Final Report

Abstract

This is a final report for the HYPERMEMBRANE project.

Final Report details

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Project Details

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Demonstration activity
Project Coordinator: Mr. Jordi Truco, EUROCONT
Partners: EUROCONT, GDP, BUILDAIR, COMFIL, CIMNE, EURECAT

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1. EXECUTIVE SUMMARY

The HYPERMEMBRANE DEMONSTRATION ACTION (GA606242) is a direct follow on from "The Hypermembrane FP7-SME-2011-BSG "Research for SME's" project. (GA 286485 "Development of an adaptable structure for architecture applications"- "Hypermembrane").

After the completion of this Hypermembrane Demonstration Action the results are extremely encouraging and the consortium is strongly determined to push forward their efforts to be able to enter the market with the revolutionary Design & Construction System Hypermembrane developed.

The aim is to enter the market with a strategy that will be focused on the relevance of the new digital paradigms in the process of designing, exploring and using new technologies, using parametric software, working on series production and researching new materials for new constructive solutions focused in building envelopes –façades and covers-.

The Consortium within this project aims to introduce the Hypermembrane construction system into the market since current architectonic contemporary needs are offering strong opportunities for this unique design & construction system called Hypermembrane.

The Hypermembrane is a lightweight structural building system that can take different forms and is governed by a digital control system and a system of actuators that might be or not automated. It is composed of a physical structure and a digital system which controls the shape and parametrically executes changes in the physical structure. Deriving from intelligent systems, many little changes on the elongation of the actuators will produce a big change on the whole structural system. The physical structure can be articulated in different forms of complex curvature within its tensional limits, thanks to the fact that it is made of materials with high flexibility (composites) and high strength. The structure behaves as a muscle, so we are talking about Biomimetic architecture. The digital system is composed by a computing system-modeling-parametric analysis methods, and if necessary it is forecast to embed a system in control engineering devices that can trigger automated changes in the physical structure.

Lightweight architectural structures have applications as large and small scale. They can be used as covers in fairgrounds, stadiums and industrial buildings; or as facade elements in contemporary buildings (the Guggenheim in Bilbao can be a representative building). Also the Hypermembrane opens the door for re-configurable architecture by being the only product able of geometrically reconfigure into different complex shapes and based on a standardized production. This can be very useful to change the form of a building envelope to produce variated comfort conditions, according to environmental demands.

The Hypermembrane structure operates in a fully standardized way and can also be built in an almost unlimited number of geometrically complex curved shapes. The components produced are always the same and it is later, in the work-site and thanks to data provided by the digital system, when the structure adopts different curvatures, thanks to the elastic properties of composite materials and different elongation of the actuator components.

The advantages of the Hypermembrane are:
-*Standard while free-form design:* Complex, customized and efficient shapes produced in serial and standardized manner.
-*Storable*: The same produced components can take different complex-curved forms since all components are the same while they are produced, and it is "in situ" where the structure is putted into the required final shape
-*Adaptable:* A single structure generates different forms. Allows changes shape once the structure has been installed.
- *Reusable:* Allows the reuse of structures that are used temporally.
- *Automated system design process:* There is a digital and parametric system that assists design and links it to construction.

2. PROJECT CONTEXT AND MAIN OBJECTIVES

The HYPERMEMBRANE DEMONSTRATION ACTION (GA606242) is a direct follow on from "The Hypermembrane FP7-SME-2011-BSG "Research for SME's" project. (GA 286485 "Development of an adaptable structure for architecture applications"- "Hypermembrane").

