nkorf was a submission in an architectural contest for the social and meeting spot in Rotterdam's Dakpark. [48] The main structural elements were paper tubes and sandwich walls made out of honeycomb cardboard panels. The design also involved 10-feet shipping containers and a grid of timber pillars and laminated timber rafters.

FIGURE 3.62 Bije(e)nkorf, visualisation, 2017

Bije(e)nkorf is an innovative and pro-ecological solution for an innovative place: Dakpark, Rotterdam. Bije(e)nkorf is a place where the local community can get

together, work together and relax. The form of the pavilion reflects the waves of water, which is vital to the port city that is Rotterdam (see Figs. 3.62 and 3.66). The organic form of the pavilion fits into the context of the city's green roof. The pavilion is divided into several zones. There are two zones for outdoor activities; both the south and the north sides of the pavilion are covered by a canopy roof. The interior is divided into several functional units (see Fig. 3.63). A kiosk is located inside the building, next to the entrance. Next to that, the main sliding doors lead the way to the entrance to the pavilion. The door can be left open, so that the interior and exterior of the building can become one. The ground floor boasts an open-concept common room and kitchen with a floor area of 30m^2. The space can be adjusted depending on the user's needs and activities. There is also a separate area measuring 4m^2 for individual work (a flexible work spot). Behind the kitchen is a service room with storage space. All the pro-ecological installations are located in the service room. They include storage for grey water, photovoltaic batteries, etc. Furthermore, there is a composting toilet that can be accessed from the outside and a small storage shed for garden tools. On the second floor there is a meeting room, which simultaneously serves as a place where plants can be cultivated. On warm days, the glass panels of the meeting room can be opened, thus transforming the room into an open terrace located on the south side of the building. The second floor can be accessed by a staircase that is easy-going for both young and old people. An additional storage space can be found under the stairs.

