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Designing and prototyping of a novel textile-based 3D panel

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Abstract

The paper describes the designing and prototyping process of a novel textile-based building component, named *Textile Wall*, conceived to quickly erect walls and roofs with a protective purpose (humanitarian sheltering, flood protection, ballistic defense etc.), or simply to divide work and home spaces. *Textile Wall* is an innovative foldable cell panel, lightweight and freestanding, made of semi-rigid PVC foils and finishing textile layers. Stabilizing or insulating materials can fill its vertical cells.

The height and the dimension of cells, together with the membrane material (fabrics, mosquito netting, papers, composite fibers), can differ in relation to its final use and the expected durability. Man-portable with a small logistical footprint, the use of digital technologies allows tailing the production of the Textile Wall in various, flexible and modular configurations. It can be deployed rapidly, without any engineering support; the easy set-up will encourage local users to repair or rebuild homes in case of disaster, taking into account own constructive and social background.

The *Textile Wall* has been one of the results of the collaborative research project S(P)EEDKITS, founded from the European Union's 7th Framework Programme - Security Theme (2012-2016), in which research institutes, universities, companies operating in the emergency sector and non-profit organizations have rethought shelters, medical care resources and other facilities provided in case of natural disaster and conflict [1].

Keywords: Shelter design, Conceptual design, Performative design, Structural optimization, Product design, Cellular structure, Textile manufacturing, Subtractive manufacturing, Welding process

1. Introduction and objectives

In humanitarian field, shelter products are mainly developed as independent prefabricated system with a low level of flexibility and adaptability with other shelters and local materials. Prefabricated systems are designed *ad hoc* and their parts often require a long time-consuming assembling process. They also do not include instructions for further post-emergency uses or disposals. As result, abandoned temporary shelters become common, sad reminder of money and resources waste. Futhermore, non-Governmental Organizations (NGOs) are asked to develop specific answers for different climatic contexts, where semi-finished and adaptable components became preferable to closed standardized systems. Recent emergencies draw attention to limits of current standard tents to be adapted in all climates or in places with high daily-temperature ranges [2].

Moreover, a novel shelter product should not only link to climate conditions, but also relate to locally available material and to cultural identity of the affected population. The NGOs aim to reach as quickly as possible an acceptable post-disaster situation, rebuilding the economic and social life of the affected area (urban area, improvised camp, rural region etc.). By providing shelter kits that are adaptable to users, a people-centered approach can orientate the whole reconstruction process: this feature can improve the acceptance level of the whole sheltering process after a disaster [3].

Within S(P)EEDKITS, the research group of Textiles Hub at Politecnico di Milano (POLIMI) focused on the development of a few smart, progressive construction kits characterized by a high level of adaptability to local context and resources. This main requirement has been orienting the whole design process, looking for both the way of ensuring a prompt first-time repair, a quickly setup, and an effective medium and long-term protection, for instance allowing its reusability as a 'core' of a permanent dwelling. Its resilience to different contexts and service time should avoid the risk to provide a closed, standardized shelter-kit, not appreciated by affected people [4].

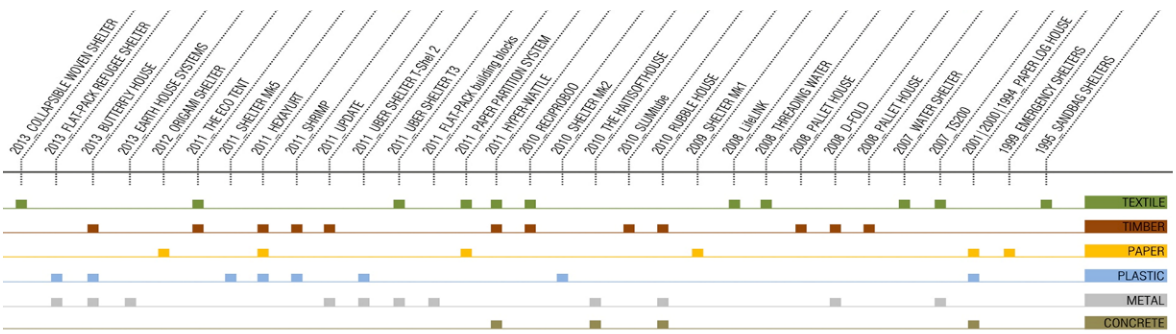
Following a time-based approach, the new concept of semi-finished panel was developed able to erect partitions that can be gradually implemented in durable walls. On the field, a self-stable textile panel could be unrolled and displaced for enclosing freeform, private spaces (e.g. in collective centers and sport halls). After an initial use as simple membrane partitions (with cell empty or partially filled for ballasting the base), panels can be gradually stuffed or used as formworks for concrete. For this aim, it could encourage local users to reuse panels to repair or rebuild homes, taking into account own constructive and social background. Panels should also work to construct raised basement or to cover flat or pitched roof, with cells used like air cavities or insulated.

