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PAPER-SHADE: DEVELOPMENT OF SUSTAINABLE MODULAR BUILDING SHADING SYSTEMS UTILIZING RECYCLED PAPER TOWARDS SERIAL PRODUCTION

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The paper will present an ongoing research for the design and manufacturability of modular building shading systems utilizing recycled paper as the primary material ingredient. The Paper-Shade project proposes a radically new solution: surplus recycled paper into a building construction product. The research aims to develop prototypes of serially manufactured modules that are sustainable in their materiality, manufacturing process, performances, life span cycle, as well as eventual re-cycling. The methodology utilized throughout the research is primarily a hands-on one. The research consortium consists of academic, industry and professional practice partners. The prototypes therefore develop through cyclical processes involving case-study assessments (theoretical and physical), cataloguing of data and outlining directives, defining desired-for specifications, testing through simulation, physical testing and laboratory results. Serial production possibilities as well as product affordability and maximized building energy performance are also considered. The Paper-Shade project may be considered as a modern-day version of vernacular building systems such as adobe bricks. It is also a new take on the modernist era's concrete shading modules that were extensively and successfully used in the past in hot climatic zones but unfortunately forgotten during the recent decades. The project aims to revive intelligent shading systems by prototyping sustainably produced and performing shading modules towards an improved built environment.

Keywords: Prefabrication, Construction, Paper-pulp, Manufacturability, Prototype, Retrofitting.

1 PAPER-SHADE RESEARCH OBJECTIVES

The Paper-Shade project is an ongoing research for the design and manufacturability of modular building shading systems utilizing recycled paper as the primary material ingredient. The outcome will be a prototypical manufactured product. As the Paper-Shade is mostly considered as an add-on to buildings and not as an integral part of its primary construction system, it enables it to be utilized for both new-built and existing buildings. This latter possibility is especially targeted by the research as it offers the option of retrofitting buildings towards upgrading existing envelopes to current European and local energy performance codes.

The Paper-Shade project proposes a low-tech production method. The modules' main ingredient, recycled paper, is likewise low-tech and in surplus abundance in the local market. The Paper-Shade product is one of three main groups of products currently under consideration, the other two being building blocks and exterior cladding systems. The desired properties may vary depending on the eventual building application, but the broader list of aimed-for performances include improved thermal and acoustic properties, vapor repellence, increased thermal mass, reduced maintenance, and extension of the building lifecycle.

The Paper-Shade range will offer possibilities for building envelope upgrades (retrofitting), with a series of designs and products that are high-performance, low in embedded carbon emission, versatile and with varied application possibilities. A positive impact on the existing built environment and a sustainable future for our aging cities is therefore a major objective of the research.

The sustainable approach is twofold: minimizing the embedded energy and carbon footprint during production and promoting social sustainability through the reintroduction of human labor against the current industry trend of total automation. The raw material itself (paper pulp) and necessary molding processes naturally resist automation, and favor custom-crafting in smaller scale, niche industries. The resulting added cost will be offset by the positive environmental and social impact. The project may also rejuvenate small-scale building component industries that are currently in decline.

The Paper-Shade project questions the current manufacturing industry assumption that a product is only worth producing when it can be done quickly, serially and in massive quantities. The expected fast-track/massive output requirement is re-proposed as slow-track/crafted.

The process of pulping recycled paper and turning it into modular building products is more similar to vernacular processes. The Paper-Shade module is a close relative of the Mud-brick module (adobe), but technologically improved through alternative industrializing in order to better respond to current building performance demands and growing environmental concerns. A recent resurgence of interest in old materials and building techniques being given a new spin is evidenced by a growing bibliography on the subject (Ruby and Ruby 2010, Sauer 2010).

Building materials for the production of shading modules currently use mostly new (virgin) raw materials, such as aluminum, fiber cement and reconstituted stone (concrete). In the case of retrofitting, these products need to be combined with other products to provide additional thermal or vapor insulation. Paper-Shade uses recycled materials and consolidates a multitude of energy and performance upgrading into a single module. Furthermore, as a retrofitting strategy, it both extends the lifecycle of an existing building and is recyclable or compostable.

1.1 Scientific and Technological Objectives of Paper-Shade Research

On the scientific level the Paper-Shade consortium brings together the academic based research, the manufacturing industry, and the architectural/engineering design and implementation industry in seamless cooperation, assuring a broader definition of hierarchies of scientific objectives. The commonly divergent priorities and objectives of academia, manufacturing and design will be assessed and cross-fertilized in a fruitful manner to best serve the development of a new methodology addressing issues across the board, ranging from inception to implementation.

The resultant Retrofitting Cladding and Shading Systems will fuse and resolve concerns that are commonly limited and singularly focused such as the academic research environment's focus on innovation, the manufacturing industry's focus on financial viability and profit margins and the design industry's focus on performance and implementation. The otherwise restricted scientific objectives will be re-informed and enriched through a broader prioritization.

The overarching objective is to develop strategies that rely solely on locally sourced materials (recycled paper), respond sustainably to both optimum production processes and building construction industry demands, as well as to the specific required local climatic (Mediterranean) performances.

