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Natural Materials in Contemporary Low-Tech Architecture

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Abstract. Contemporary tendencies of sustainable and energy-efficient architecture imply an urgent reconsideration of society's relationship to nature. Nowadays, building technology demands a responsible approach to construction that involves fostering of low-tech architecture, as an alternative to high-tech architecture. Those are current challenges that architects and the building technology face to improve the application of natural materials in architecture. The necessity for advancement and contemporary usage of building materials as wood, stone, soil, straw, natural insulation materials have also resulted in the increasingly present low-tech architecture. This research aims to delineate through several contemporary case studies how serious global problems related to the energy and environmental crisis are increasingly reflected in the intention towards the use of natural materials in the architectural design. These contemporary designs implement innovative solutions of natural materials in the case of building envelopes, construction details or structural elements. The comparative analytical method involves a critical reflection on the integration of natural materials between traditional vernacular application and its contemporary innovative solutions. These contemporary precedents represent diverse design approaches that reinforce the importance of environmental and ecologically responsible design. Current problems related to the energy and environmental crisis highly influence the underlying design concepts and final building design. The contemporary usage of natural materials as a building resource indicates the evolving advancement and re-evaluation of an ecologically responsible architecture. Whereas the contemporary ways of integrating natural materials carry universal values which originate from the principles of vernacular architecture.

1. Introduction

The prevalence of the topic of natural materials in different contexts is increasingly present in the architectural scene [1-6]. From the end of the 20th century, a deliberate approach to construction is manifested through the process of re-examining the attitude of the society towards the environment, and more thoughtful use of nature and its resources. Low - tech, green, ecological, and sustainable architecture arose from the demands of preserving the already well-disrupted natural environment. This new trend is characterized by a faster, less complex and inexpensive construction, reduced energy consumption, the usage of eco-friendly, recycled and renewable materials, passive heating and cooling systems, and natural lighting and ventilation.

Nowadays society is characterized by the imbalance of four fundamental realms intertwined in sustainable development, precisely the economic, environmental, social, and construction. The meticulous use of natural resources for "healthy" microclimatic conditions of architectural space and environmental protection is based on the election of suitable materials (table 1), structural design, and architectural elements (modern methods of construction - MMC) [7]. The adherence to these modern methods and the principles of vernacular architecture denotes the path to contemporary sustainable construction, that contributes to balancing this development [8].

Recalling the vernacular principles in contemporary design that embrace the values of natural resources, without the use of high technology, presents a challenge not only for architects, but nowadays also for investors, engineers, and researchers. Especially, as these universal values of vernacular building methods and techniques in the application of natural materials could result in a standard for environmentally, energy-efficient, and cost-efficient building design. Additionally, they could lead towards an improvement of other materials and construction techniques, based on the principles of sustainability, that involve:

- minimizing pollution and adverse environmental impact such as CO_2, particularly minimizing the ecological footprint of the building and a suitable site planning (site sustainability)
- building energy efficiency and rational energy consumption throughout the building life cycle
- embodied energy optimization (e.g. exploitation, processing, transportation, installation, recycling, reuse) of building materials and natural resource management
- minimizing internal pollution and an adverse impact on the health and wellbeing of users

Table 1. Natural materials and their characteristics

Natural materials	Density ρ [kg/m3]	Thermal conductivity λ [W/(mK)]	Embodied energy [4] [MJ/(kg)]	Usage
Wood	400 - 1000	0.075 - 0.25	1.19 – 9.19	Elements of load-bearing structure (wall, roof, ceiling, floor), infill, cladding, roofing
Stone	1500 - 2000	1.16 - 1.4	0.5	Elements of load-bearing structure (walls), cladding, roofing
Gabions				Elements of structure, infill, cladding, roofing
Loam	1000 - 2200	0.20 - 0.95	0.5 - 1.2	Elements of load-bearing structure (walls), infill
Rammed earth				Cladding - green envelope
Straw	90 - 180	0.044 - 0.063	14.5	Elements of load-bearing structure (walls), infill, cladding, roofing
Sheep's wool	13 - 25	0.039	29	Structural infill (thermal and sound insulation)
Hemp and flax	20 - 40	0.040 - 0.045	50	Structural infill (thermal and sound insulation)
Cotton	360-450	0.040	55	Structural infill (thermal and sound insulation)
Wood fibres	35 - 900	0.039 - 0.050	30 - 40	Structural infill (thermal and sound insulation)
Cork	130	0.045 - 0.060	18 - 30	Structural infill (thermal and sound insulation)
Cellulose fibre	20 - 60	0.039 - 0.04	16 - 35	Structural infill (thermal and sound insulation)