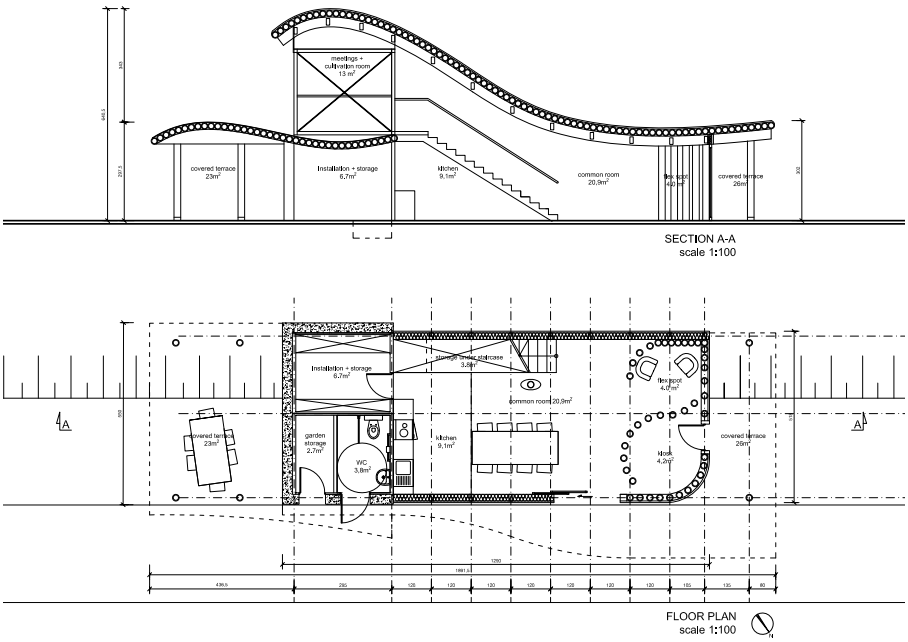

FIGURE 3.63 Bije(e)nkorf, section and floor plan, 2017

The Bije(e)nkorf was designed to serve as an innovative and eco-friendly pavilion (see Fig. 3.64). The structure of the southern part, which has two floors, is made out of four ten-foot shipping containers. One of them is already in use on the site and can be incorporated into the building. The walls of the ground floor of this part of the building are clad with bales of straw bales and clay. An *insect hotel* is installed in these organic walls. The upper part of the building is glazed and can be opened on warm days, on which it will serve as a south-facing terrace. Another part of the pavilion has a mixed timber-and-cardboard structure. Timber pillars and beams carry the roof, which consists of paper tubes impregnated against moisture and fire and also covered with PVC membrane. Water from the roof is collected at the back of the building and re-used as grey water in the kitchen and in the toilet. The wall panels with round windows are composed of paper honeycomb panels with high thermal insulation properties. The interior partitions are partly made of paper tubes, which determined the exact size of the kiosk and the flexible work spot. The material can be obtained from recycling and can be recycled afterwards.The estimated budget of the 65.4m^2 building was €100,000.

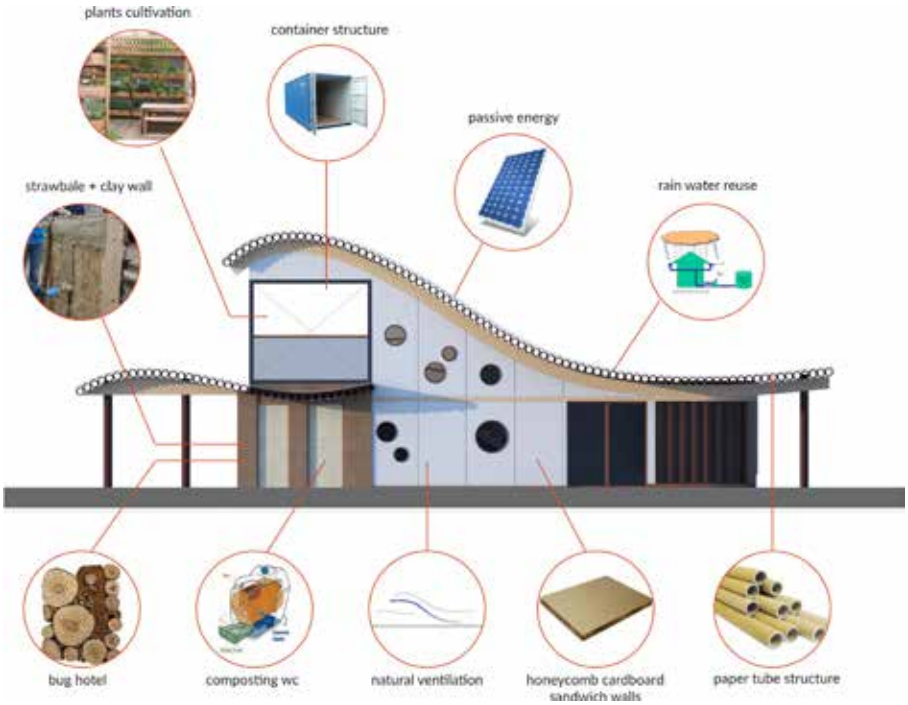

FIGURE 3.64 Bije(e)nkorf, section and floor plan, 2017

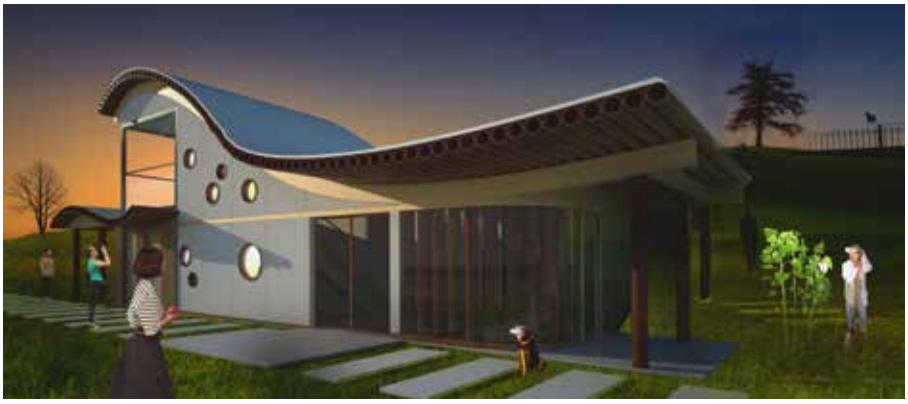

FIGURE 3.65 Bije(e)nkorf, visualisation, 2017

Selected public buildings made out of paper and actually realised are described in detail in Chapter 4: Paper structures. Case Studies.

