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FILIGRAN CONSTRUCTION

I. MEANINGS OF „FILIGRAN“

1. DEFINITION

B1 : „Glashaus“Material, Structure and construction, Dr Belakehal, Architecture Studies LMD.

This work deals with the topic of filigree construction and a possible adaptation for the architecture in Cuba. The word filgran originally comes from Latin and is composed of the words filum (Latin thread or wire) and granum (Latin grain), literally translated as “grained wire”.[1] In a figurative sense, the term filigree describes a goldsmith‘s work consisting of a fine mesh of wires made of gold and silver.[2] In architecture, filigree is not a firmly defined, but a compound term that tries to describe a certain type of construction that could also be described as delicate or light. In many cases, the term filigree construction is defined in contrast to solid construction, in which the space-enclosing parts of a building, such as walls and ceilings, take on the load-bearing function, whereas in filigree or lightweight construction the load-bearing function is taken over by other types of components.[3]

Basically, you have to differentiate between two different perspectives when looking at a building with regard to its filigree. On the one hand, an aesthetic assessment of the effectiveness of a building and, on the other hand, its structure, i.e. the assessment of the quality of the construction.

In this elaboration, the structural design of filigree supporting structures

B2 : Station roof Luxemburg-Cessange

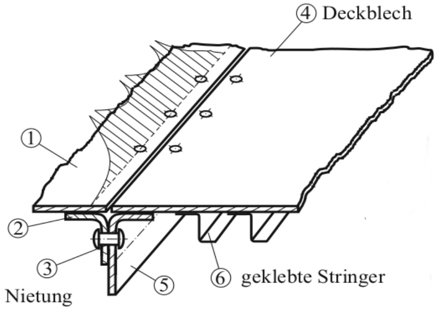
will be discussed, various classifications of filigree or lightweight construction will be shown and the materials used and their possible uses will be presented. Finally, the possibility of transferring these results to buildings in Cuba is being considered.

Behind the filigree or lightweight construction there is a construction principle which aims to reduce the weight or mass of the building material used[4] and to design the optimal design of the load-bearing structure for the given loads[5] p.3. Filigree or lightweight constructions have a low surface-related mass and are very slim and flexible. As a result, these constructions often have a lower heat storage capacity than massive constructions, which often leads to high temperatures inside the building on warm days because there is no storage mass[6] p.308.

Lightweight constructions are often chosen in order to build resource-efficiently. The question of whether this is achieved in individual cases can only be clarified by examining the ecological balance (LCA, Life Cycle Assessment). Using standardized methods, the resource requirements, the environmental impact of products and the constructions over their life cycle are quantified and measured. The results for the life cycle assessment are largely uniformly regulated in the building industry and are presented in different impact categories[6] p.309.

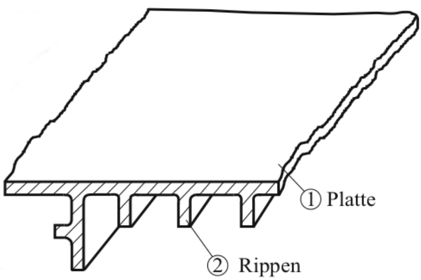
There are many different classifications of Filgran or lightweight constructions, some of which are presented below.
The constructions can, for example, be roughly subdivided into bar and surface structures. A framework is a support system that is made up of one-dimensional elements, and a surface structure is a support system that is made up of two-dimensional elements. In both cases, the overall system can be designed spatially, e.g. as a frame construction, a folded or shell-shaped surface, a network structure or a spatial framework.
Bar and surface structures can be further subdivided based on their structure and their function. A distinction can be made between „tensile structures (cables, nets, membranes), tensile + pressure + shear structures (rods, trusses, membrane shells and folded structures) and bending + torsion structures (beams, frames, plates and bending shells)“.[5]

Another classification of filigree or lightweight constructions according to B. Klein and T. Gänsicke is made through the choice of design.
With the differential construction, the different materials or individual parts are added together, which facilitates recycling and later necessary repairs. The components to be joined are connected to one another using different methods, e.g. riveting, welding, screwing or gluing.



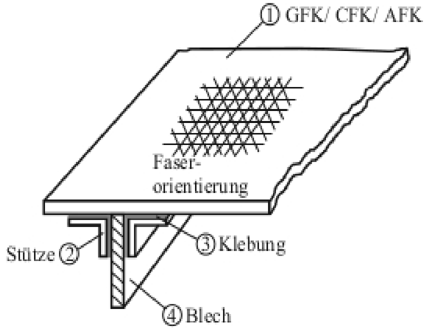
B3. Differential construction

In the case of integral construction, one tries to minimize the structure-forming individual parts as far as possible and to implement function-forming elements during the shaping. This is usually achieved by casting or stamping components. Due to the high planning effort and the high production costs, this type of construction is only worthwhile for very large quantities. Components manufactured in this way can usually only be repaired and recycled at great expense.

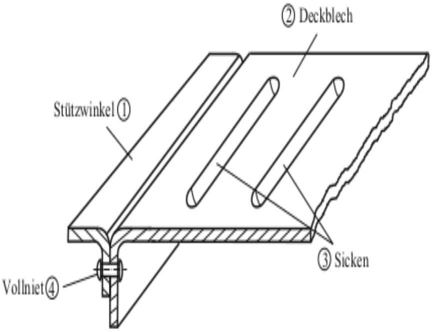


B4. Integral construction

A special form of integral construction is the integrating construction. With this principle, individual elements of a structural unit are joined together at defined interfaces, so that components that were manufactured in an integral construction can later be easily replaced or dismantled. This can reduce the cost of maintenance and dismantling.