With the use of natural materials, innovative building techniques have brought to light a completely different trend in understanding and conceptualizing contemporary architecture. These designs resemble a homogeneous unity of the building volume and its envelope, which is constituted of a seamless transition between walls, roofs, or vertical, oblique, or curved forms. The contemporary building is devoid of a clear distinction or emphasis on individual architectural elements or depicted by the common and inevitable change of materials. Hence, the building design denotes the continuity of the architectural form with the use of natural materials as a means of achieving a contemporary identity (figure 1).

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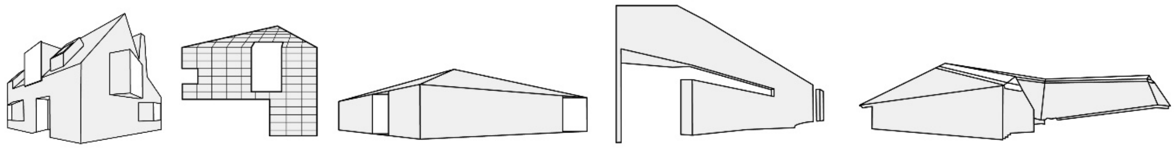

Figure 1. Diagrams of contemporary buildings with natural materials

This research attempts to elaborate on the natural materials used in contemporary architecture, reflecting on the advantages of its characteristics and the variety of possibilities in its application. It focuses on the vernacular principles and its contemporary application through several contemporary precedents. Besides exploring the importance of its use, requirements, and technical properties, their contemporary precedents are demonstrated through a set of drawings, pointing out the design approach and the details of the building envelope. Finally, the research indicates the advantages of these design approaches by rethinking vernacular principles and the use of natural materials in contemporary low-tech architecture.

2. Natural materials and contemporary architecture

The contemporary architectural design addresses the substantial human needs employing low-tech methods and tools which are cost-efficient and energy-efficient. Contrary to high-tech, low-tech architecture evokes values of vernacular principles, the usage of natural, renewable or easily accessible materials, with minimal embodied energy. These natural resources are from the immediate environment or site, or recycled materials that are cost-efficient. The turn to these natural building materials and techniques demonstrates the manifold of building advantages, which cope with rapid technological advancement, energy crisis and sustainable and efficient design. Several studies on the use of vernacular principles indicate the increasing necessity for reconsideration of their advantages in contemporary design. These examples are depicted by the use of natural resources, innovative techniques in their application, and a holistic mediation towards the environment.

2.1. Wood

Wood as a natural "living" material to the highest degree satisfies all principles of low-tech, sustainable architecture. Based on the experience gained through tradition, buildings, components, and elements made out of wood are continuously present and constantly improved in the construction industry. Today, even buildings with long-span timber structures and multi-story timber structures are being built. Additionally, wood is also a renewable natural resource, with good thermal properties, with high thermal capacity, and above all is a long-lasting building material. Besides the well-known timber temples in Japan, or churches in Norway, traditional houses in Bosnia and Herzegovina are built in a *bondruk* system with adobe infill, stone base and other structural timber elements.

The production of timber structural elements, like cutting, transporting, processing or other technological processes and installation, requires minimal embodied energy (table 1) in comparison to other building materials. Also, during the exploitation of the building and the material life-cycle, the wood consumes less energy. Timber structural elements require 10-15% less energy, and thus 20-50% less greenhouse gas emissions compared to thermally equivalent steel or concrete structures [9]. Wood is a lightweight material with good soundproofing properties, an eco-friendly material, easily accessible, easy to use, maintain, replace and recycle, and contributes to a healthier natural environment and wellbeing.