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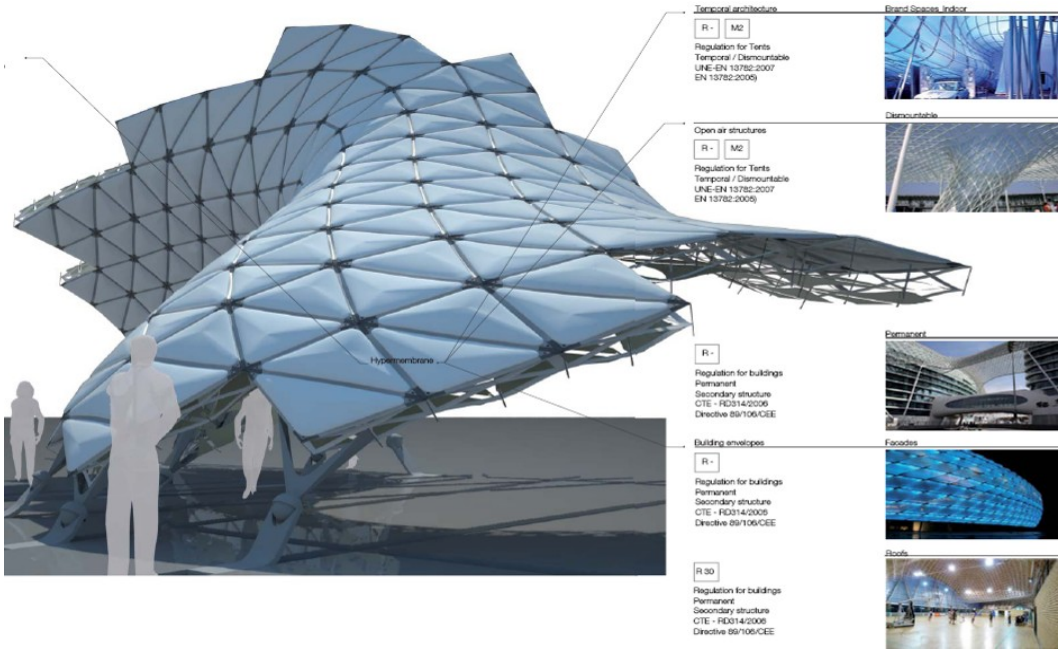

General view of state of technology result and envisaged applicability for the Exploitation Phase

Construction industry has a disturbing lack of technification when compared to other building industries (aerospace, car, shipping…). This is an abnormal situation that generates extremely negative social and economic consequences (low quality of the product, high accident rate, lack of exportability, employment instability…-see extended comments in section 3.1-). When The HyperMembrane System enters the market, European construction industry will benefit with a technological design&construction system that will completely fit into the current standard and globalised markets.

Construction industry is looking for new technological products that simplify/standardize design processes and their follow up construction procedures, yet raising the aesthetical values of the architectonic proposals, and its quality and legal guaranties. The HyperMembrane is a totally industrialized and standardized constructive product for the design and construction of light-weight architectonic structures for short to long spans that enables to build singular and free form architectonic structures within the limits of a reasonable cost.

The HyperMembrane very distinctive characteristics also allow for shape re-adaptation and reuse of a structure for different purposes (energetic, programmatic, cost reduction…)

The possibility of building singular and freeform-surface constructions have been always viewed with great interest by architects and entities that need to be represented architectonically with a building or an architectonic space. The range of applications in the building industry for this qualifying characteristic of the project is extremely wide: from

(a)"Temporal Architecture" (Stands, canopies, temporal promotion/exhibition buildings),
(b)"Short/Medium span open air structures" (Patios, markets, auditoriums, porches for stations), to
(c)"Singular free-form building envelopes" (Permanent building roofs and/or façades).

HYPERMEMBRANE is fit as a standardized high-tech integrated Construction & Design system for adaptable (meaning reconfigurable/reusable), and customized free-form architectonic structures.

The innovative properties of this structure (elasticity, shape adaptability, algorithmic control, self-supporting strength in an unlimited number shape configurations-when actuators and boundaries are tightened-) has posed the participating SMEs the unavoidable necessity for development through the DEMO project, in the fields of disciplines such as composite materials, software programming g, structure engineering and technologies of actuation devices.

The development has achieved the following main outcomes:

- *Physical HyperMembrane (PH):* A working shape-adaptable self-supporting prototype that fits general architectonic standards. The final output is 1/1 scale, so that the composite beam strips *(Result 2),* and motion-transfer components – actuators and ground connections- *(Result 3),* demonstrate their functionality, and so that the (PH) HyperMembrane System (Result 1) is a piece of system with surface enough as to prove that complex geometries -coming from the use of Digital System *(Result 5)*- are achieved with this standardized system.
- *Digital HyperMembrane (DH):* A software package for the design of the PH *(result 5)* including: Friendly user interface in order to model the global geometry of the structure and to deliver with the required length in each actuator for the building to achieve the desired shape and automatic link to real time finite element calculation to meet structural requirements

The DEMO Project has already shown that the HyperMembrane System is fit for purpose for open air structures.