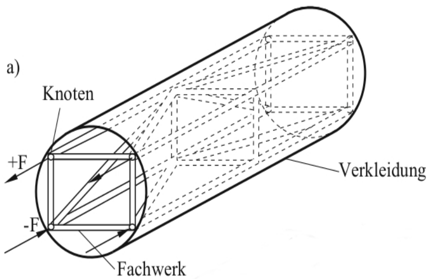
B6. Composite construction



B5. Integrating construction

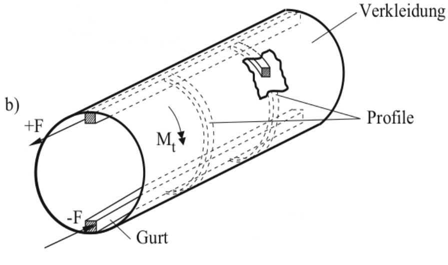
Another design is the composite construction. Typical examples of composite construction are coated and uncoated sandwich panels or fiber composite structures. The composite construction is usually very complex to manufacture. The force introduction points when joining the various components require special attention and care in order to avoid problems with force transmission.

Solid wall and shell systems are often used for large structures. The forerunner of this construction method is the framework principle, in which there was a clear separation between the transfer of loads by the framework and the force-free cladding. With full wall systems, the function of carrying and cladding is linked.



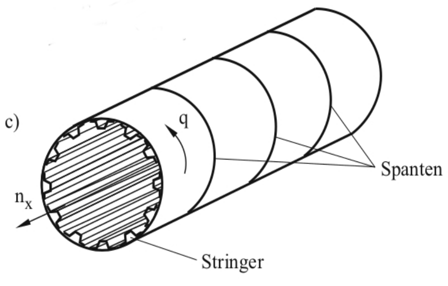
B7. Framework construction

With full wall systems, the function of carrying and cladding is linked. The cover is connected with massive single straps, whereby the cover absorbs the transverse forces and the straps absorb the moments, creating a stable unit.



B8. Full wall construction

The shell construction is a further development of this construction. The stringers and spanners are connected to the shell, which ensures that the forces that occur are largely distributed throughout the structure. You need special inlet and outlet constructions for the power flows to make these constructions safe. As a rule, this requires a large amount of tools, which means that this type of construction only makes economic sense for large quantities.[7]



B9. Shell construction

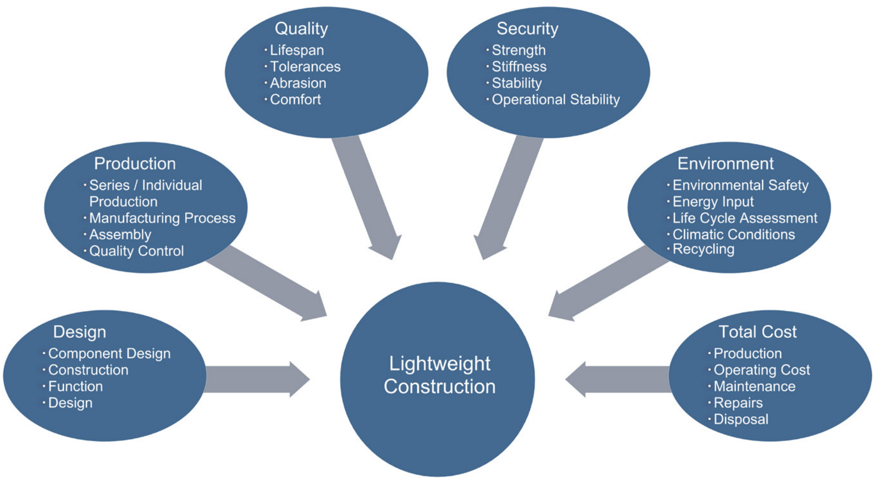
Another common division of filigree or lightweight construction is made according to B. Klein and T. Gänsicke with regard to the strategy used. A distinction is made between lightweight fabric, lightweight manufacturing, production lightweight construction, conceptual lightweight construction and conditional lightweight construction.
Lightweight fabric means the replacement of a material in use with a lighter material that must have comparable properties. Owing to the lower modulus of elasticity of lighter materials, larger wall thicknesses or installation spaces are often required. When selecting materials for new constructions, load-related lightweight construction indicators offer good assistance in choosing suitable materials.

All weight reduction measures that have an effect on the manufacturing process are summarized under lightweight manufacturing. Different joining techniques that help to reduce the accumulation of material at the joints are just as much a part of it, as are forming processes that improve the material properties, such as hot forming or superplastic forming.

The goal of production lightweight construction, is the optimal distribution of the material in the workpiece according to the loads that act on the component. This can be achieved through a variety of measures. Plastic deformations at a suitable point,

such as crowning, the introduction of beads or ribs, can structurally stiffen components. Cast parts in which the material is reinforced in heavily stressed areas and minimized in lightly stressed areas help to save material and thus weight. The making of holes in structurally harmless places, be it in sheet metal or beams, e.g. I-beams, can also help reduce weight.
Conditional lightweight construction examines the external factors that affect a building, for example. The design is optimized with regard to lightweight construction from the resulting knowledge. Weight can be reduced through targeted reduction in loads, strain, resilience and proper use. Constructive measures can also be incorporated. The shortening of lever arms, cantilever arms or load paths is another way of reducing weight. Another constructive requirement would be to replace the stress on components due to pressure from tension and the stress from bending due to pressure. Considering the lifespan of a building structure can also contribute to weight reduction, for example by doing without solid walls in temporary buildings.[7]

