L'ARMADILLO®: A NEW LOW COST READY TO BUILD HOUSE SYSTEM

Prof. Ing. Marco Imperadori*

Dipartimento BEST (Building, Environment Science and Technology), Politecnico di Milano
Atelier2 (Gallotti e Imperadori Associati), Milano

Abstract

L'Armadillo® is a new system conceived by BrianzaPlastica (a firm specialised in insulation panels based in Italy) to find new applications for its existing product Elycop® (curved sandwich panel). L`Armadillo has been designed by Atelier 2 (Gallotti and Imperadori – Milano), in collaboration with a team of experts/consultants. L'Armadillo® is based on an innovative building concept, with multiple flexibility, and easy to transport and assembly/disassembly on site. It can be used for different purposes: housing, hospitals, churches, schools, restaurants, etc. for both permanent and temporary accommodations. The result is a shell-formed architecture where a light steel bearing structure supports the insulated polyurethane sandwich-panel shell. Lightweight façades are shaded by two textile extensions and on the roof by a ventilation layer. A prototype as been built in order to optimise the system and to test all the structural calculations with a particular attention to lateral stability and shell-stability system collaboration under wind and earthquake loads. L'Armadillo® basic unit measures 6,60m x 8,00m (3,30 m is the radius of sandwich panel). The volume optimises the thermal behaviours and maximises energy efficiency. The building can be equipped with thermal or photovoltaic cells. L'Armadillo® thanks to its high performance, quality of space, flexibility, cost competitiveness and adaptability to extreme conditions is a clear alternative to 3d tunnel elements or caravans and Its.

Keywords: Building Innovation; Sustainability; Flexibility; Demountable; Technology Transfer.

* Marco Imperadori, via Ponzio 31, Milano, e-mail: marco.imperadori@polimi.it; Atelier2 (Gallotti e Imperadori Associati), Via Pietro Custodi 16, 20136 Milano, e-mail: atelier2@arcoquattro.it

INTRODUCTION: STRUCTURE ENVELOPE (STREN) TECHNOLOGIES FOR POST DISASTER RECONSTRUCTION

Marco Polo describes a bridge, stone by stone.
"But which is the stone that supports the bridge?" Kublai Khan asks.
"The bridge is not supported by one stone or another," Marco answers, "but by the line of the arch that they form."
Kublai Khan remains silent, reflecting. Then he adds:
"Why do you speak to me of the stones? It is only the arch that matters to me."
Polo answers: "Without stones there is no arch."
Italo Calvino, Invisible Cities

Simple constructive principles and systems normally require complex process of analysis that leads to the synthesis of their final form and technology.
Industrialized systems of construction, based on sandwich panels or stratified layers supported by a frame structure, seem to offer several advantages in a quick reconstruction situation. The field of application of the stratified layer construction derives directly from vernacular buildings; hybrid systems at low cost and low processing are possible and suitable in many emergency or post disaster situations, where a quick response to large amounts of houses is often requested. The durability/quality of the solution is also very important considering that the temporary solution tends in most cases to become the permanent one. As a consequence temporary accommodations have to fulfil to higher performances than simple tends, caravans or containers.

The lightweight stratified layer building system is a Structure-Envelope system where the lightweight steel structure, supports the outside envelope. The latter is made of sandwich steel and polyurethane panels (the inner envelope could be realized later on its own secondary structure). In the vacuums between the 2 main envelopes, further insulation could be added for winter and summer time. This would provide the necessary delay time of heat transfer from the outside to the inside in warm climate. Services can be applied both to the structure and/or to the sandwich panels. Close to the Tropics and to the Equator the hyper-insulation is less influent because the envelope must mainly face overheating, which means necessity of shadowing the building and introducing natural ventilation.

A practical, technical and functional result can be obtained through esthetical expression by using materials (such as simple wood panels or thin undulated metal sheets or sandwich panels) used in a different way, from their normal purpose, with simple rules of stratified assembling and resistance. This shows that the value of architecture is not contained just in the costs of the materials but also in the investment in intelligence, using very simple materials in a clever way.