The process of wood impregnation provides protection from moisture and weather, and thus from rotting and deterioration. It enables the usage of wood as cladding or roof covering or as the outer final layer of the ventilated building envelope (figure 2). For this purpose, the most commonly used type of wood is larch, spruce, pine, yew, fir, western cedar and teak. The most up-to-date technology (kebonization), uses biotechnology that results in permanent modification of the surface cell structure and better softwood properties. From the aspect of fire protection, a wooden structure burns more slowly due to the moisture content (about 15%), which evaporates before the wood ignites.

Figure 2. Wood as building envelope, from vernacular to contemporary - House in B&H, Han Pijesak 1946-1947; Valley Villa by Arches and House Bierings by Rocha Tombal

The LiYuan Library designed by Li Xiaodong Atelier depicts a harmonious structure blending into a natural context, where this balance is achieved through the choice of materials and its design (figure 3). This rather simple library building emerged out of the consideration of using local resources as wooden piled sticks and forming all sides of the building envelope. The particular façade design consists of wooden sticks placed in between horizontal and vertical steel structure and double-layered glazing. They not only form a specific texture of the envelope, but they also create a perfect sunscreen for the interior. Precisely, 45 000 arranged wooden sticks of different sizes, dependent on the weather change the appearance of the façade during the year [10]. Additionally, the building integrates a passive strategy with natural heating, cooling, lighting, and ventilation system.

Figure 3. Wooden sticks façade and detail - LiYuan Library by Li Xiaodong Atelier

2.2. Stone

Stone is a substantial natural resource, and a building material of the past, present and future [4]. The exploitation of quarries dates back to the early Middle Ages, specifically the Mediterranean area, where the dry stone wall is the oldest technique used in construction. Stone supplies are unlimited, very widespread, they do not require a lot of energy during exploitation, processing, delivery or installation. It is a long-lasting building material, recyclable, and does not pollute or emits noxious substances.

Stone walls have a very high thermal capacity, while thermal properties are at a satisfactory level due to the thickness of the structure of 100 cm or more. That is the reason why buildings built of stone blocks are monumental and symbolize strength and stability. Stone blocks were used for load-bearing structural elements of historic buildings or only for the underground walls, while the rest of the building was built of brick. Nowadays, the stone is used as a final outer layer, cladding or roof covering, or in the system of ventilated building envelopes [11]. Pieces of stone can be used in metal cages (gabions) creating a contemporary design of a ventilated building envelope (figure 4). Gabions are an inexpensive and efficient mode for building envelopes that provide a high thermal mass of the outer wall.

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Figure 4. Stone as building envelope, from vernacular to contemporary - House in B&H, Stolac; House 9x9 by Titus Bernhard and Lagoa das Furnas by Aires Mateus

Stone slabs can be placed over transparent building envelopes, as movable screens or brise-soleil, used for sun protection and regulation of overheating of the architectural space. The Cultural Center designed by Brückner and Brückner represents a refurbishment on a former grain store built 1902 in Würzburg (figure 5). The building design denotes a constant shift between old and new, where the longitudinal structure is framed between two cubic volumes. The façade is composed of horizontal stone strips which harmonize with the existing structure. Horizontal strips of Udelfanger sandstone louvres dimensions of 100 x 250 mm are supported by a steel substructure [12]. The unique stone screen design enables the possibility of different façade appearances and lighting conditions, as the horizontal stone strips rotate on the vertical axis in regulating heat and light gain.

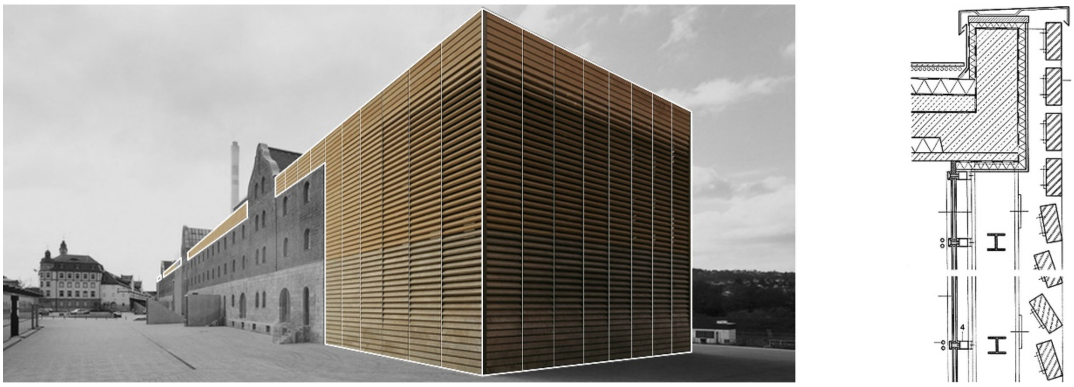

Figure 5. Stone strips façade and detail **-** Cultural Centre in Würzburg by Brückner and Brückner