In sheltering market sector, production cost of new product should maintain quite cheap for do not lose competitiveness. Cutting-edge technologies can fabricate tailored products, but the risk to increase cost is elevated. The research strategy was to extent the analysis to different textile manufacturing fields, with the aim to consider a large point of view for using technologies from other production chains. Resilience, cheapness, and lightness represented the main evaluation metrics for drawing up a preliminary State of the art (SOTA).

2. State of the art

A preliminary investigation focused on the most common construction technologies and materials used to build/repair massive walls in the emergency field (Fig. 2A). This analysis underlined that, in some rural areas, the use of formwork still depends from the availability of local timber, as it happens for erecting traditional rammed earth walls that are largely used in different desert zones. During the last decades, several academic researches and no-profit projects have been deployed different solutions for erecting insulated massive structures for the humanitarian field. The following ones represent two examples of previous researched focused on the theme of vernacular reconstruction:

- Cal-Earth Program (Cal-Earth Inc., Geltaftan Foundation, since 1991). The no-profit organization Cal-Earth has developed a largely used method to build shelters by using woven polypropylene sandbag filled with concrete or any inert material (Fig.2B).
- Rubble-House Project (SUPSI Polytechnic, Conscience International Inc., since 2011). The project has been developing home solutions made of metal gabions that are filled with debris recovered from the demolition of undamaged buildings (Fig. 2C).



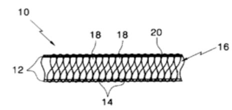
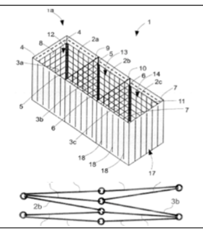
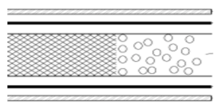
A

B

C

Figure 1: A. SOTA research matrix; columns collect case studies, while rows classifie them for material used; B. Sandbags used in Cal-Earth Program; C. Metal gabions of Rubble House Project [Source: Viscuso *et al.*, 2014]

After this preliminary investigation, an anteriority research drawn up the analysis of similar patented designs. The search focused not only on products used for sheltering purpose, but also on that ones developed in different market fields, such as logistics and retail. Table 1 collects few examples of examined patents.

Id. Num.	Patent Code	Patent Name	Patent Assignee	Author / Inventor	Status	Picture	Description
01	KR20010081471	Sandwich panel	HUN KUK FIBER GLASS	CHO SE HYEON CHO YONG JUN	Lapsed (from 2000-02-15 to 2009-08-29)	 Materials: two-dimensional fabric layers (12) connected together with a three-dimensional fabric layer (14) that is impregnated and hardened with high molecular resin.	Sandwich panel suitable to: (i) reduce the weight; (ii) improve the acoustic absorption property and the heat shield property; (iii) increase the mechanical strength.
02	WO201154638	Material for lightweight construction elements made of a multi-wall woven fabric filled with foam	WIRTZ CHRISTIAN WIRTZ MARKUS	WIRTZ CHRISTIAN WIRTZ MARKUS	Lapsed (from 2010-10-13 to 2012-12-12)		3D woven fabric filled with expanded thermoplastic polymeric material – polyurethane (PUR) or polyisocyanurate (PIR)
03	WO2010/029349 A2	Sight screen	HESCO BASTION LTD.	JAMES HESELDEN	Granted (from 2010-03-18)		A foldable gabion comprising opposed sidewalls connected together at spaced intervals by a plurality of partition walls. One or more surfaces of said gabion further comprises material to prevent a line of viewing there through and allow the passage of air.
04	KR20070040315	Sandwich Panel	HANWHA L & C	HUR CHURL KIM NAM HYEONG LEE JAE SUB	Granted (from 2006-10-10 to 2026-10-10)		Sandwich panel formed with two layers of thermoplastic PP fibers on the upper and the lower sides of a glass fiber mat.