The aimed-for product characteristics will be designed and tested with quantifiable and scientifically measurable qualities in a cyclical or more accurately a ‘spiraling’ process. This means that a desirable design will be developed, physically implemented, tested and then utilizing the data provided through this research cycle, it will be re-designed, re-implemented and re-tested; completing a number of cycles towards optimum product characteristics. These spiraling cycles will occur both on an individual ‘module’ level as well as on a comprehensive ‘system’ level - meaning an adequate number of modules together as an integral building construction system. See Figure 1.

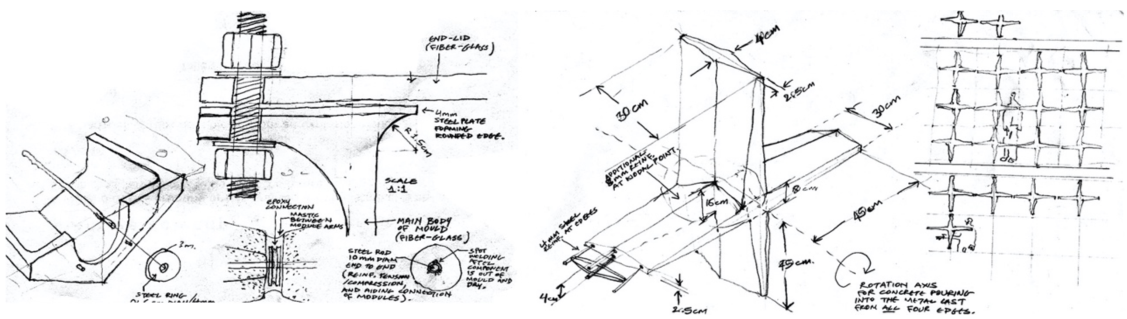

Figure 1. Design development of an individual module as part of a system.

These characteristics and properties will include among others:

- Very high thermal insulation properties
- Utilization of recycled material decreasing the product’s carbon footprint
- Minimal embedded energy in its production (no firing process)
- Compatibility with existing building structures in the local and Mediterranean region
- Very light weight (by volume)
- Excellent buildability (larger units / less erection time and labor)
- Good thermal mass provision from its interior facing mass
- Water resistance to be increased with polymer coatings
- Excellent sound insulation properties
- Adequate tensile and compressive strength (with/without additives)
- Adequate fire resistance with possibilities of increased resistance
- Good possibilities for integrative installation of building services

It is therefore vital for the project proposition to avoid singular focus or over-appreciation of a limited number of individual properties data. The overall scientific and technological objectives of the project will allow for broad, synergetic, and comprehensive assessments of resultant individual data, culminating in an innovative and ‘smart’ product.

2 HISTORICAL AND SCIENTIFIC PRECEDENCE, AND PROJECT INNOVATION

2.1 Building on Existing Knowledge

Throughout the history of architecture and the evolution of the built environment, a close relationship of material availability, climatic response and socially/culturally relevant design may be observed. This is evident through an array of different time periods, cultures, geographical locations and climatic zones. This apparent historic holistic approach to the built environment is generally associated with a more direct and 'practical' utilization of available material and technology towards the provision of 'shelter'. In addition, it evidences a historically stronger bond between vernacular architecture (folk, architecture without architects) and high architecture (monumental and/or designed-for). Evidences for both applications may be seen from the times of the ancient Egyptian Mastaba structure utilizing mud bricks for monumental structures (Trachtenberg and Hyman 2003), to modernist employment of modular perforated systems for shading such as in the work of Marcel Breuer (Breuer 1962, Bergdoll and Massey 2018).

This close relationship with the natural environment seems to have collapsed with the 18th century industrial revolution, as both the new production of building materials as well as construction processes afforded an increased liberation from the restrictions of the past. A further disassociation from the natural environment occurred during the late 19th and early 20th centuries with the advancement of mechanical systems for building conditioning. Contrary to this, more recent sustainability concerns have started to reverse this dissociative trend.

The proposed ingredient of recycled paper turned into a building construction material, has in the last decades been explored in small scale, custom-crafted, unique building applications; usually as a pourable mixture cast in-situ (in on-location custom erected formwork), as a building wall system (West 2017). These precedent trials have been carried out rather informally, usually based on small-scale trial-and-error experiments, commonly without the scientific support or data that might lead to improvements and process directives. The casting in-situ approach practiced so far, also poses logistical problems such as on-site pulping of the paper, on-location paper pulp pumping, the erection of on-site wooden formworks and the necessarily slow process of pouring a thin layer of the pulp at lengthy time intervals in order to allow for natural drying. The aforementioned practices are labor intensive, slow and ineffective; lacking necessary control of parameters such as exact measurements, accuracy of ingredients and processes, variables in temperature and humidity, and the inevitable unpredictability of environmental conditions.

The proposed research results will open up a new array of possibilities. The new prefab prototypes will be scientifically tested for compliance with European and local building codes. Going back to the basics, and reconsidering the binary low-tech/high-tech may afford a series of previously unthinkable and untapped smart products and systems. Reconsidering old and humble materials in a new technological context may provide new and ingenious solutions (Sauer 2010).