Jean Prouvè was the master in this area during the Modern Movement. His ability to interact with the industry opened a new era to the paradigm of the mechanic assembly of buildings. This allows the application of the paradigm of mechanical

assembly and connections to very ordinary buildings, with medium/low budgets, using a light structural skeleton and internal and external light weight envelopes.
The use of steel sandwich panels with polyurethane (normally applied in industrial buildings or roofs) is an example of how existing technology can be used to make low cost homes, resistant to strong winds or hurricane, naturally ventilated and shaded, used in both normal conditions, thanks to the velocity of construction, for temporary/emergency accommodations.

The “Armadillo” is based on a simple concept but it is the result of integrated design among architects, engineers, and the building industry. This helped to achieve different goals: the use of products already available on the market, the weight optimisation and the logistic, transport optimisation, simplicity and speed of assembly, and last but not least important, pleasant architecture.

The design approach has similarities to the one used in the car industry, where options can be added to the basic version. As a matter of fact Self Supporting Corrugated Steel Shells have also been used by the military for many decades but Armadillo is a different thing for many reasons. Armadillo is a “mecano kit” and this allows to be transported in rather small parts, on the contrary self-supporting shells needed big spaces to be transported, therefore only with military trucks and never stored in a container like the Armadillo is. That’s why there isn’t need for making the arches self supporting but using them only as envelope and use the steel “skeleton” structure as bearing frame. This solution allows also to reduce as much as possible the foundations to few points instead of be obliged to design a foundation platform (therefore using a lot of water which can be a problem in some regions) like military shells needed.

Picture 1 – Prototype of L’Armadillo in Carate Brianza (MI) integrating photovoltaic cells on the top.

Technology: “L’Armadillo”, ready made industrialized home

The building system is made of a lightweight dry assembled kit. The foundations are in concrete on single elements or platform/raft, depending on wind loads. Due to the lightweight of the module the wind load becomes the critical factor to the foundation design. The principal bearing structure is made of galvanized steel profiles, shaped in a semi circular frame (linked at the base with a main beam to hold the secondary beams and the floor), which holds 2 secondary square tubes. The structural elements are connected with simple bolted connections. The curved Elycop sandwich panels are fixed to the secondary structure with steel screws. The sandwich steel panels are fixed to the ground floor secondary beams with steel screws. The façades panels are fixed to the sandwich floors and to the sandwich shell. The floor is totally above ground where only 3 steel supports for each main frame descend to concrete foundations and are fixed to them with simple bolted connections.

Façades are completed with 2 tends that protect the building from sun irradiation, which is much more intense on the vertical surfaces than on the curved shell, except from the top third where is necessary to fix also a further metal sheet to ventilate the upper part of the sandwich arc.

The main steel structure is made of three hinges arches that support square steel sections that act as purlins. The main arcs are connected with a floor beam that distributes the weight to three fitted stabilisers. Over the master beams there are secondary beams supporting the sandwich panels floor, suspended above ground and therefore ventilated, made of 80 mm-thick sandwich panels in pre-painted steel and filled with polyurethane hardened foam. The outer covering consists of end window walls made of aluminium pre-painted windows and doors inserted in the 80 mm-thick sandwich panels. Elycop panels are modular. Normally they are used for industrial roofs and their commercial dimension is 40 mm. For the “Armadillo” a new evolution of Elycop’s use has increased the panel thickness to 80 mm in order to give better thermal and static performances. This product improvement has been introduced to guarantee the same performances to be achieved by both the vertical façades and horizontal bearing floor (which are also made by 80 mm sandwich panels). To increase the thickness to 80 mm accurate studies in the fluidity of polyurethane foam and time of expansion have been undertaken. This allowed to adapt the same machines used to produce the 40 mm panel without the requirement of expensive technology. This has given very good results in terms of economy of the solution and the distribution of polyurethane in the curved sandwich has been successful and without air voids.

