MODULAR ECOTECHNOLOGICAL ARCHITECTURE: A RESPONSE TO THE DEMANDS OF THE 21ST CENTURY

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ABSTRACT

Constant change in current market and social conditions has triggered the demand for a more adaptable building stock. The capacity to assume and accommodate change has thus become a new requirement for buildings. At the same time, there is a growing demand for more environmentally conscious buildings. New protocols, building codes, and certification systems are becoming stricter regarding buildings’ CO₂ emissions, energy efficiency, and other environmental aspects. The current building industry fails to satisfy these two demands; conventional buildings rarely enable change, unless undergoing complex renovations, and rarely consider environmental features beyond mandatory legislation. In this context, this paper proposes Modular Ecotechnological Architecture as a response to both demands. The basis is an integrated design that looks at energy, water, and materials’ efficiency altogether, combined with a modular industrialized building system. The system allows buildings to grow or reduce in size according to their needs, with little impact for their inhabitants, enabling versatility for a variety of uses within the same space and over time. This paper presents the concept of this new building system together with the technical, building code-related, and economic challenges encountered throughout recent experimental projects.

Keywords: ecotechnology, green architecture, sustainable building, modular building, industrialized building
INTRODUCTION: THE CONTEXT FOR CHANGE

A growing demand for more adaptable buildings

The adaptation of buildings once designed for a specific use in a specific time to a different use in a different time, is not new. The European urban landscape of the end of the 20th century holds numerous examples of an industrial, merchant, and military age which, having fallen into disuse, have become available architectures that have adapted to the most unlikely projects, lending themselves readily for modification (Bordage 2002). Industrial, commercial, and military buildings are now cultural centers, concert halls, and museums, among others. The Reina Sofia Museum, in Madrid, is an example of a former military hospital converted into a museum. In Bilbao, a 1600s baroque church now hosts a popular concert hall, Bilborock. While the natural lighting and acoustics may make these types of buildings ideal for certain activities, it is the great structures and absence of partitions what enables a physical polyvalence to host a variety of uses.

Besides singular buildings, the demand for adaptability has reached the wider building stock, triggered by constant change in market and social conditions. The most widespread need today for adaptability is either within or between residential and tertiary uses. For instance, large dwelling units are being split and turned into smaller units, as the average household size has decreased and smaller units result more marketable due to high real estate values. At the same time, many municipalities in the Basque Country are currently modifying their bylaws to allow residential uses in street-level floors formerly planned for tertiary uses, mainly office and commercial. Again, a combination of new market and social demands, as these spaces, under their former land use designation, remain undeveloped. This situation has its opposite in many residential buildings, in which dwelling units are often used as offices for a certain period of time. The capacity to assume and accommodate change has thus become a new requirement for buildings, which must adapt to different uses and situations throughout their lifespan.

The current building industry fails to achieve such goal. Most buildings in the Basque Country are built with post and beam concrete structures, where interior partitions have no significant structural role, and could therefore allow for change in the floor plan layout. However, the extended use of brick for interior partitions makes adaptation a complex process that involves time and user discomfort, as well as a significant generation of waste material. The recent use of lighter solutions for interior partitions, such as plaster boards or dry walls, contributes to adaptability. According to Pladur, the most popular plaster board company in Spain, their system has been used for over 20 years in over 250,000 dwellings and hundreds of office, hospital, hotel, cultural buildings, etc.

The need for a more environmentally conscious building industry

Buildings have a significant impact in the environment, both as great consumers of resources (e.g. energy, water, materials) and as generators of waste (e.g. CO2, waste materials).

Energy consumption

In Europe, buildings (represented by the housing-services sector) are the greatest consumers of energy (41%), ahead of industry (28%) and transportation (31%) (European Communities 2008). In Spain the impact of buildings in the total energy
consumption is somewhat lower (27%). The Basque Country presents a different picture, with a housing-services sector energy consumption share of 19%, behind those of industry and transportation (46% and 33%, respectively). However, while transportation consumption has dropped in the last year by 5%, housing has increased by 10% and services by 8%, positioning the housing-services sector as the fastest growing one per year in terms of energy consumption (EVE 2009).

**Water consumption**

Buildings in the Basque Country, again represented by the housing and services sector, are by far the highest water consumers. They represent almost 70% of the urban demand, and 45% of the region’s total water consumption demand (Ihobe 2009). Within the sector, domestic consumption is 5 times greater than the services one, making residential buildings a key player to reduce the region’s overall water consumption.