3. MAIN S & T RESULTS/FOREGROUNDS

The SME partners can be classified in different disciplines required for the whole implementation of the commercialization/design/production processes. As leader and SME directly connected with the market, EUROCONT will pursue the search for clients and the commercialization of Hypermembrane Structures supported by BUILDAIR, GDP, and COMFIL that will act as component suppliers -as covering provider and the others as expert composite suppliers (strips production).
The RTD centers CIMNE and EURECAT will continue their R&D support whenever needed.
This bottom-up structure of implementation will cover the entire added-value chain, assuring the interest of the participants in obtaining the defined objective.

In terms of building design and construction, with the HyperMembrane System the construction industry will benefit with a new product to offer to the market. The product will enhance significantly the state-of-the-art because it changes the up-to-day approach to design of singular free-form structures optimizing their design – management – production – and erection due to its 3 most distinctive properties:

-Production of complex curved structures through a mass-production process. The elements produced are always the same; the structure adopts its curved shape on-site through the combination of the different elements previously produced.
-There is a digital tool for the design of the system –DH- that absolutely links design and construction. This means less time spent during the design process; and constant update of the real cost of materials.
- One structure can adapt to different shapes. It opens the door to real time adaptable architecture.

The previous properties imply the next advantages:

Product:
Adaptable. Allows change of shape once the structure has been erected.
Reusable. In the sense of reusable roofs for temporal events, or adaptable and reusable structures.
Transportable. It is a light system. In its flat position all the profiles of the beams are identical.
Stockable. This allows for easily storing all components and composite strip.

Design process:
Organic curved shapes. No extra cost for singular and customized design. Unlimited repertory of shapes
Organic curved shapes. No extra cost for singular and customized design. Unlimited repertory of shapes.
Friendly Interface for the digital design tool. The research aims to design parametric software that allows visualizing and modifying the desired shape of the structure in the computer screen

Production process:
Incorporated management and measurements and budgets will be included within the software.
Stock of elements is possible since the elements produced are always the same.

Construction process:
Fast erection of the structure. It is an industrialized system.
Low cost in the hiring of site workers. Few medium specialized site workers. The process of setting up the actuators is repetitive.

In order to achieve previous characteristics, the consortium achieved the following foreground:

_ Applicability of HyperMembrane System and Baseline Demonstration Criteria

A market analysis of the applications of the HyperMembrane System has been pursued.
A report of effective baseline demonstration criteria for the HyperMembrane technology within the markets of "Open-air structures" and "Building envelopes-Façades" has been done.

Baseline criteria has been based on:
- Requirements of programmatic use (Open-air vs. Building envelopes)
- Building regulation involved.
- Acceptable costs of the final product,

In this demonstration activity the aim has been fully set the demonstration criteria for the technology to comply with the necessary commercialization requirements in the targeted uses. It has to be pointed that architectonic regulation is very security demanding to security standards.

In order to assure that all the range of applicable baseline criteria is regarded, and that the main system advantages derived from the market analysis are effectively justified, this work package has ended with the report of 2 developed case studies (one for the open-air and the other for the façade structure).