2.3. Soil (rammed earth, loam or clay)

Soil after bamboo is the second most widely used building material in the world. It is a natural material with energy storage capacity that can be used in passive design strategies. Rammed earth buildings have been known since ancient times. Modern technologies of heating and cooling in residential spaces, such as geothermal systems, rest on the application of these passive principles (deep soil provides a warmer environment in winter and a cooler in summer than atmospheric air above ground). In the history of architecture, building in the underground is known in different climate areas (warm, moderate and cold climates), as well as building with loam or rammed earth above ground level.

In industrialized less developed and developing countries, more than 30% of the world's population live in clay buildings [4]. In the 80s of the last century, the use of rammed earth as building material experienced a resurgence in some countries in Europe and North America. The use of rammed earth walls and clay mortars is increasingly prevalent while adapting ancient techniques to the contemporary ways of construction. Rammed earth walls are of great thermal potential (they accumulate heat in winter and cool down in summer), they are very strong, long-lasting and able to withstand loads (figure 6).

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Figure 6. Rammed earth façade and detail - Nk'Mip Desert Cultural Centre by Dialog

Although very accessible, soil materials are still untapped and represent a significant resource of the future. Loam is a natural building material with good performances in terms of heat accumulation, moisture regulation and retention, and improves the indoor living climate. It requires minimal energy for the process of exploitation and installation than it is required for other building materials like concrete or brick. It is an eco-friendly building material with a long life span and its construction causes minimal pollution. It provides good acoustic protection, fire resistance and it is recyclable [13]. Loam can be combined with straw, having an impact on the increase of structures made from straw from local fields, with controlled quality and then baled (converted into building blocks) and plastered with the earth rather than lime or cement.

Heating clay or using terra-cotta cladding is far more acceptable than building with concrete, due to a "healthier" climate of the indoor space and the regulation of humidity due to other physical processes. It can be recycled, the waste is inert and has no harmful effects on the environment, except for those brick and ceramic products painted with pigments, which contain heavy metals or fire-resistant products, whose waste must be disposed of separately.

Pope John Paul II Hall designed by Randic and Turato resembles a new intervention into a historical context. It mimics the traditional roofs of the village with its contemporary interpretation in shape and materiality (figure 7). The terra-cotta rainscreen cladding system is punctured with a specific pattern of gradual voids of different sizes to gain light in the interior. The building envelope consists of 500x150x50 terra-cotta elements that are extruded with three holes, positioned on a double aluminium frame and elevated around 335 mm from the waterproof structural deck, creating a seamless transition from the wall to the 45degree pitched roof [6].

Figure 7. Terra-cotta cladding façade and detail - Pope John Paul II Hall by Randić & Turato

2.4. Straw

Straw besides being a highly eco-friendly material neither requires any additional energy in manufacturing or recycling and does not harm the environment. The emphasis on the rough-textured material relies not only upon the fact that the material allows diverse applications and cheap construction, but it also embraces an energy-efficient construction (figure 8). The construction industry uses straw in the form of the bale that must satisfy a certain density, tightness and moisture content. For architectural structures, the recommended density is 112–128 kg / m3, because beyond that is a limited amount of trapped air (breathability of bales) which reduces thermal resistance. Consequently, there is a wide range of usage and alterations of thermal characteristics of straw bales. The recommended bale humidity is up to 20%, in order to reduce mould formation and rotting process within the structure. Additionally, straw must be dried, grown without pesticides and chemicals, used without seed and properly oriented to avoid the development of pests, such as insects or rodents [14].