**Waste generation**

Buildings directly generate waste materials during the building phase, renovation, and demolition. In this sense, the building sector in the Basque Country generates around 1.8 million tons of waste per year, representing 15% of the region’s total waste (Ihobe 2009).

**Building codes and certification standards**

The negative impact of the current buildings stock in the environment has generated a trend of environmental consciousness in both the public and the private realms. In Spain, the new recent building code (Código Técnico de la Edificación, CTE) includes specific energy consumption considerations, as well as the use of energy efficient utilities and renewable energy production in buildings. Apart from legislation, the government has set up the incentive-based Spanish Energy Efficiency Saving Plan, which in the Basque Country is carried out by EVE (Ente Vasco de la Energía). On the other hand, the private sector is slowly beginning to specifically include environmental benefits in its projects, as “green” becomes trendy for the market. Certification systems and standards, such as Passivehaus, LEED, BREEM, etc. are still underway in both Spain and the Basque Country. LEED is perhaps one of the most popular ones, applied in few specific outstanding buildings, such as the Iberdrola Tower in Bilbao. There are around 15 buildings in process of LEED certification in Spain, and up to now, none are residential developments.

Perhaps the flaw in current public efforts is putting all the eggs in the energy basket. That is, concentrating most of the new legislation and incentives towards saving energy and cutting down emissions, leaving buildings’ responsibility on water and materials aside. Bioclimatic and ecological practices and certification standards such as LEED, Living Building Challenge, HQE, provide a more holistic approach towards sustainability and buildings’ environmental performance.

**The context for change**

Either market, socially, or environmentally - driven, there is a growing demand for an adaptable and more environmentally conscious building stock. These concerns, related to the way buildings perform over time, are generating a context in which a substantial change in the building industry is needed. At the same time, the economic crisis, while it is significantly affecting both the Spanish and Basque building sectors, represents an opportunity for innovation in new building models. Increased efficiency in terms of time,
labor, and material consumption are key to reduce cost guaranteeing, and even improving, quality. It is worth mentioning that, in order to accomplish significant change, these new models should look beyond new construction and over to existing buildings.

THE CONCEPT OF MODULAR ECOTECHNOLOGICAL ARCHITECTURE

This paper proposes the concept of modular ecotechnological architecture as a response to the demands for adaptability and environmental friendliness in buildings. The basis is an integrated design that looks at energy, water, and materials’ efficiency altogether, combined with a modular industrialized building system.

Integrating design and technology to enhance environmental performance

Ecotechnological architecture is understood by this paper’s authors as the integration of design and technology to significantly improve buildings’ environmental performance. The concept considers three key areas due to buildings’ high impact on them: energy, water, and materials. The first two are mainly related to consumption, while the latter to waste generation. These three areas of buildings’ impact represent a starting point, acknowledging there are other ones within environmental sustainability to be considered (e.g. site, biodiversity, air quality).

In order to significantly improve a building’s environmental performance, this paper proposes three ambitious goals, based on the application of the concept of zero energy buildings, beyond energy, and on to water and materials.

Zero energy goal

Although the term “zero energy building” (ZEB) has recently become quite popular, there is a lack of a common definition and understanding of what it means. There are different variants, such as net-zero site energy, net-zero source energy, net-zero energy costs, or net-zero energy emissions. Defining the zero energy goal affects design choices and whether one can claim success (Torcellini et al, 2006).

In this context, this paper uses the net zero site energy goal, which can be easily verified through on-site measurements. A site ZEB produces as much energy as it uses, when accounted for at the site (Torcellini et al, 2006). In order to achieve this goal, design and technology come together to first, reduce the building’s energy demand, second, maximize the efficiency of its utilities, and third, generate the energy it needs.

Zero water goal

This goal applies the zero energy site concept to water (again, to provide a simple way to measure performance). The concept of net zero water, defined by the Living Building Challenge, proposes 100% of occupants’ water use must come from captured precipitation or closed loop water systems that account for downstream ecosystem impacts and that are appropriately purified without the use of chemicals (International Living Building Institute, 2009). As in energy, the first step towards achieving the goal is minimizing demand, through low consumption devices, and secondly capturing rain water and treating grey water.