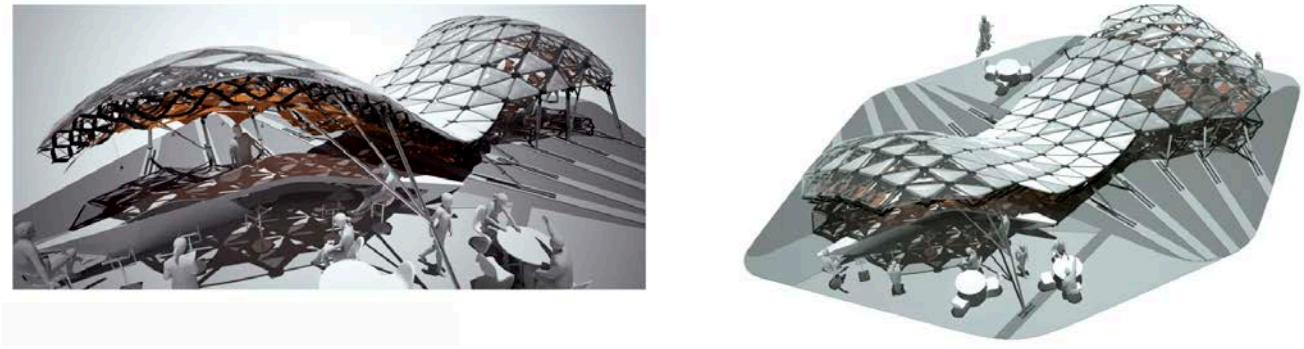

Fig 1.1. Case study: Open-air structure

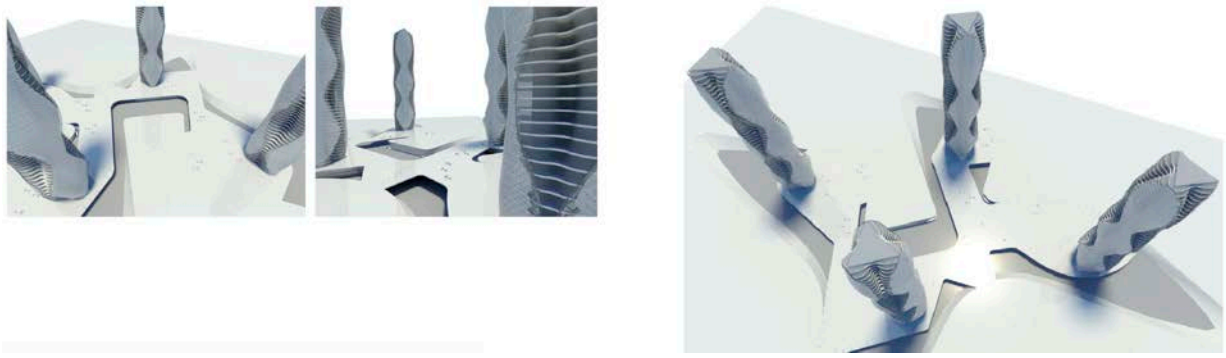

Fig 1.1. Case study: Building façade

As a result of this WP, it has been stablished a list the baseline Demonstration Criteria within the markets of "Open-air structures" and/or "Building Envelopes-Façades" in order to guide the technical implementation for the validation of the Hypermembrane system and components.

_"Industrial validation of design and modeling tools",

HSDP-HyperMembrane Software Design Package (Digital HyperMembrane (DH)) is an automated design tool that incorporates formal and structural characterization of the Physical HyperMembrane and that that is able to analyze all potential shapes of the structure and bring the end-user those shapes that are practicable and the required elongation in each actuator member (The actuator length is the required software output in order to reproduce the shape with the Physical HyperMembrane System).

The HSDP that will be completed in the framework of the Research Project includes all research required features. HSDP has been industrially validated and implemented for end user expectations:

- have an attractive & commercial interface design;
- allow for faster in-time post processing numerical results (geometric and structural);
- work with a wider variety of boundary conditions and therefore making the design HPDC and structural validation tool HSAC more flexible in terms of morphology variability.

_ Industrial validation of HyperMembrane Components

All the industrial components necessary to build a HyperMembrane structure has been re-designed and validated to enter market competences. The industrial components to be developed under this WP are:

Actuators and Connection to Ground. This task has delt with the implementation of new technical solutions in the actuators and grid connection to ground components already developed in previous research project. The aim has been to fulfill market performance requirements (outdoors requirements, repeatability requirements, motion transfer requirements, cost requirements).

Membrane Covering. The HyperMembrane membrane-covering has been implemented in order to fit open-air structure requirements. It is important to present the HyperMembrane structure as a complete product, and this includes the implementation of a covering solution based on existing technologies of actuation components. This task includes the validation of the membrane system for commercial use in HyperMembrane Structures.

_ A pilot production line of Composite Strip

A pilot pultrusion line has been developped in order to enhance productivity rates up to a weekly production volume of almost 3000 linear meters. The improvement of the pultrusion has implied the development of all the tools involved into the pultrusion process: guiding system, pultrusion die, pulling system and cut-off system.