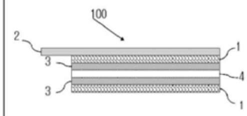
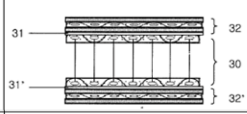
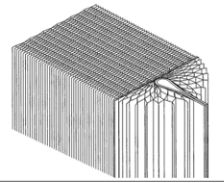
Id. Num.	Patent Code	Patent Name	Patent Assignee	Author / Inventor	Status	Picture	Description
05	KR100707336	A heating insulating materials using a weaving cloth glass and metal fiber	YOON GAB HO	YOON GAB HO	Granted (from 2006-09-22 to 2026-09-22)		The heat insulating material (100) is composed of a glass non-woven fabric (3) and glass insulating materials (4) embedded in a sandwich form; a cloth (2) coated with silicon at the outer side; and a glass/metal fiber woven cloth (1) formed by integrally weaving glass fibers and metal yarns with inserting one metal yarn into a piece of glass fiber, and inserted in a layer form.
06	KR20060062086	Method of manufacturing double-wall tarpaulin product and tarpaulin product by the same with textile coating structure	LG CHEM	NAM YOUN WOO YOON CHAN OH	Granted (from 2004-12-03 to 2024-12-03)		The double-wall tarpaulin manufacturing method comprises the steps of: (i) applying adhesive (31) to one side of a tarpaulin sheet (32); (ii) combining the coated tarpaulin sheet with a spaced fabric (30) to form a laminate;
07	WO 2010072003 A1	Flexible furniture system	MOLO DESIGN	TODD P. MACALLEN STEPHANIE J. FORSYTHE	Granted (from 2010-07-01)		Flexible furniture material having a core formed from a plurality of laminar panels of a flaccid material joined together in honeycomb cell structure.

Table 1: Anteriority research sample [Source: Viscuso, Zanelli, 2015]

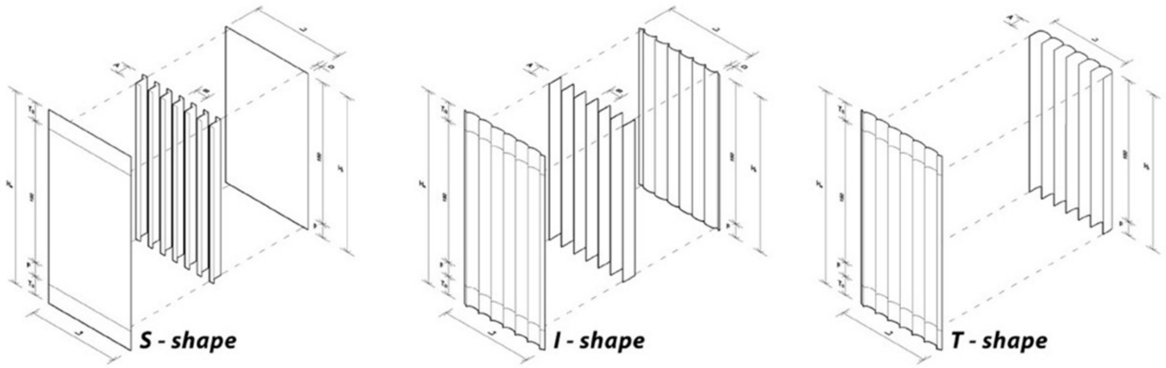
3. Concept design

The idea to develop a fillable, flexible panel (called Textile Wall) was conceived during the research activities of S(P)EEDKITS, dealing with the rapid deployment of shelter materials and facilities. The objective was the development of solutions able to speed-up the NGOs response just after disasters. The fillable panel needed to be durable enough to be used by affected population during the first repair and reconstruction.