Pictures 2-3-4 The construction of the prototype. The 3 hinges main arches are in ordinary steel profiles HEA 120 mm and they carry the secondary box beam section profiles. The sandwich panel of 80 mm act as bearing floor.

The Outer shell consists of three modules (a middle unit and two side units) which are shaped to fit at the joints after they have been heated and made water tight; the conjunction of the curved panels is located at 60°.

The internal space can be partitioned with gypsum board dividers or wooden panels. The under-flooring is made with plywood planking, which allows for gluing top flooring.

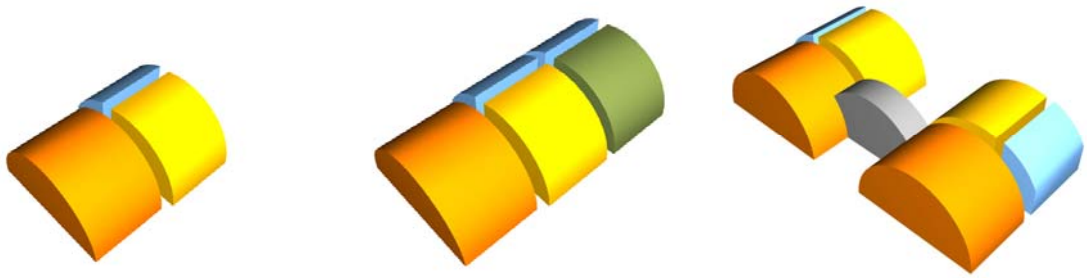
In general aesthetic and functional characteristics of Armadillo make it available for a wide range of uses. It can be used as a single unit or assembled with other units in

both of the main axis of expansion to create larger, living spaces, emergency hospitals, first aid, temporary houses, schools, emergency food storage areas or restaurants etc.

The living unit, realized as a prototype and tested, is a small curved shell measuring 6.60 x 8.00 m, which can be divided into sub-units of 6.60 x 4.00 m, or enlarged into units measuring 6.60 x 12.00 or 16.00 m, by adding one or two spans to the basic module. Since the interior of the shell is completely empty, and can therefore be fitted according to the client's needs, many different configurations, both for residential uses and other functions, are possible. Also different modules can be joint together along the transversal axis to obtain open spaces for different purposes.
"Armadillo" is surprisingly spacious inside, and so any arrangement is possible. The interiors clearly show the difference between this and other industrialised homes (especially containers or caravans), and also demonstrate its adaptability to different requirements.

It can be assembled like a "meccano" construction system, in just a few days, on a simple load bearing foundation. Elycop panels are fastened over the light, durable metallic frame, also to increase the whole structure's level of rigidity.

The system can be supplied in separate kits, depending on the project requirements. They can also be autonomously devised by the client who has the option of buying only the building frame and order separately the other components. Reliable insulation and the correct position of openings results in high savings on fuel for heating/cooling needs and also on electricity. "Armadillo" can also easily be equipped with photovoltaic systems or solar panels, and therefore be totally independent of fossil fuels. The majority of the building components are made from recyclable, environmentally friendly materials.



Picture 5 The multiple flexibility of L'Armadillo.

Prototype and site tests

A prototype has been realized and tested in 2005 in Carate Brianza (MI). Dimensions are 6,60 m x 8,00 m (more than 50 sqm), which is the surface corresponding to the base unit. Interiors have been conceived as kitchen/living room, bed room, bath room and a terrace, 2 sun shadings screens have been integrated with the front and rear facades.