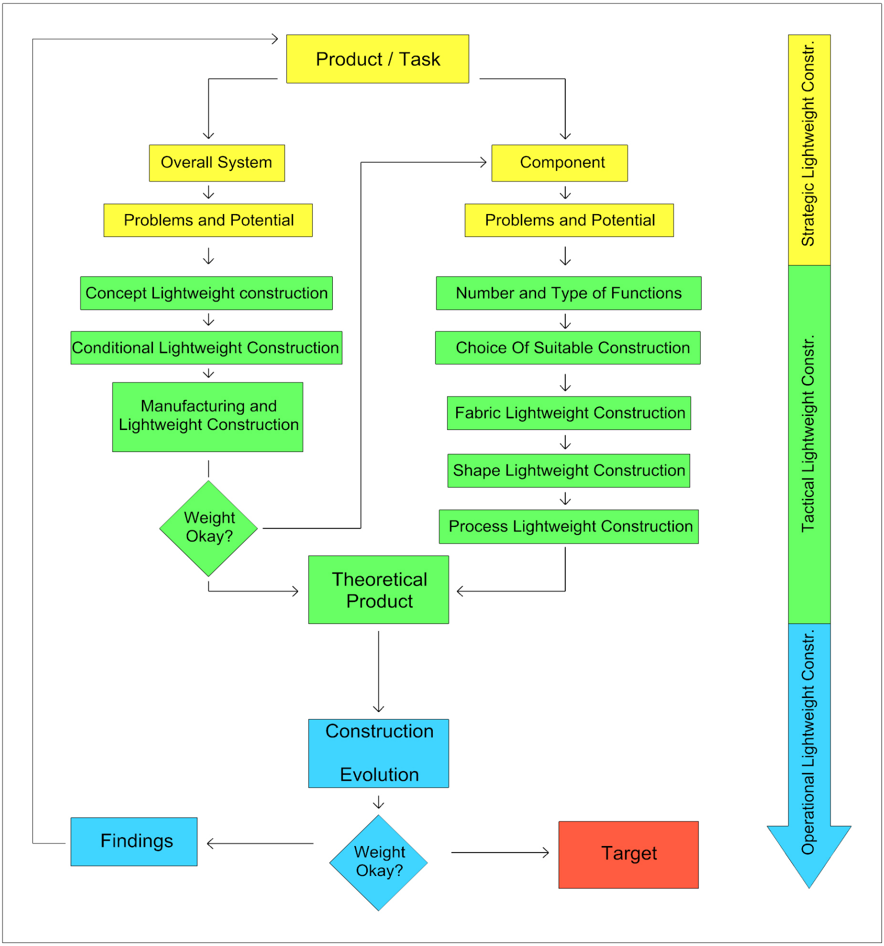
FRAMEWORK CONDITIONS



B10. Framework conditions for lightweight systems

The presented classifications of filigree or lightweight construction can be systematized and combined into meaningful application strategies in order to design the design process in a targeted manner and to determine the appropriate construction. At the beginning of the construction process, the basic conditions for the construction task should first of all be determined and examined and compiled according to certain criteria. The design, the type of production, the quality, the safety of a building, environmental aspects and the costs are sub-aspects that need to be recorded, assessed and determined.

HOLISTIC APPLICATION STRATEGY



B11. Holistic application strategy

Once the framework conditions have been clarified, a chronologically structured structure can be used for the design process, which is helpful in mastering the building task and selecting the appropriate construction. The upper part of the diagram highlighted in yellow looks at the goal setting, also called strategic lightweight construction, which involves the formulation of the construction task or construction. The area shown in green deals with tactical lightweight construction, which includes the planning phase in which the different lightweight construction methods are compared and examined. The third phase of this model, marked in blue, the operational lightweight construction, then deals with the implementation of the knowledge gained, i.e. the implementation planning.[7]

5. CARACTERISTICS

1. DOMINANCE OF TRELLIS FRAME [8]

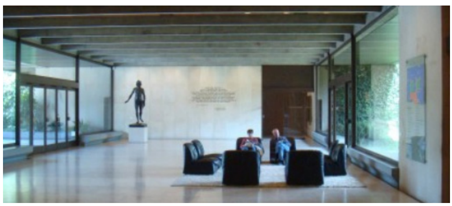
- Linear element horizontal and vertical
- Extremely reduced aerial structure




2. NO SEPARATION BETWEEN INSIDE AND OUTSIDE

- Lack of separation between interior and exterior
- Undefined spaces immediately





B12 : „Exemple of Filigran architecture", Dr Belakehal, Architecture Studies LMD.

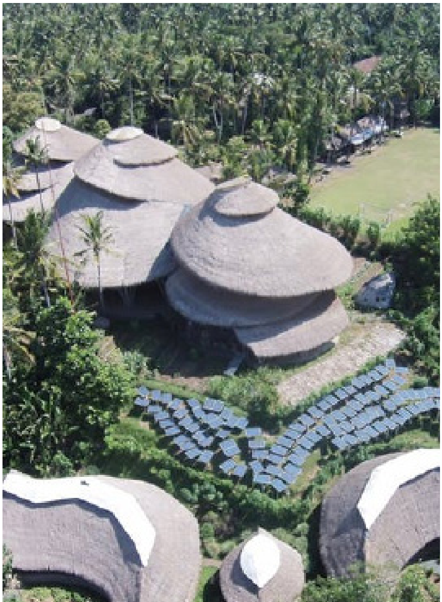
B13 : „Green school in Bali", Bambou house in Bali, https://rencontres-woodrise.ch/architecture-en-bambou-renouveau-global-a-bali/

Bamboo has always been a basic building material in tropical latitudes.[9] But generally it has been used for cheap cabins, stalls, fences, scaffolding, and sunscreens. If left untreated, bamboo is very sensitive to fire and degrades naturally in two or three years, as insects and fungi quickly devour the sugar and starch-rich sap inside the canes.

In Bali in the 1990s, Irish-Australian designer Linda Garland was the first to use bamboo in a contemporary way.[10] She worked with scientist Walter Liese of the University of Hamburg to treat bamboo from beetle pests and turn it into a commercially viable building material.

An essential preparation technique is to pierce the center of the cane with long steel rods, then apply repellant and fire-resistant chemicals. This often involves a soaking solution that includes borax salt powder. The bamboo is then dried for several days to several weeks.

Today, the Bali Green School and several associated companies are playing a leading role in a third millennium movement to build geometrically irregular, often winding, structures.