In order to respond to the above requirements, the *Textile Wall* should represent the main structural element for do not need to provide on-site additional heavy material. For this purpose, it needed a manufacturing method that optimizes the anisotropic behavior of the final product without using expensive solutions. In construction field, high-strength textiles can work as effective textile formworks with different permeability, interlacement structure and loadbearing capabilities, but in the humanitarian chain the use of fiber-reinforced materials greatly overcome the prices of competitor products.

To avoid the development of a complex construction process, the concept generation took into account the quick-installation as unavoidable first requirement. Once arrived on site, cylindrical packaging tanks can also work as foundations useful not only to fix textile panels in each wall corner, but also to build a raised floorboard. One or two wall-kits permit to develop diverse transitional shelter layouts with footprint area between 17.5 and 35 sm; walls are set up starting from two 15 m-length textile panels, while the roof is obtained with a stretchable membrane that adapts itself to the chosen layout (Fig. 2B). In order to check the real flexibility of the proof of concept with the local constructions of last affected areas (Haiti, Syria etc.), the novel textile panels were thought and rendered into real emergency contexts, where NGOs have been erecting transitional shelter-structures and durable partitions in unfinished buildings or collective centres (Fig. 2C, 2D, 2E).

Starting from several concepts made with PES/PVC fabrics (350-450 g/sm, 1100dtex), who were based on diverse procedures of welding fabrication of tridimensional panels several with internal cavities (‘S shape’, ‘T shape’, ‘I-shape’), POLIMI research group selected 8 of them, with different thickness and cells dimensions (Fig. 2A). The aim was to fabricate and testing panels with the support of the other research partners, such as the International Federation of Red Cross (IFRC) and SIOEN Industries NV. For each proof of concept, POLIMI perfected a welding plan which would be replayed by an industrial process [5].



A

B

C

D

E

Figure 2: A. Concept generation based on the welding process optimization; B. Saharan context; C. Syrian slum; D. Unfinished building; E. Collective center [Source: Source: Viscuso, Zanelli, 2015]

4. Experimental tests

On October 2013, SIOEN fabricated 12mt-lenght prototype of T-shape *Textile Wall* with thickness of 20 cm and height of 150 cm. The roll was shipped in the refugee camp of Sanioniogo (Burkina Faso). From the 3rd to the 10th November IFRC and POLIMI set up the wall under a tensioned roof (developed by VUB University of Bruxelles), with the support of Lux Red Cross and Burkina Red Cross (Fig. 3A). In that case, due to the dry environment (and soil) it was not possible either to prepare trenches or to collect a large amount of filling material. Therefore, it was not possible to fill the panel without inserting structural elements into its small cells.

After positioning the Textile wall along a covered area of 15 sm, locally available dried eucalyptus poles were used to prepare two frames made with horizontal and verticals elements crossing each other every 1mt approx. Connections were fixed with ropes. This first prototype erected in Sanioniogo has been shown during the MILIPOL, the annual exhibition about safety and risks, held in Paris from 17th to 20th November 2013, achieving a good evaluation from NGOs and field operators.

In parallel with the welding approach, the research partner SIOEN also proposed to prototype two additional manufacturing strategies: the 'Foam concept', made of a foam board between two external PES/PVC layers by means of glue, and the 'Weaving concept', fabricated with a PES 3D fabric coated on external sides with PVC. Results of second test phase (Milan, 7rd-10th May 2014, Fig. 3B, 3C) scored that the Weaving concept was not self-stable and difficult to tension. Moreover the panel was hard to install and easy to break by means of poles or filling material. The huge volume of the Foam Concept when packed and its weight and cost made this solution not applicable in humanitarian logistics. Otherwise, the tests verified the joining stripes of Welding Concept could stiffen the wall itself, when it was positioned in a symmetrical way on both eternal sides of the panel (I-shape).