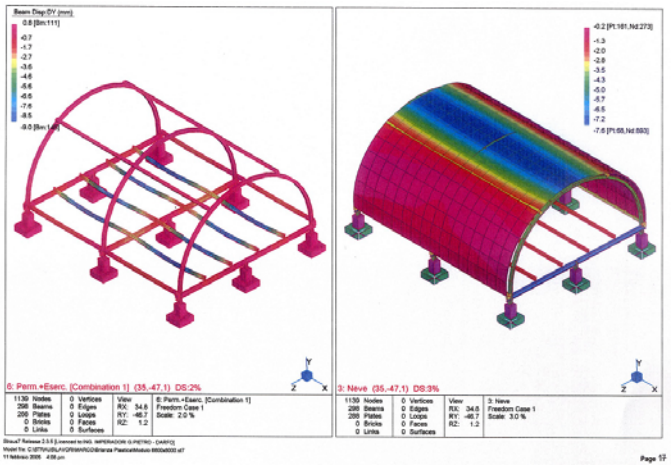
The 3 hinges main frames (spaced 4,00 m) are in ordinary steel profiles HEA 120 mm. The arches carry the secondary box beam section profiles. The main arches are linked with a base beam ILS 200 mm, connected to foundation with 3 short steel legs, bolted in concrete. Secondary floor-beams ILS 140 sits on the main beams and carry the sandwich panel of 80 mm as bearing floor.

The Thermal resistance of the 80 mm polyurethane panel has shown to be performing very well in winter-cold conditions and in summer-hot condition the system can rely on natural ventilation and the presence of a further ventilation layer on the shell improves the overall condition.

The curved panel overlapping guarantees water and wind tightness and all the connections with vertical façades or floors are carefully protected for the same reason (in some case also with additional polyurethane foam). In the prototype, the internal space has been partitioned with gypsum boards panels. The finished floor is a rubber layer glued on a wood layer, which is fixed with screws to the floor bearing sandwich panel.

The structural system has been calculated first with Straus automatic finite elements program both for stress and strains and the prototype has been tested to verify the structural calculations. The design and testing on site have been undertaken following the Italian Building regulations[1].

[1] Names and references of Italian legislations and norms applied: Legge 05/11/1971 n.1086 “Norme per la disciplina delle opere in conglomerato cementizio armato, normale e precompresso e a struttura metallica”; D.M. 11 Marzo 1988: “Norme tecniche riguardanti le indagini sui terreni e sulle rocce, la stabilità dei pendii naturali e delle scarpate, i criteri generali e le prescrizioni per la progettazione, l’esecuzione e il collaudo delle opere di sostegno delle terre e delle opere di fondazione”; D.M. 9 Gennaio 1996: “Norme tecniche per il calcolo, l’esecuzione ed il collaudo delle strutture in cemento armato normale, armato e precompresso e per le strutture metalliche”; D.M. 16 Gennaio 1996 “Norme tecniche relative ai criteri generali per la verifica di sicurezza delle costruzioni, dei carichi e sovraccarichi”; CNR – UNI 10011 “Costruzioni di profilati in acciaio formati a caldo. Istruzioni per l’impiego”; CNR – UNI 10022 “Costruzioni di profilati in acciaio formati a freddo. Istruzioni per l’impiego”; EUROCODES1/2/3.



Picture 6 The structural system has been calculated with Straus automatic finite elements program both for stress and strains.

Horizontal load tests have been carried out on the prototype by applying hydraulic jacks to the main frames and to the secondary structure in order to verify the theoretical model and also to prove that the presence of sandwich shell allowed to avoid bracing the structure in the direction of the load. The introduced stiffness without additional bracings maximises the usable space and reduces costs. Different scheme tests have been carried out by adding curved panels to the bearing structure in order to prove the enhancement of stiffness thanks to the collaboration of the sandwich shell. The 2 hydraulic jacks applied were driven by an oleodynamic system controllable and measurable with pressure manometer.

Structural deformations have been evaluated with a tolerance of 0,5 mm and the results show a substantial elastic behaviour with some plastic corrections very probably due to a small plastic assessment of the connectors and joints (bolted or screwed).

Picture 7-8-9 Horizontal load tests have been carried on the prototype by applying hydraulic jacks to the main frames and to the secondary structure.