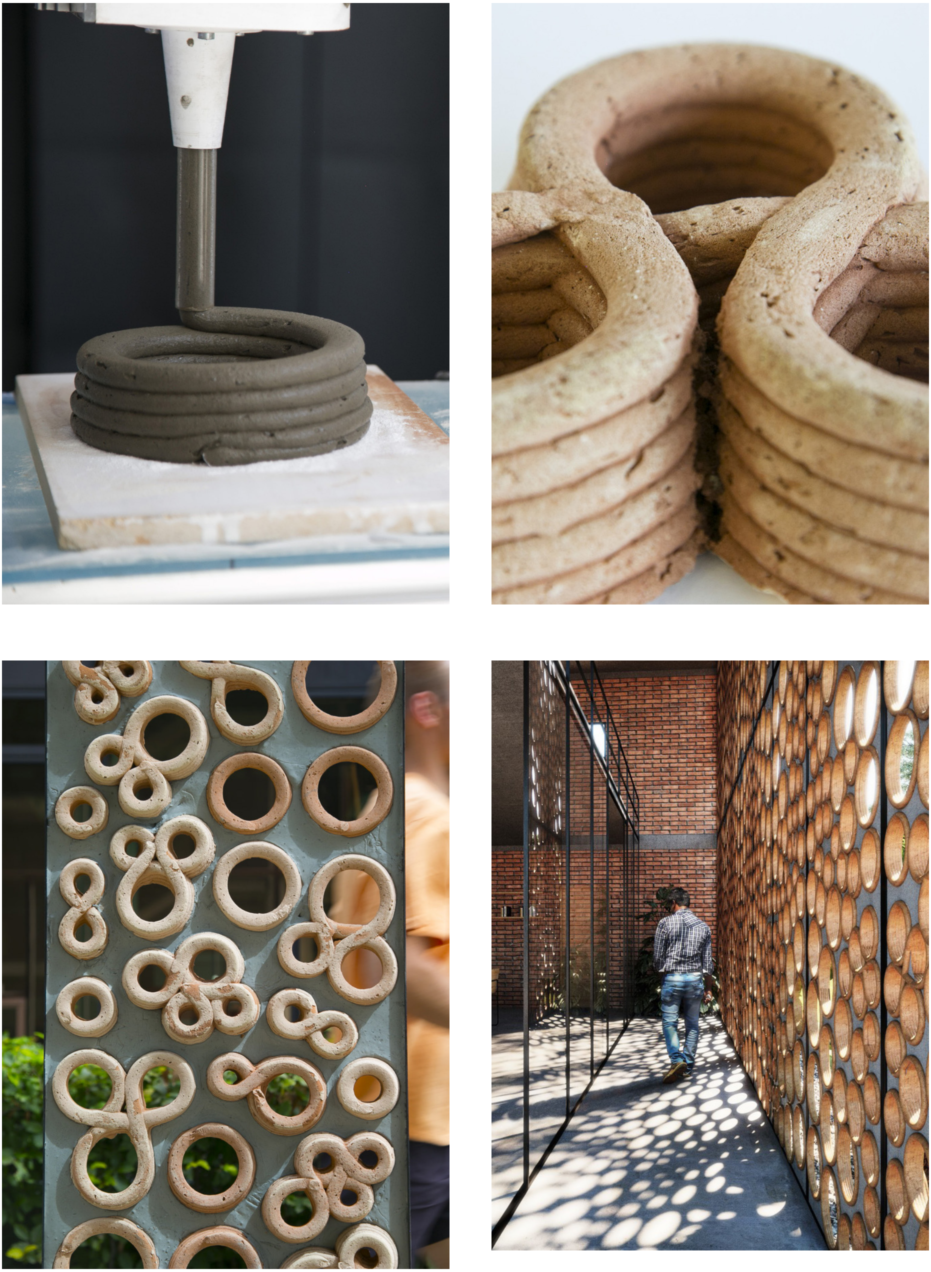
B14 : „Green school in Bali", Bambou house in Bali, https://rencontres-woodrise.ch/architecture-en-bambou-renouve-au-global-a-bali/

Bamboo is not an endemic plant in Cuba;[11] the first varieties were introduced at the beginning of the 20th century by foreign companies, such as the United Fruit Company, which occupied large areas of land in Cuba and sowed bamboo with the intention of using its long and strong stems as fulcrums for its banana crops. Today there are 30 varieties of bamboo throughout Cuba that have adapted to the environmental conditions of the country. However, the percentage of existing bamboo plantations is insignificant in comparison with other species found in Cuban forests, as it constitutes only 1% of Cuban forest heritage. The importance of bamboo in Cuba is not based on the fact that there are large plantations, but that it is the only existing plant in the country that after four years of being planted can create a wood sufficiently formed to grow be exploited economically. To use bamboo in filigree constructions in Cuba, it would be useful to mix it with other materials. Many bamboo buildings today include wood or concrete slab floors because they can be laid evenly flat. But researchers at Empa, the Swiss Materials Research Academy, have come up with very durable and temperature-resistant floor and patio boards made from bamboo fibers and resin. These prototypes are currently being tested in one of the Vision Wood student apartment modules in the Empa NEST test center in Dübendorf.

B15 : „Scaffolding bamboo Construction in Hong kong", https://www.alamy.com/stock-photo-construction-site-in-hong-kong-with-bamboo-scaffolding-54890862.html

B16 : „Robotic 3D printing : the new lightweight architectures" https://www.archdaily.com/952445/the-master-of-advanced-studies-in-architecture-and-digital-fabrication-at-eth-zurich-unveils-its-latest-thesis-achievements/

This project is a thesis proposed by a student of the Zurich university. He proposes a way to build with numerical impression for light construction. Discrete construction elements used in low-cost architecture can be designed and produced thanks to high-tech digital fabrication and materials research.[12] This master thesis project presents a contribution to this goal through the design and fabrication of lightweight architectural assemblies. These have been developed during 12 weeks and as part of a larger research endeavor investigating C3DP with mineral foams, derived from abundant non-flammable, and fully recyclable industrial waste. Starting from the early development of the print material, various designs from 3D-printed mineral foam were systematically explored through an extensive prototyping exercise. The fabrication method is robotic 3D-extrusion-printing and the printed elements were sintered in a furnace to achieve their full mechanical strength. As a final demonstrator, an ultralight screen façade was manufactured with mineral foam discrete elements and cast on UHPFRC Ultra-High-Performance Fibre concrete. Due to its geometry, they allow natural lighting and ventilation, highlighting the benefits of using this material to create lightweight, innovative, sustainable, and low-impact architectural elements on the environment. The main goal of the research is to explore design challenges for 3D printing with mineral foams, promote awareness on the future built environment, and give a conclusive outlook discussing the future avenues of research.