The I-shape concept's welding stripes can support connections between panels without damaging textiles (e.g. connecting panels by means of clamps), or they can also stiffen the wall with lightweight aluminum or plastic profiles inserted along welds. Besides providing external rigid elements to increase the rigidity of the wall, it was also designed the feasibility of a textile panel already provided with lightweight, stiff elements that facilitate the filling process and reinforce the panel one filled. In the 'I-structural shape', thin PVC foils can be directly welded with external fabrics by using hi-frequency or thermal welding machines [5].

Figure 3: A. Field test in Sanioniogo, Nov. 2013; B. Wall layout in experimental test, Milan, May 2014; C. Filling process tested in Milan, May 2014 [Source: Viscuso *et al.*, 2014]

5. Product prototyping

After tested the diverse welding plans for fabricating the designed concept, the research focused on finding an already-existing production line that could be useful for quickly fabricating the most effective concept (I-shape). Thermal machines gave a useful contribute not only to join textiles, but also to create an 'accordion' type (Fig. 4A). Parallel, welded pleats could perform the final product with an anisotropic behavior, thus more structured in vertical direction. The accordion path was also strategic for the reduction of the packaging volume of final panels, which collapse along folds for the transportation. Current pleating machines are available in different working widths (also 3000-3500 mm-width rolls) and pleats depth (from 10 to 100 mm). They are particularly suitable to pleat fabrics, mosquito netting, papers, composite fibers and every kind of filters. They are commonly used for fabricating fabric bellows largely used for protecting machine tools in mechatronics (e.g. CNC pantographs).

Subtractive manufacturing, such as automated cutting on plotter, milling and water jet systems, realized plastic bars starting from large PVC foils with thickness between 2 and 8 mm (Fig. 4B). Numerical control was suitable to customize bar shapes and obtain diverse cross-section geometries (rectangular, trapezoidal etc.) in relation to the final use of panels. An algorithm - developed in Rhino Grasshopper - calculated the stress distribution in plastics and optimized the cutting pattern for do not compromise the stability of cells (Fig. 4D).

The production line ended with the thermal or high frequency welding process that combined two folded textile rolls with plastic bars (Fig. 4C). Pleats were connected with the long sides of plastics; moreover, the use of thermal bars allowed to join more plastic bar with textiles in only one welding step.