At the site level, it is also important to achieve zero storm water runoff generation. That is, taking care the building’s site run off within it. This maintains the site’s original hydrological balance, contributing to overall water and waterways’ quality, reducing flood risk and the need for expansion of municipal infrastructure.
Zero waste goal

This paper proposes the zero waste goal applying the cradle to cradle concept to building materials: To eliminate the concept of waste means to design things from the very beginning on the understanding that waste does not exist (McDonough and Braungart, 2002). The aim is to use building materials wisely; not only to reduce resource consumption during the construction phase, but mostly to guarantee their recuperation, either for reuse or for recycling, when the building’s useful life is over, reducing waste by demolition. Ideally, no building materials should end up in landfills.

Modularity and industrialization, a consequence of environmental consciousness

The “modular” in modular ecotechnological architecture is a consequence from the concern to reduce consumption of building materials and generation of waste (materials) throughout a building’s lifespan; during construction, renovation, and deconstruction processes. On the one hand, industry and thus industrialized systems have always been more material-efficient than the construction industry. On the other hand, reducing waste in renovation and demolition basically entails the use of “dry” systems that can be recuperated at a certain point in time. Traditional use of concrete and brick on-site would therefore not meet the goal, as the materials used are not able to be recuperated, ending up in landfills.

Modularity and industrialization through open building systems are ideal to accomplish the zero waste goal. These systems are constituted by elements or components from different precedence; are able to be collocated in different types of buildings (industrialized or not) and in different contexts; usually make use of pretentiously universal joints, delimited modular ranges, offering an almost total project flexibility (Salas 2008). According to J. Salas, the development of these systems, particularly between 1990 and 2000, has been the germ for a new building philosophy, a term he has coined as “subtle industrialization”.

Research findings indicate significant construction waste can be cut down through open building manufacturing techniques: Reductions of 100% of waste can be achieved in plastering; from 74% to 87% for timber formwork; from 50% to 60% for concrete, and from 35% to 55% for reinforcement bars (Tam and Tam, 2007).

Enabling adaptability and, hence, contributing to sustainability

The use of off-site industrialized systems, either from different precedence or having been assembled in one specific off-site location, allows buildings to grow or reduce in size according to their needs, with little impact for their inhabitants. At a smaller scale, the “subtle industrialization” of open building systems entails an elasticity of construction solutions based on components which has made possible the compliance of new energy saving legislation and responses to demands for other types of architecture (Salas 2008). Modularity in these components facilitates the design and construction / assembly process (and thus, time and money), while at the same time offers a vast range of end-user solutions.

Within the different structural solutions of open building systems, those with less structural elements in plan provide the maximum adaptability to different user-activities. Providing a clear plan with few master partitions enables versatility for a variety of uses (e.g. residential, office, educational), within the same space and over time. This is a critical aspect for adaptability and flexibility of use.
A word on adaptability and sustainability

Modular ecotechnological architecture intends to enhance adaptability and environmental performance through the integration of design and technology, using modular open building industrialized systems. The concept is intrinsically sustainable, as it contributes socially, environmentally, and economically. Socially, it responds to changing social demands (e.g. smaller household size, related to need for space, and housing size, related to affordability). Environmentally, it reduces buildings’ energy, water, and material consumption and waste generation. Last, economically, it responds to changing market conditions, enabling different economic activities, and reducing cost (through increased time, labor, and materials efficiency).

CASE STUDY: EXPERIMENTAL PROJECT FOR SINGLE FAMILY HOUSING

The following case study is an experimental project for single family housing applying the concept of modular ecotechnological architecture. The south-facing rectangular site is located in a rural environment in the Basque Country, on a relatively steep East-West slope, with views down to the valley on the East.

From the beginning, the project program required adaptability of use over time. The program is proposed for a household of four (2 adults and 2 children), with an annex for hobbies, guests, or the children as they grow up. However, in the first years, the annex would be used by a close relative, as an independent apartment (Figure 1). The annex thus required a specific distribution in the short term that could at one point become one single open space. At the same time, the overall program required independence between the two units, and spatial coherence as well, as, in the end, it is one single dwelling. At one point a new adaptability requirement came up, due to affordability reasons: the possibility to build the house in phases (the main unit first and the annex later).

The client was interested in modular ecotechnological architecture for several reasons: program adaptability, shorter building time, lower overall cost, and a strong belief in ecological friendliness and technological innovation.

![Figure 1: Plan view.](image)
Technical aspects and challenges encountered

Below is a compilation of the technical aspects and challenges encountered throughout the project, divided into four key areas: structure, envelopes, interior partitions, and utilities.