§ 3.7 Emergency buildings

Emergency and relief buildings, intended for people who have lost their houses due to poverty, social exclusion, natural disasters or human-made disasters, are described in section 5.5 of the Chapters 5.

§ 3.8 Conclusions

Several aspects have to be taken into account when one uses a paper-based material The previously presented projects show that paper base materials can be successfully used for production of different types of design products and architectural structures.

There are five main functional categories, where paper is implemented as a main building material. Those are:

- Furniture, interior design, industrial design, arts and crafts and products for everyday use.
- Exhibition pavilions, scenography, objects for temporary events.
- Houses and building used by private customers.
- Public buildings.
- Emergency and relief architecture.

Those categories can be realized in four different scales (S, M, L and XL) which not only reflects to the physical size of the objects but also the complexity of the structure, the budged and expenses as well as the process of design, research and implementation.

Several aspects have to be taken into account when one uses a paper-based material for the production of interior and industrial design, arts and crafts, products for everyday use or temporary structures such as pavilions or exhibitions. These include the production process and processing of the material, as well as the need for harmonisation between cardboard and paper producers and designers, end product manufacturers and marketers, especially when series or mass production of the products is expected. Paper and cardboard definitely have pro-ecological connotations, especially when recycled material is used and the product can be recycled once more after its lifespan. For this reason, the popularity of paper and cardboard in furniture and interior design has increased since the late twentieth century. The most suitable

types of paper for use in furniture and interior design are Kraft packaging paper, paper tubes, corrugated cardboard, honeycomb panels and paper board. Another excellent option is Japanese washi paper. However, the latter is hand-made, therefore expensive. Paper-based materials' low resistance to moisture should be taken into consideration during the design and production processes. However, products to be used indoors are obviously less likely to be exposed to moisture. Another aspect that should be taken into consideration is the flammability and public perception of the material.

An important factor that affects the quality and price of a product is whether or not the design is valuable, as will often be the case with products created by famous designers. When this is not the case, the price of a product will only be a few times higher than the costs of the material and production. Furthermore, the product will be even cheaper if recycled material is used. In many cases paper and cardboard products are designed to be folded and assembled by the customer, and are distributed in flat packs. The characteristic factor of partitioning projects involving paper-based materials is their modularity and flexibility.

The products presented above, from the small-sized furniture, interior design, industrial design, arts and crafts and products for everyday use category are just a small part of the vast array of objects and buildings made of paper and cardboard. Bigger structures like pavilions, houses, public buildings and emergency architecture pose a completely different challenge in terms of research, design, production and implementation. The broad variety of implemented temporary structures presented in this chapter, prove that cardboard and other paper-based materials are suitable for small and large pavilions and installations. The presented projects indicate the high potential of using paper in mass-produced elements in commercial applications.

Looking at the dynamic of contemporary human and constant changes in spatial needs of one's house it is reasonable to ask whether the houses built for fifty to one hundred years are needed in the same extend as before. The concept of the a home has become more ephemeral. Therefore a new generation of materials and structures which are sustainable, easily produced, low-cost and can be re-used or re-cycled after the life-span of the building become a new market demands. Paper and its derivatives can fulfil this demands and become a complementary material to the traditional building materials existing on the market.

On the other hand buildings made out of paper-based elements require a vast research and development, which often results in high costs of the construction and time-consuming preparation works. Nevertheless the innovative approach and breakthroughs in science, design and architecture, even if requires large investments and extended research are the only way to achieve a development of the societies.

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