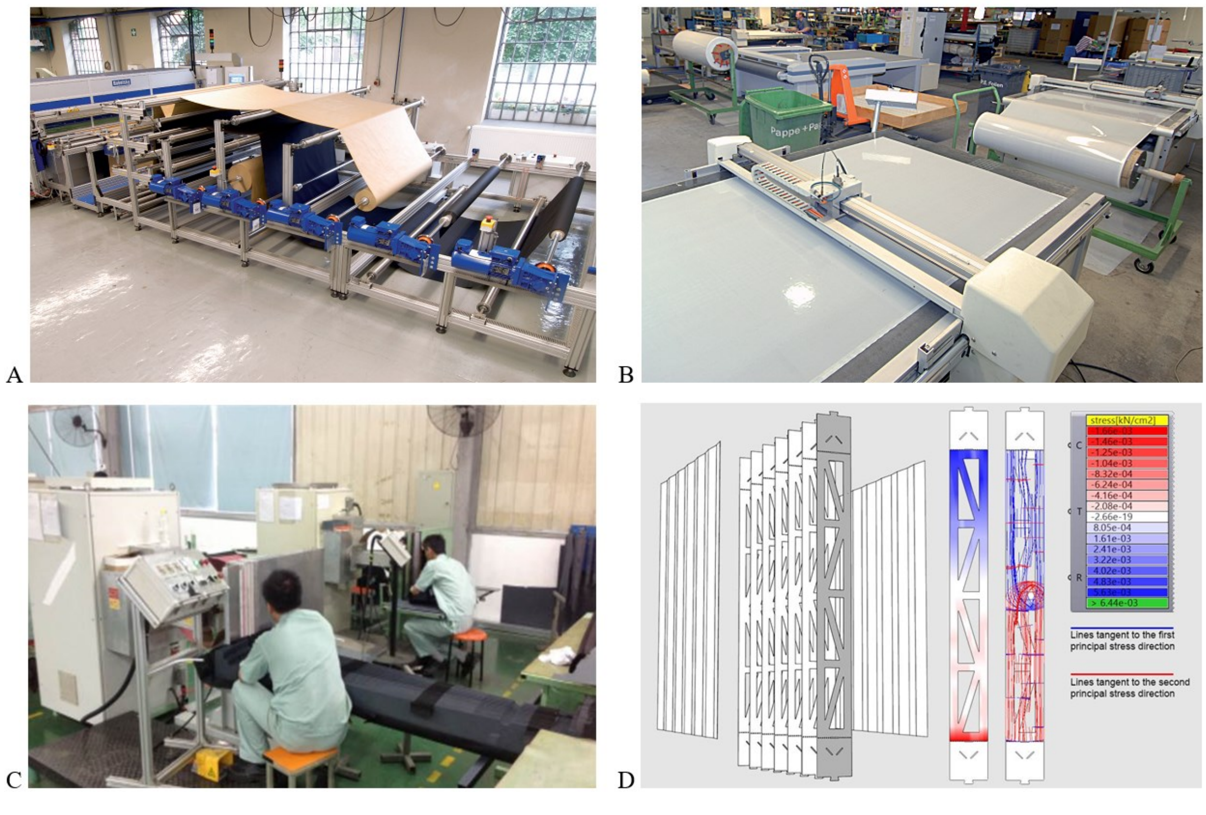


Figure 4: A. Pleating machine; B. Cutting centre; C. Welding process [Source: courtesy of MöllerWerke GmbH]; D. Principal stress map

In 2015, the POLIMI research group commissioned the production of the I-shape concept (Fig. 4C) to MöllerWerke GmbH, which is a MöllerGroup division operating in the field of machine tool construction. Their industrial plants are equipped with fully automated production lines that has been refined after numerous years of experience, especially in bellows production.

Fig. 5 explains the ease of use of this final solution. Panels are transported in the closed, pleated configuration. Firstly the bending of caps at the bottom of the semi-rigid foils and, conseguantely, the insertion of flaps on own related front incision are straining the external textiles and blocking cells in an opened configuration, thus structuring the base of the wall panel. Before closing the foldable upper cap with the same method, cells can be filled-in by a stabilizing or insulating material. The drawings also show how a straight vertical partition can change its configuration following a a curvilinear path by stretching membranes and fixing the base to the floor or the soil.