B17 : „Step of porous assemblieswith 3D printing“https://www.archdaily.com/952445/the-master-of-advanced-studies-in-architecture-and-digital-fabrication-at-eth-zurich-unveils-its-latest-thesis-achievements/

B18. Pavillion Kahla, TU Dresden

Concrete or reinforced concrete has been used in the construction industry in Europe since the end of the 19th century.[13] Reinforced concrete structures are ideally suited for transferring large loads through the steel introduced, which absorbs the tensile stresses that occur. However, the susceptibility of steel to corrosion is a disadvantage of this composite material, which must be counteracted by a thick concrete cover. This leads to an increased weight of the components.[14] Research into alternatives to steel as reinforcement in concrete has been ongoing since the late 1990s. The result of the research in Aachen and Dresden is a new type of composite material, textile-reinforced concrete. The carbon, basalt or glass fibers used for reinforcement are alkali-resistant, light, stronger than steel, corrosion and aging resistant and are inserted like a mat.[15] The fiber materials introduced help to save weight and thus resources. Textile concrete is suitable for self-supporting components such as facade elements and load-bearing structures such as supporting shells. Façade elements made of textile concrete can be made much thinner than those made of reinforced concrete, which can mean a weight reduction of up to 75%.[14]

B19. Research project RWTH Aachen, shell construction

B20. Research project RWTH Aachen, facade detail

A self-supporting sandwich structure was used for the facade elements in the new RWTH Aachen institute building, which was funded by the EU. The facade elements have a core made of stable PUR rigid foam and two thin textile-reinforced glass fiber concrete shells. The inner shell of the sandwich construction bears the weight of the facade elements through brackets welded to the transom-mullion support structure. The load on the outer shell is transferred to the inner shell by diagonal anchors. Joints in the edge area of the facade elements accommodate the seals.[14]

In the course of a research project at RWTH Aachen University, a thin-walled, load-bearing concrete shell structure was implemented. The pavilion consists of four individual prefabricated textile concrete parts that have been reinforced with textile carbon fibers. The shells are supported on four reinforced concrete columns that were delivered as prefabricated components. The shells were produced on site in a tent using shotcrete technology. After every 5mm thick layer of shotcrete, a layer of non-impregnated textile reinforcement was laminated in. This made it possible to produce a shell that is only six centimeters thick and spans an area of 7m x 7m. After the shells were assembled, the pavilion was given a glass facade and is used as a seminar and event room. The interplay of the transparent facade and the thin shell roofs underlines the filigree of the building.[14]

B21. Research project RWTH Aachen, shell construction

B22. Research project RWTH Aachen, finished building

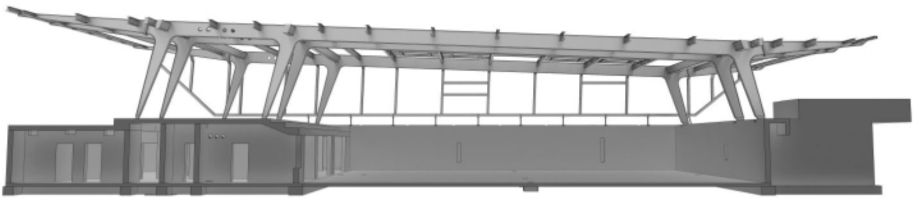
According to K. Hanses, steel has been one of the most important building materials used by architects since the industrial revolution. Since steel can absorb tensile and compressive forces very well, it is particularly suitable for wide-span supporting structures with little material expenditure. That makes steel a very efficient material. One shortcoming of the material is its susceptibility to corrosion and thermal deformation. Both phenomena must be countered with suitable measures to protect the construction, for example weatherproof or rustproof steels can be used outdoors. The good formability, different joining techniques, further developed material properties, various surface treatment options and a wide range of manufacturing processes make steel versatile. Be it in bridge or hall construction as rope or half-timbered constructions, as facade cladding, concrete reinforcement, etc.[16]

B23. Three-field sports hall, Friedrich-Ebert-School, Pfungstadt, building view

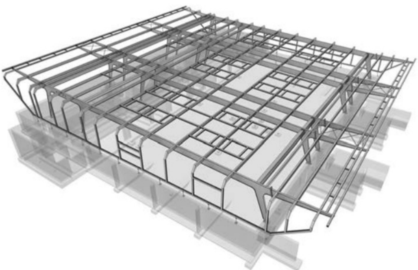
For the Friedrich-Ebert-School in Pfungstadt, a new three-field sports hall was built between 2014-2018 by the architects Engelsmann, Peters. The building has an east-west orientation. The east and west facades are inclined and fully glazed, the other two facades are mostly closed.

The foundation is made of reinforced concrete, carries the steel structure of the roof, houses the ancillary rooms and provides the area for the playing fields. The primary supporting structure consists of six three-legged multi-span frames that run in the longitudinal direction of the building. The frames span different spans, protrude at both ends, are built on the concrete foundation and have a total length of 54 meters. The dimensions of the frames change partly with the flow of forces of the loads. The arrangement of the frames depends on the arrangement of the playing areas. The secondary supporting structure made of rolled sections runs transversely to the girders and runs downwards on both sides and forms the supporting structure for the north and south facades. Together with the trapezoidal sheet metal covering on the secondary structure, a bond is created that looks like a disk and takes over the reinforcement in the transverse direction. The side facades are made of diamond-shaped PMMA plastic panels. The transition areas between the side facades and the roof are made of the same material.[17]