Figure 8. Straw as building envelope, from vernacular to contemporary - House in B&H, Posusje 1930; Living on the Edge House by Arjen Reas and Facts Tåkern Visitor Centre by Wingårdh AB

In the example of Yusuhara Marche by Kengo Kuma & Associates straw units are applied on a modular curtain wall façade (figure 9). In contrary to a usual pitched roof construction where the application of straw is fixed vertically, these modular units (2000x980mm) are horizontally bound extending the life-cycle of the material [15]. The designed pivots on which the inclined straw units are fixed enable rotation, easier maintenance and natural ventilation of the building. Besides this adaptability of the façade, several modular openings break the seamless façade of modular straw units and create a playful design.

Figure 9. Straw units curtain wall and detail - Yusuhara Marche by Kengo Kuma & Associates

2.5. Natural insulation materials

For the improvement of the building energy performance, apart from passive design strategies (horizontal and vertical plan, or the shape factor, sustainable site planning – site selection, orientation, and distance), it is necessary to isolate the building thermally. The use of natural materials with natural binders, and even with a cement binder, has a significant environmental advantage over mineral fibres or thermo-insulating materials of secondary origin (extruded - XPS or expanded polystyrene - EPS).

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The implications that natural materials have, both due to their thermal properties and embodied energy (local and eco-friendly materials), are extremely important in the construction process, especially for a passive house (U-Values <0.15 W / m2 ° C).

Alternative building products in addition to the environmental benefits must take into account also certain disadvantages compared to conventional thermal insulation materials. Thermal properties of building products made from natural materials as sheep's wool, hemp and flax, cotton, wood waste, cork, cellulose, scrap paper, expanded clay, perlite, straw, or coconut are slightly inferior to classic materials. Especially for those materials of organic origin that need additives to achieve or improve a specific level of fire resistance. Still, they have a lower level than some conventional insulation materials. Additionally, the price of alternative materials is usually higher than conventional products for which there is no indication of durability.

Sheep's wool is a natural fibre with similar thermal properties as other fibrous materials. Obtained from renewable sources, it is biodegradable and does not harm human wellbeing or the natural environment. Minimal and embodied energy during production (cleaning, washing, exposure to air and thermal bonding treatment) is only 14% of the amount of energy required to produce thermal insulation such as glass wool and 25 times less CO2 emissions [16]. Sheep's wool products can have different strengths ranging from 16 to 120kg / m3 (EN 1602). The material is commonly produced in the form of felt thicknesses of 50, 75 and 100 mm, and in rolls of 40 and 60 cm wide. Although sheep's wool is hygroscopic (absorbent of up to 33% of its own weight) it does not significantly alter its thermal properties. Sheep's wool has the ability to regulate air naturally, that is, to absorb moisture and release it when the air inside the building is dry. It also affects air quality and breathability. In addition, this natural building material has good acoustic performances and is one of the flammable materials that when burning do not melt or release any toxic gases. The disadvantage in terms of insect sensitivity and rot is possible to eliminate by various treatments, such as pine salts.

Hemp and flax are fibres of herbal origin that are used for the production of insulating building panels with satisfactory thermal and acoustic properties. Hemp blocks and lime-based binder blocks are also produced as insulating infill materials, while load-bearing structural elements are made of brick, wood, or steel frames. In the production process, shavings and pieces of hemp and flax stems are used, and the level of incarnated energy is low. Hemp fibres are natural, renewable materials, which in the production process omit no waste while the energy consumption in planting and harvesting is minimal. They are non-toxic materials and have no adverse effects on the environment. Likewise, the fibres are allergen-free and resistant to mould and fungus. Since the fibres have low fibre strength and absorb moisture they are appropriate for ventilated façade systems, as to facilitate the diffusion process. Hemp mixed with lime mortar can be used as an interior plaster. Hemp in terms of fire protection achieves an acceptable level of protection (Class E) in the process of impregnating fibres with boron salts. The use of these fibres in construction is not common due to its higher costs (30-40%) than other polystyrene-based thermal insulations. Nevertheless, fibres are suitable for use, especially if they adhere to specific norms during harvesting and plastering.

Cotton is a renewable natural raw material from which low-level energy-efficient building materials with good thermal performance are produced. The cotton raw material is processed with a chemical additive. To avoid mould formation and improve fire resistance (Class E) it is treated with pine salts. It is an eco-friendly material that can be composted or recycled, in case the raw material is not treated with pesticides and harmful fertilizer.