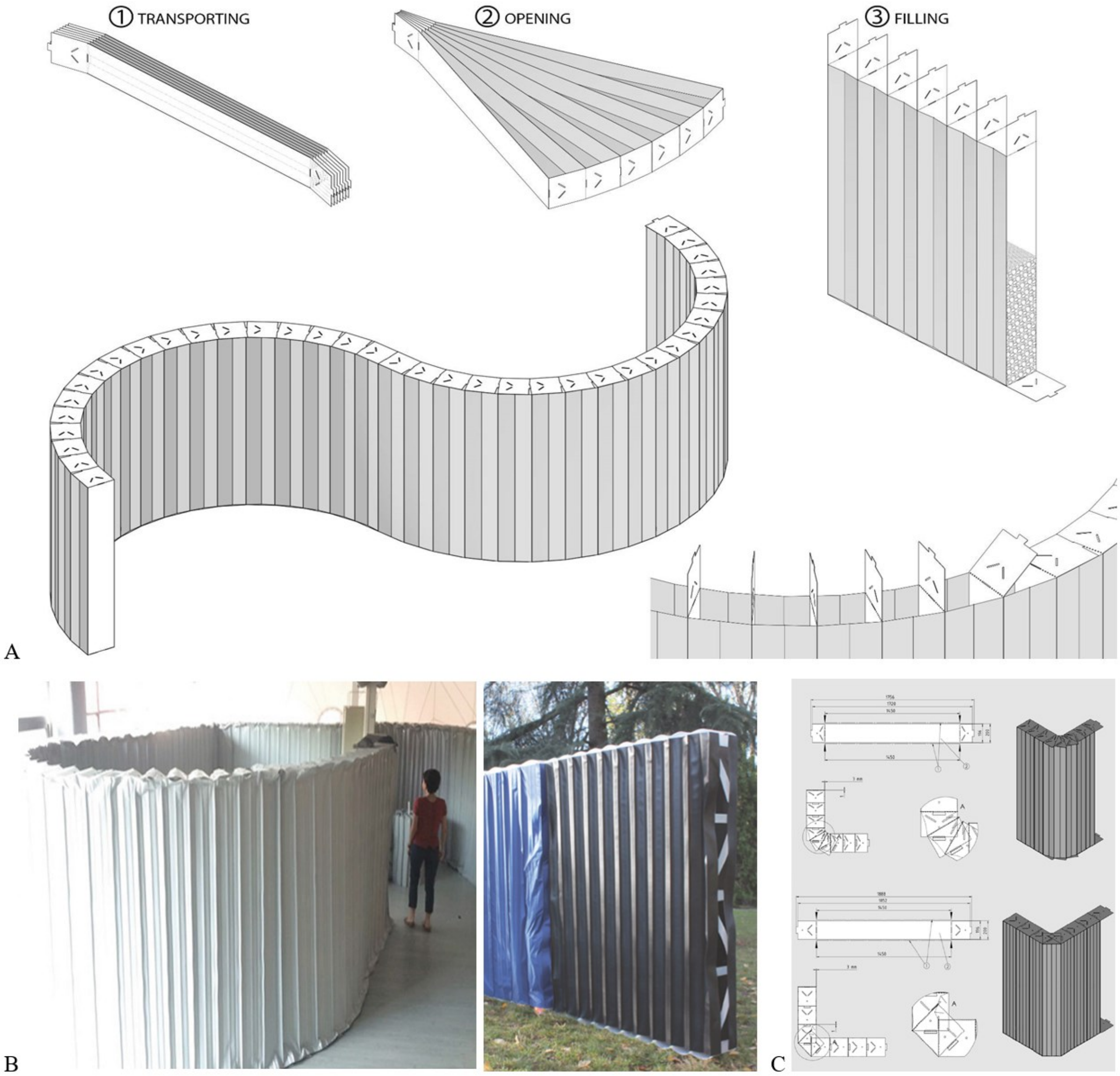


Figure 5: Setup of the final solution; B. Prototypes fabricated with the support of MöllerWerke GmbH;
C. Shop drawings [Source: Viscuso, Zanelli, 2015]

6. Further applications

In addition to the emergency field, the *Textile Wall* will be able to provide personnel and infrastructure protection in Military, Security and Environmental applications. When filled in of gravel or sand, it affords protection from small arms fire right up to explosive devices and heavy artillery in both military and security applications, or it guarantees a barrier against floods. In the environmental protection field, the *Textile Wall*'s proven cell technology makes it ideal for flood protection and ground stabilization.

The invention offers enormous logistical advantages compared to other deployable Force Protection systems. Up to ten times lighter and five times more compact than gabions, Textile Wall cuts delivery costs, uses less supply chain resources and is more effectively deployed to forward positions. The modular packaging also gives significant improvements in storage and transport costs. This product can also provide a smart partition system for dividing work spaces: the flexible design allows to configure the office or store as the users choose to do, and move it as necessary.

7. Conclusion

This paper is intended to describe the design and prototyping process of a novel sheltering component that contrasts the global production of plastic-based emergency material through a 'glocal' approach: a universal panel that can be replicated and adapted to local constraints or for a specific use. This feature may change the current, local perception of sheltering provision because it link prefab production with local markets and relative construction technologies, favoring the acceptance from beneficiaries.

After a detailed analysis of the state of the art and several experimental tests made with first homemade concepts, the research investigated the final solution (I-shape) for ensuring a cheap, large-scale fabrication. Panels can be realized though few manufacturing steps that are already systemized in other production lines. A thermal pleating machine folds the textile rolls with an accordion path, while a CNC plotter cuts semi-rigid PVC foils. Final shapes of textiles and bars are optimized for avoiding any processing waste. Textiles are thus welded on the edges of obtained plastic bars by following the thermal folding lines. In 2015, POLIMI filed a PCT patent that covers the novel exploitations of the above production line [6].

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