2.2 Paper-Shade Project: Innovation and Originality

The Paper-Shade project proposes innovation and originality on two main axes: Recycling matter in a completely new use (such as paper into building construction cladding systems), and new and alternative concepts in manufacturing processes (such as 'slow' versus 'fast').

It is a known fact that the common practice of recycling any specific material for the production of the same as the original product, reduces the quality of the resultant matter and the overall specifications with every additional cycle of reprocessing (such as paper to paper, glass to glass, packaging to packaging, etc.).

It is also a known fact that the European and local market is already becoming saturated by the abundance and surplus of recycled materials and the lesser demand for the same regenerated products. The recycled paper produced in many European countries for example, is hardly ever absorbed by local paper and carton industries, forcing some countries (such as Sweden), to utilize recycled paper as bio-mass.

The assumption is that the only viable and profitable way for industrializing products is by maximizing quantity and speed of output and minimizing human labor involved. These assumptions will be questioned by the Paper-Shade project by offering viable alternatives such as 'slow' and 'crafted' processes.

The Paper-Shade project will also open up further future possibilities in both the same industry field, as well as in altogether different ones. Further future applications might include prefabricated systems for emergency housing, basic modular building components as well as built-in interior components and furniture. The Paper-Shade resolutions for small-scale and 'niche' manufacturing industries are expected to substantially improve the emergence of new operations locally and possibly Mediterranean-wide and Europe-wide. It is expected that it will stimulate economic growth and contribute directly to social progress and sustainability.

3 RESEARCH METHODOLOGIES TOWARDS PROTOTYPE DEVELOPMENT

The overarching methodology for the implementation of the proposed project is a 'spiraling' one. This method involves a non-linear approach. All major objectives and results stemming from separate groups of activities will be re-targeted and re-assessed within each additional cycle of the project development process, until reaching the intended maturity of the useful and ready-to-apply deliverables. This methodology is chosen to best reflect and deal with the nature of the proposition. The diverse interests of the consortium partners (academic research, manufacturing industry and architectural design practice) will induce a desirable process of enriched and dynamically informed questions and accordingly prompt multi-responsive resolutions. In every consequent cycle, the most viable and promising solutions will be re-tested within a yet regenerated ever advancing and refined questioning environment.

The following is an abbreviated list of research activities set towards prototype development.

3.1 Parameters and Specifications

a. Gathering data on existing research.
b. Selected case study assessments.
c. Studying, comparing and contrasting relevant products existing in the current construction industry market, as well as selected products from other fields that exhibit similar concepts.
d. Developing and defining the aimed-for specifications.
e. Setting the parameters of the actual material components.

3.2 Prototype of Unit and System Configurations

a. Determining the appropriate sizing and configuration of the module.
b. Reciprocal re-informing of designs, oscillating between the module and the overall system.
c. Production of catalogues of possible solutions exhibiting the most promising qualities.

3.3 Physical Sampling, Testing and Data Evaluation

a. Designing and constructing a series of alternative formworks.
b. Developing through actual and physical trials the ideal mixture of ingredients.
c. Designing and accounting for efficient and effective manufacturability process.
d. Laboratory tests and qualitative assessments of variations in design and physical prototypes.
e. Comparative assessment, qualitative and quantitative, of the properties of the actual and physical modules produced and tested as in 'd' above. See Figure 2.

3.4 Testing Live Conditions Via Large-Scale Assembly

a. Testing on a larger scale the 'as built' characteristics and performance/behavior of the prevailing cladding and shading module, into an actual constructed wall system.
b. Testing live compatibility with varied existing buildings' conditions.
c. Design, install and evaluate other systems to be integrated.

Live conditions may also include live testing of integration of common building elements such as doors and windows with relevant connectivities, seals, flashings and lintels. The live conditions of installation processes and consequent reactions and behavior of the Paper-Shade system in complex and demanding integrative conditions, and within 'live' environments (sun, rain, humidity, wind, temperature swings) will provide the essential information for finalizing design and concluding with the fine-tuning of all product parameters.

Figure 2. Testing physical prototypes and alternative formwork designs.

4 PAPER-SHADE PROJECT: BENEFITS AND IMPACT

The cladding and shading system modules are to be utilized as a singular and comprehensive solution for the 'envelope' (exterior, perimeter glazed walls) of buildings. The product is not limited to specific types of building in terms of use (residential, office, retail, public), nor to its technical/physical make-up (structural system, building services concepts), and not exclusive to a single type of climate (hot and arid, temperate, cold and dry etc.).

The project is expected to yield a number of innovative results, leading to potential licensing of intellectual properties and product and methodology copyrights. As the local manufacturing industry currently relies heavily on purchasing and acquiring licensing of products developed by other (international) companies, the potential in-house licensing is estimated to be of very high value. Likewise, for the design and academic partners, it will be a unique asset, as the current local licensing and patenting output is at a critically low level.

The project aims to revive intelligent shading systems by prototyping sustainably produced and performing shading modules towards an improved built environment.

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