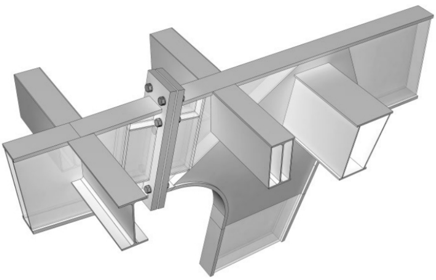
B24. Three-field sports hall, Friedrich-Ebert-School, Pfungstadt, inside view



B25. Three-field sports hall, Friedrich-Ebert-School, Pfungstadt, inside view



B26. Steel construction



B27. Detail steel construction

B28. Inside view

3. PROPOSAL FOR FILIGRAN IN CUBA

1. BAMBOO TO CONSTRUCT VILLAGE

B29 : Plan of the plot, Salto y Ganuza. Source: Bamboo Tourist Village. An alternative for hotel Development in Cuba, 2018

At this time, bamboo is used almost exclusively in the elaboration of furniture and handicrafts, despite the fact that its use in construction is not new at the national level, since it is known from experiences in Granma, Holguín, Villa Clara, mainly in the construction of rural houses, projects promoted by the National Commission of Bamboo and Ratán (CNBR), the NGO Habitat Cuba and the Bambú Biomasa project.

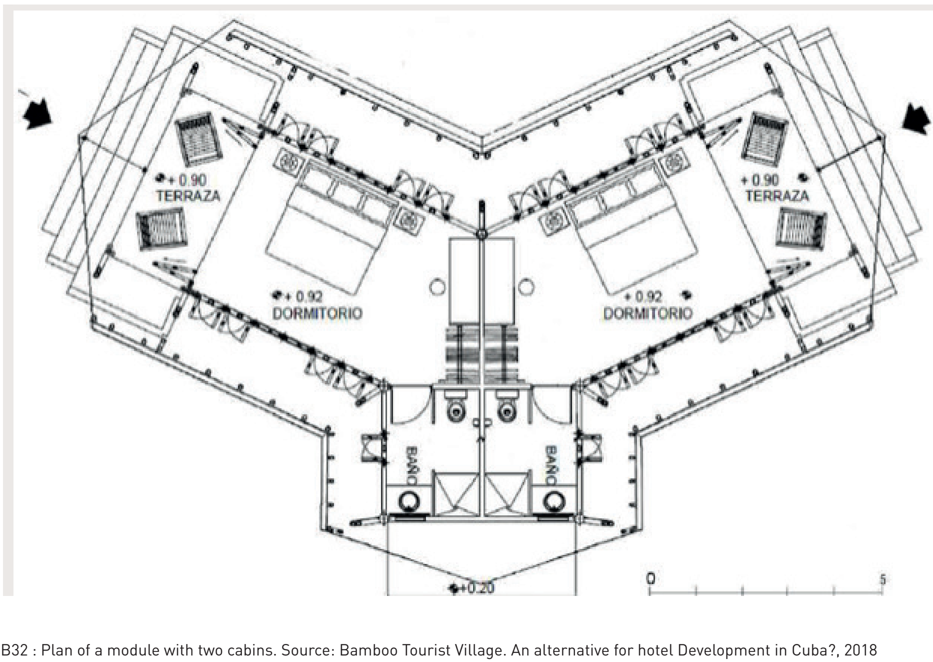
In 2018, a group of Cuban architects and engineers, from the Technological University of Havana (CUJAE) and the University of Las Villas ¨Martha Abreu¨, carried out a research project that explored the advantages and limitations of bamboo as a material constructive, in the proposal of a tourist village in the north of the province of Villa Clara, with which it is expected to contribute in the search for solutions to diversify the tourist offers of the country. The design proposal of the town is made for the area known as ¨Salto y Ganuza¨, located north of the Corralillo municipality, in the province of Villa Clara, since this site was the one that most satisfied the starting requirements, thus like the interest shown by local tourism authorities. The concept is based on the intrinsic characteristics of bamboo as a material that contributes to the preservation of nature, and affects the sustainability of the built environment. This was used to propose a nature-friendly tourism offer that not only made use of this noble material for construction, but also took advantage of environmental resources for its bioclimatic operation.

The facility is characterized by having a well-defined center, made up of public and service areas, from which the trails leading to the cabins start. The socio-administrative building is presented as the first and the highest of the complex, and has the main function of receiving visitors. This building stands on a reinforced concrete floor, and its main premises are built with mortar block walls. However, the areas of social exchange that surround it are open, and share a large roof of bamboo structure covered with guano.

B30 : General plan of the tourist village in Salto y Ganuza. Source: Bamboo Tourist Village.

B31 : General view of the recreational building. Source: Bamboo Tourist Village. An alternative for hotel Development in Cuba?, 2018

The cabins have a Y-shaped scheme, with a common rigid core for two rooms, conceived not only to collaborate with the structure and contain the functions where electrical, hydraulic and sanitary installations are concentrated, but also to serve as a refuge. in the event of a major meteorological event. The rest of the spaces in the cabin use bamboo as the main construction material, although certain measures are foreseen to guarantee strength, stability and durability, such as: use of reinforced concrete in the foundations and piles, reinforcement with mortar and steel of the bamboo bars on floors, columns and main beams, and the independence of the portal structure from the rest of the cabin to avoid the negative effects of the wind. In turn, the cabins are designed for the passive use of natural resources for ventilation and lighting, providing for the use of ceiling fans as a complement. Although no specific calculations were made in relation to the indoor environment, it is estimated that the insulating properties of bamboo, the use of high struts, and the solar protection provided by the roof, are factors that can positively influence the thermal wellbeing indoors.