Structural system

The structural system consists of 9 rectangular tridimensional modules. Each one is made up of four tubular steel posts and a prefabricated concrete slab. Modules attach to one another through a joint specifically designed for this structural system. The system and choice of materials responds to the zero waste goal, in that the building can be taken apart into its modules, and the modules can be taken apart into their components, ready for reuse or recycling.

The choice of modules only consisting of the minimum number of pillars is the cornerstone to provide an adaptable space. The combination of modules positioned contiguously on their long side provides a clear open plan (Figure 2).

Module dimensions are 2.5 m wide, 7.5 m long and 3.1 m high. One of the first challenges encountered in the design were dimensional and weight limitations. The modules were to be built off-site, so transportation and on-site assembly capacity were key aspects.

Building envelopes

Building façades respond to site attributes, such as valley views, and orientation, to optimize solar gain and reduce energy demand. The building is mainly open to the South, with glazing and solar protection (Figure 3). To the North and West, prefabricated wood panel ventilated façades with few openings and extra insulation, as the North West winds are the coldest in the area. Openings on opposite façades allow for cross ventilation. Façade panels and openings respond to the modular system (Figures 1 and 3).

Green roofs provide a horizontal garden for the dwelling; an outdoors usable space in a site with a steep slope. The roofs include a shallow water deposit that covers the whole roof. The system not only reduces heat gain in the summertime, but also retains rain water in periods of heavy rain, and most importantly stores water for toilet use. Thermal panels on the roof provide energy for heating and domestic hot water use.
Interior partitions

Interior partitions are made up of industrialized plaster boards that offer a simple assembly and are able to be taken entirely apart. This is relevant for the waste goal as well as for the adaptability demand. The modular system allows flexibility of plan distribution (Figures 1 and 4), although partitions do have to follow the modules to a certain degree. This can be considered a design limitation.

Utilities

As mentioned, the building contains thermal panels for heating (radiant floor) and hot water production. Default energy supply is natural gas. Lighting is through low consumption light bulbs and LEDs. Bathroom elements, taps with air pressure devices, and the roof deposit for toilet use, minimize the buildings’ water consumption towards the zero water goal.

The main challenge in this sense is technological innovation, and the cost related to it. Some of the proposed systems are out there on the market, although not quite meeting all the project requirements (e.g. few radiant floors meet the zero waste goal). Others are just not there, either in development or yet to be developed. Another challenge encountered is the modular system requires bathrooms to be included within a single
module (Figure 4). This poses a certain design limitation, as, once built, these elements prevail throughout the different plan distributions.

Normative aspects and challenges encountered

As with many technological innovations, the challenge with legislation is either it directly does not consider certain systems, or it penalizes others. For instance, the new Spanish building code (CTE) does not include open building manufacturing, and the new stricter acoustics section makes design with light interior partitions relatively difficult to comply. At the same time, Spain requires a 10-year structural responsibility for the developer, for which a technical control office must approve the project. These offices have little knowledge on open building systems, and require specific certifications (DITE) to give their ok.

Economic aspects and challenges encountered

The project is currently on standby for reasons beyond the project's control, so the real economics are based on a forecast. According to the manufacturers consulted, the building could be completed within 4 to 6 months, whereas the average time in conventional building would be 18 months. Indirectly, this means cost reduction. On the other hand, the project budget resulted in 10% below a previous project for a similar dwelling. The biggest challenge, nevertheless, was the cost of specific ecotechnologies in order to meet a cost objective to fit the market. Finally, although this project was not the case, there is a generalized market perception that prefab is low cost and low quality, and it applies to modular industrialized systems. This is a major challenge.

CONCLUSIONS

The concept of modular ecotechnological architecture intends to respond to recent demands for adaptability and improved environmental performance in buildings, contributing to the expansion of the Sustainable Open Building knowledge. The concept sets ambitious goals in the areas where buildings significantly impact the environment: energy, water, and waste. Such goals are meant to be objectives towards which to work and be able to measure performance and (hopefully) progress. Lessons learned from the case study presented suggest key elements to provide adaptability are modularity, structural system, and interior partitions. For environmental performance, envelopes and utilities are key for the energy and water goals, while structure, envelopes, and interior partitions are key for the waste goal. Ultimately, modular ecotechnological architecture is based on the integration of design and technology, and requires substantial imagination and innovation in order to meet the proposed goals and overcome the diverse design, technical, technological, normative, and economic challenges.
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