Static analysis on the simple automatic model has given very good results compared with the real behaviour of the prototype. After analysing a partial model and testing the prototype on site, under horizontal loads to verify the increasing rigidity of the system due to shell panels, a full complex model automatic has been completed.
This model has been finally checked under single or combined load actions (permanent loads, variable loads, snow, lateral winds, frontal winds, earthquake). All stress and strain outputs have been inside the limits of safety and functionality, previewed for this typology and for the applied materials.

CONCLUSIONS

This building system, ready-made and quick to assemble, shell-shaped called “L’Armadillo”, for its reminiscence to the funny animal of the forests, is a house composed by finished industrial product, the result of a commitment to specialisation, research and product innovation between the company policy of a pool of designers and the industrial client BrianzaPlastica. The result is a modular unit designed and built with quality products, present on the market and often used for non-residential purposes.

Its modular nature allows for a wide range of project solutions, and the basic unit can be enhanced with a vast selection of complements and accessories, included in the project, that make various applications possible in relation to the different living needs.

“Armadillo” is designed to be shipped in a container, mounted and dismantled, if necessary, through simple, quick procedures. It’s streamlined conformation optimises the heat loss and win ratios between the internal volume and the outer

surfaces. Application of solar and photovoltaic panels can transform the unit and make it independent from other energy sources in case of need.

This extremely durable living unit was even designed for use in areas where seismic activity and high winds are prevalent, according to Italian regulations, and therefore can be used in areas with extreme climate conditions. The use in other specific areas will request to verify the specific wind loads in order to verify the bearing and bracing structure (which is the shell itself) for the area selected to the application, as well as the dimension of foundations or concrete platform.

The particular curved shape, which gives also a clear expression of contemporary aesthetic, could in some cases be in contrast with the typology of constructions in the region where Armadillo will be applied. As a matter of fact contrast or dialectic approach in architecture can also be a value if it is well studied and possible variation on the final skin (added by simple screws on the final ribs of sandwich panels outside skin) could optimise its insertion by empathy or total contrast with the natural or artificial surrounding. More than this, Armadillo's flexibility (both in longitudinal and transversal axis) allow to create common spaces to be used during disaster period but also to reuse units which can be houses during disaster period and, if a reconstruction is done in the time, afterwards can be turned in public spaces (schools, little libraries, bars, common rooms, kinder gardens, etc.).

Design:

Architectural and Technological Designers: Atelier 2 (Gallotti and Imperadori) - Milan
General Co-ordination: Studio IDEAG (A. and R. Francieri) - Milan
Structural Design: Gian Piero Imperadori - Darfo
Art Supervision: Dubosc et Landowski – Paris
Other components applied to the System :

- Inner envelope: Vanoncini-Knauf
- Eventual roof windows: Velux
- Resilient floor: Mondo
- Interior design of the prototype: GM Design Revolution


Pictures 10-11-12-13 The modular nature of L'Armadillo allows for a wide range of project solutions. Basic unit can be enhanced with a vast selection of complements and accessories, which make various applications possible in relation to the different needs and conditions.

REFERENCES

Addlesson, L., Rice, C. (1995). *Performance of Materials in Buildings,* Butterworth-Heinemann Ltd, Oxford.

Zambelli, E., Imperadori, M.; Vanoncini, P.A. (1998). *Costruzione stratificata a secco*, Maggioli editore, Rimini.

Imperadori, M. (1998). *Stratified layer building systems*, Proceedings of CIB World Building Congress, Gävle.

Imperadori, M. (1999). *Le procedure Struttura / Rivestimento per l'edilizia sostenibile*, Maggioli editore, Rimini.

Imperadori, M. (1998). "Stratified Layer Building Systems", *Proceedings dell'International Symposium CIB Construction and the Environment*, Gävle.

Imperadori, Marco (2004). "Centro di primo soccorso industrializzato per Emergency", in *Progettare per la sanità n°79*, Milano, gennaio/febbraio, pagg. 48-51.

Bologna R., Terpolilli C., (2005). *Emergenza del Progetto – Progetto dell'Emergenza. Architettura con-temporaneità*, Federico Motta Editore, Milano.