Wood fibres building products also belong to ecological materials, since the processing of wood waste from sawmills and adding mineral binders, produces wood boards with different densities and thermal performances. Wood fibre insulation boards have a high-energy storage capacity, high strength, and fire resistance class E, are easy to shape and have a wide application range. They can absorb moisture from the environment up to 20% of their own weight without losing thermal properties.

Cork is also a natural material, derived from a layer of oak bark, recyclable, and therefore a completely eco-friendly material. Products in the form of lightweight cork boards are obtained by grinding the bark and expanding cork particles, or pressing with a binder such as bitumen, or other adhesives. Cork boards are 2-10 cm thick and due to its relatively good thermal insulation properties, good strength and elasticity, it is suitable for various purposes (as infill walls, floors, roofs or a wooden structure). Cork can be shipped in bulk. In addition to its good acoustic properties (impact noise), cork boards leak steam and are resistant to chemicals, mould, rot and various pests. The level of embodied energy is relatively low, but due to the small amount of cork, (the tree must be 25 years old, and only every nine years the bark can be removed) the price is high and long transport routes are an obstacle to a greater application in architecture. Cork is a flammable material and classified as class D in fire protection.

Cellulose fibres are usually made from recycled paper, by adding pine salt, aluminium hydroxide and other binders (polyvinyl acetate adhesive - PVAC) to laminated boards in the form of thin sheets (2-3mm thick) [4]. In addition to laminated boards, cellulose fibres may be in the form of loose or bonded particles, which are blown or spliced on the surface of the building envelope. In addition to improved fire resistance, insulation additives provide very good fungicidal and insecticidal resistance. The low embodied energy production process produces an eco-friendly material with good thermal and acoustic properties. To reduce moisture absorption, waterproof substances as bitumen, latex and paraffin wax are added. Although fibres can absorb water vapour from the environment up to 40% of their own weight, they do not lose their insulation properties. The cellulose building product can be combined and laminated with polyethylene or aluminium as reinforcement. The durability of these products is good. Pure cellulose materials and laminated boards, with natural latex, are weather resistant and can be recycled and used for other purposes.

3. Conclusions

Current construction trends based on high-tech construction capabilities and a large selection of building materials are under review due to the harnessing impact on the environment. It is the necessity to draw attention to the development of interest in the use of natural materials in architecture. The use of eco-friendly and completely renewable materials, with unlimited quantities of production and processing, is one of the conditions of passive strategies, of the continuous development of future architectural design, and a means of consolidating with future generations. Above all, we must return architecture to responsible architects, their knowledge and the knowledge of all those who participate in the process of planning, designing, construction or building maintenance. Indeed, this should rely on the foundations of science and experience, with nature and its processes, models, and its free resources left for an environmentally conscious, balanced and planned exploitation.

The unbalanced relationship between the aforementioned pillars of sustainable development, where the unsustainable correlation of economic and technological advancement, that accompany construction are leading, as opposed to the social and environmental. Destructive technologies based on sterile and chaotic systems favour profit and neglect natural processes are short-term solutions that endanger the survival and have a negative impact on the environment. Therefore, the technological progress must rely on ethical, social, energy, environmental and economic aspects, i.e. an "appropriate" technology which results in low-tech architecture.

The usage of natural materials and reduction of energy consumption throughout the entire building construction and its life-cycle (from material exploitation, through production, installation, usage, to ease of recycling without damage and reuse), and the development of appropriate technology that accompanies these functions and requirements, will result in low-tech architecture whose maintenance will be cost-efficient.

Examples of case studies in this article, as contemporary trends in construction, represent positive solutions for low-tech architecture. They do not disturb the natural harmony of the immediate environment and have no negative impact on its surrounding, the productivity of the natural system, construction techniques and favour recycling. The presented case studies denote the possibility of rethinking conventional design solutions by adopting vernacular principles and implementing the use of natural materials. They indicate a unique tendency of adopting site-specific techniques and unifying different architectural elements into a homogeneous enclosure that is emphasized by its materiality. These solutions furthermore denote the invention of material application, structural invention or innovative detail design. Nevertheless, they all do attempt to reconsider the possibility of an eco-friendly building design while taking into consideration our environment as the main determinant in the design process.

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