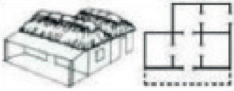
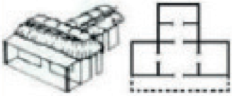
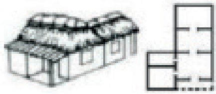
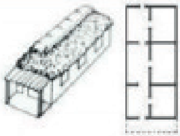
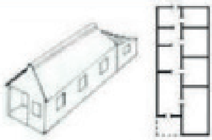
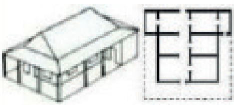
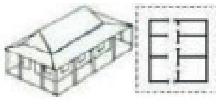
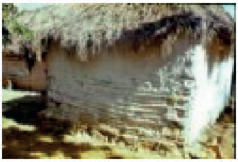
B32 : Plan of a module with two cabins. Source: Bamboo Tourist Village. An alternative for hotel Development in Cuba?, 2018

B33 : Photographie of bamboo rural housing. Source: Bamboo Tourist Village. An alternative for hotel Development in Cuba, 2018

The constructive tradition in the use of natural timber resources, which continue to be accepted by the Cuban rural population for the solution of their habitat, has been hampered by the deforestation process to which Cuba was subjected; Despite the country's current reforestation policy and the gradual increase in forests, the timber species traditionally used in the construction of rural housing in Cuba have a slow development and exploitation in the short term is not allowed.

This situation leads us to think about the application of alternative materials to replace traditional wood, thus thinking of bamboo, as a sustainable source of raw material for the construction of Rural Popular Housing in Cuba.

Bamboo is a versatile and renewable resource, characterized by its rapid growth relative to other species, high strength and low weight, and it is easy to work using simple tools. As such, bamboo constructions are easy to build, resistant (when properly designed and constructed) to the wind and even to the forces of earthquakes, to which important areas of rural settlements of the country . in the eastern region are subjected and can be quickly repairable at the time of damage. It has a long and well established tradition as a tropical and subtropical building material, and is widely used for many forms of construction particularly for housing in rural areas. Products associated with bamboo also find applications similar to those used in construction processes with wood, which have been used in constructive response. to rural housing in Cuba.

colgadizo			
		En forma de T 	**En forma de L** 
Vivienda económica			
Chalet			
Otros tipos	**Sobre pilotes.** 	**Embarrado** 	**De lo urbano a lo rural** 
Tabla resumen No. 1 Tipos y tipologías			

B34 : Table that shows the types of rural housing in Cuba and their tipology. Source: "El bambú, una alternariva sostenible en la solución de la vivienda social".

Of the aforementioned types and typologies, it is necessary to point out that from the so-called economic housing, schemes of the spatial distribution of urban housing begin to be inserted, which is accentuated with the introduction to the rural scale of the solutions with the prefabrication technology, with the use of reinforced concrete, from the 1960s. The use of bamboo is established in substitution of other timber species, in constructive response to Cuban rural housing: wood is considered as the most versatile material used in construction and, probably, the only one with which it can be built. totality of a house: structures, cladding, doors, windows, accessories, furniture; Cuban rural vernacular housing is an example of this.

3. LIMESTONE CALCINED CIMENT PROPOSAL FOR CUBA

At a time when cement ranks as the second most used material on the planet and its production one of the most widespread and harmful to the environment, a formula developed by Cuban and Swiss specialists seeks to transform this dichotomy.

According to international data, global cement manufacturing exceeds 4.4 billion tons and is responsible for between five and eight percent of carbon emissions into the atmosphere, a reality that could change with the introduction of LC3 (Limestone Calcined Clay Cement - calcined clay cement).

LC3 is a novel mixture that has as novelty the synergy between calcined clay and limestone, which influences the reduction of clinker volumes, the most polluting element in common compositions.

The novelty of LC3 not only lies in its environmental potential, but also reduces production costs due to the feasibility of the materials and its resistance can be compared to that of unmixed cements such as Portland despite having 50 percent less clinker.

Only with some 300 million tonnes of LC3 we managed to reduce carbon emissions globally by one percent, explains Fernando Martirena Hernández, director of the project and in addition to the Center for Research and Development of Construction Materials (Cidem), attached to the Central University of Las Villas (UCL).

¨The Kyoto project established the need to reduce the percentage of emissions by 12 units and we are talking about achieving one percent less with a single technology and a minimum investment in less than three years¨. With this objective, experts from Cidem and the École Polytechnique Fédéralede Lausanne, Switzerland have been working together since 2009, with results that today extend to Asia, Europe and America. Countries such as Guatemala, Colombia, Ecuador, Peru, Mexico, India, China, Thailand and Portugal are already demanding the manufacture of low-carbon cement, which, according to Martirena, finds potential consumers precisely in developing nations.

Despite the proven results of the LC3, this new material maintains as one of its challenges the conquest of the Cuban and world industry for its production on a commercial scale, a phase that begins its first steps in the largest of the Antilles.

The three fundamental advantages of the mixture with a view to entering the international market are: lower cost, lower carbon emissions and greater resistance.

After almost a decade of studies, Cuba began the commercial production of LC3 cement, which will allow it to supply the growing demand without having to make large capital investments, and with a reduced environmental impact.

The factory located in the town of Siguaney, Sancti Spiritus province, will produce about four thousand tons of the formula, in what is considered the first commercial production of LC3 produced on the planet.

To reach the industrial step, the team of researchers managed to test the resistance of low-carbon cement after its preservation under difficult conditions for three years in different geographical locations. In the same way, they obtained a special regulation from the Ministry of Construction (Micons), and their release to the market is expected at lower prices than those currently sold on the island.

Another of its advantages is the possibility of producing it locally, grinding brick waste, which is ultimately calcined clay, without the need to carry out extractions or move many materials.

The world demand for cement and other materials that include it in their composition such as concrete, confirm the dire need to achieve a less polluting way of building, especially in developing nations such as India or Latin American countries.

According to Martirena, no other solution such as adobe, wood or steel has sufficient volumes on the planet to solve the problem of the millions of people who do not own a home. This reality has been worrying the cement industry for decades, focused on finding more sustainable and economical ways to build, as proposed by LC3.

In Cuba, a 250 percent growth in cement production is expected, necessary for the planned development for the next ten years. Today less than two million tons are produced on the Island, and it is expected that by 2030 production will increase to 7.5 million tons of cement, destined for the construction of roads, ports, buildings, factories and other works. Within this perspective, the spectra foresee that the LC3 occupies 40 percent of the national production, with a strong boost from the local industry.