In this goal, the adaptation of a standard pultrusion line has been done in GDP facilities for making in the same step the pultrusion and the conformation of the profile. This enable to produce in a continuous way conformed Hypermenbrane strips. Specific process parameters had been settled, so as to coordinate the speed of the conformation and the pultrusion. The machining has been made manually in the same time than the production of the strips.

Pultruded and reshaped strips have been validated by mechanical tests in order to proof the goodness of both processes according to reference parameters coming from tests, to validate the selected material and the pultrusion process, made into the previous FP7 HyperMembrane project.

_ Demonstration pilot and System Performance Validation

This WP is the core of the HyperMembrane DEMO Project. The aim has been to build and validate for market phase the individual components and a 1 to 1 scale pilot HyperMembrane Structure within the field of "Open air Structures and Building façades".

The pilot of the HyperMembrane includes its Digital and Material features:

- A fully working software package that will be used for the design of the pilot HyperMembrane
- *A fully working physical structure.*

The HyperMembrane to achieve industry awareness so it is very important to demonstrate that the HyperMembrane is a complete standard design&contruction solution for non- standard architecture.

The implemented and modified components resulting from WP4 industrialized strips for beams, and WP3 Components (actuators, grid connections to ground, and membrane covering) have been fabricated within the frame of present WP and then integrated a demonstration pilot for the targeted uses of the HyperMembrane System (Open-air structure).

4. POTENTIAL IMPACTS AND USE

The HyperMembrane System is a High-Tech Construction and Design System.

Driven by the exponential integration of new digital technologies into architectonic design processes, nowadays the architectonic community has the possibility of dealing with great complexity in the design of building morphologies, far from the traditional Cartesian plane. This community contrast to reality when the advanced possibilities of their design technologies face with the lack of resources for free-form construction in traditional building industry: In the construction industry, there is a need for constructive products that enable to build singular, customized and free form architectonic structures within the limits of a reasonable cost.

The envisaged resulting product is a standardized system for design and construction meaning that: On the one hand the *physical system* aims to be made of simple standard and storable components that will be industrially produced and assembled in site by medium skilled limited number of workers; and on the other hand the *design process* will be highly systematized through a design software that will aim to reduce time, cost, and construction solution detailing. For these reasons, the present project will help to raise technology level of the European industry.

European opportunities for the exportation market should be enhanced by simplifying current construction processes: With the development of HyperMembrane new technology, European construction industry will improve its competitiveness at an international level with a technological product where design & management processes and construction timescales are significantly reduced.

Due to its aimed standardization and lightness qualities, the HyperMembrane system requires from a low number of medially specialized site-workers for the assembling process. For the design, a high profiled worker can be inserted within the enterprise: We believe that high-tech construction industry supports European employment stability and allows for systematizing quality control within enterprise policies. Control in in-house processes of enterprises, absolutely reverts in better occupational health and safety results.

The HyperMembrane structure is light, dismountable, collapsible, storable, adaptable, and reusable. These are very important points when we approach sustainability taking into account the whole of the life cycle of buildings. In is important to approach sustainability from a wide point of view in order to avoid resolving one problem while creating another. When approaching sustainability within the building industry it is important to take into consideration the whole of the life cycle of a building (both goods and services). Composite materials used for the Hypermembrane, as well as the previously listed characteristics of the overall system have relatively low direct and indirect embodied energy when compared to other heavy or non reusable constructive methods.

It is important to state that this project will not only have a remarkable effect within the construction industry, but also will promote other economic areas:

On the one hand the expansion in market, knowledge, technology and know-how of emergent material industries (composite) and production processes (pultrusion). World credited professors like Julian Vincent, George Geronimidis or Adrian Beukers make claim for the revolutionary change of approach to design of structures that composite technologies are triggering.

On the other hand opening new markets for actuation devices, the development of the present project opens the way to further development in real time adaptable architecture:
-shape adaptable self-supporting structures may better face solar rays for best capture of energy
-morphological changes in buildings may save energy in air-conditioning spaces.
-dynamic structures for façades in high-rise buildings may allow performing better structurally in relation to wind forces.