B35 : "Cuba produce cemento ecológico menos costoso y más resistente".https://www.google.com/amp/www.cubadebate.cu/noticias/2018/03/31/cuba-produce-cemento-ecologico-menos-costoso-y-mas-resistente/amp/

Coastal protection works play a fundamental role in the development and protection of the human species. They govern, in essence, the development of port and maritime activities. Among the most widespread are breakwaters, breakwaters and piers (walkable breakwaters).

The seawalls are coastal structures that have the purpose of protecting the coast or a port from the action of the waves of the sea or the weather. Cuba, being a country totally surrounded by water and frequently hit by inclement weather, needs this type of structure and its implementation runs the entire width and length of the island.

The penetration of the sea in coastal areas can mean the loss of human life, as well as material goods, so it is essential that the structures designed to counteract this type of situation are sufficiently resistant. Concrete and steel are the construction materials most used worldwide in this type of structure, but the disadvantages of their use in such aggressive environments increase even more when the problem of steel corrosion continues to be an unknown to be solved.

For the aforementioned reasons, it is evident that the use of new materials that cover the weaknesses of steel in this type of environment would mean a greater durability of the structures, which would be reversed in a decrease in their maintenance costs.

Composite materials have emerged since the 1960s to replace these drawbacks of steel. Within this range are the Fiber Reinforced Polymers (FRP). Today these FRP products can be found in the form of bars, cables, bands, meshes, plates, etc. They can match or improve the functions of commonly used steel elements such as bars, prestressed tendons, and tie plates.

PRF composites are defined as a polymeric matrix, reinforced with a fiber or other reinforcing material with a length / thickness ratio that provides a clear reinforcing function in one or more directions.

The fibers can be glass, carbon, aramid, and basalt. These compounds are different from other materials traditionally used in construction, such as steel or aluminum, since the former are anisotropic (their properties vary with the direction of analysis) and the latter are isotropic (they have the same properties in all directions, regardless of the applied load).[5]

Consequently, the properties of PRF compounds are directional, and generally, the properties are manifested in the direction of the fibers.[5] Next, advantages and disadvantages are described according to this same reference.

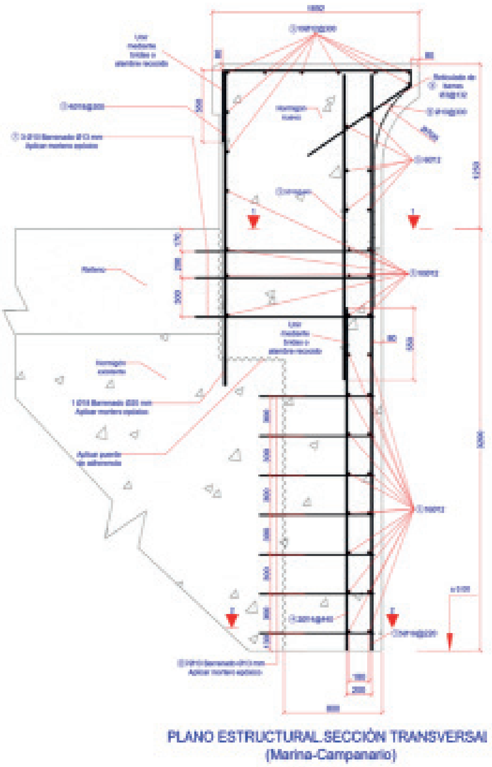


Figura 9. Disposición del refuerzo en el muro

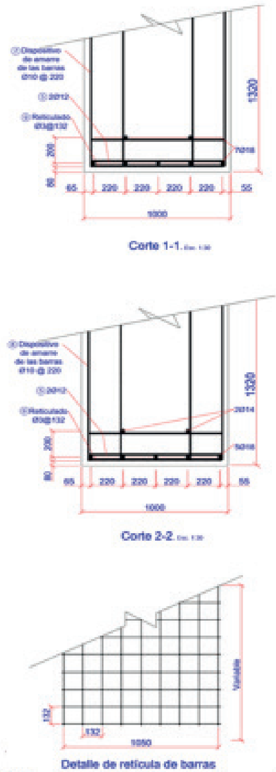


Figura 10. Disposición del refuerzo en el muro. Secc

B36 : Arrangement of wall reinforcement. Source: ""Desing of the wall of Havana seafront armed with polymers reinforced with fiberglass"

The literature recognizes that the shear-resistant capacity of concrete is mainly due to the contribution of the concrete from the compressed area, not yet cracked, and the contribution of the longitudinal reinforcement by bending, that is, the segment effect. In the present case, the contribution of concrete in the compressed area of the section is quite large due to its dimensions, which makes up for the low shear resistance of the GRP reinforcement. The section was designed for the Moment ELU following the aforementioned procedure. An arrangement of five 18mm diameter bars spaced at 220 mm to resist the bending limit state was concluded, but when checking the shear ELU, the arranged bars did not remove the necessary resistance and the section had to be redesigned by adding two more bars.

The reduction of the covering of 10 cm established from being steel the reinforcement to 4 cm with GRP guarantees a considerable saving of concrete.

For example, for a kilometer of boardwalk, the use of GRP would mean an approximate saving of 370 m3 of concrete, counting only the coating in the area of action of the loads produced by the sea. The use of GRP as structural reinforcement presupposes a reduction in material transfer costs, reduction of execution times and labor, greater durability of the structure and reduction of maintenance work.

The reconstruction of the Malecón Habanero reinforced with GRP would bring benefits of a social nature, since being more durable and resistant to the work increases its functionality, which consists of safeguarding the surrounding structures of great patrimonial value, as well as the well-being of the inhabitants of the themselves.

In this research, a design methodology is applied to carry out the preliminary draft of the new variant of the wall of the Malecón Habanero reinforced GRP. This methodology can be applied to similar structures built in other areas of the country.

The resistance of the wall, for the most unfavorable conditions, is guaranteed with the distribution of seven bars of 18 mm in diameter arranged in two layers and spaced at 220 mm. This distribution guarantees a good performance of the element during its service stage.

B37 : View of the Havana boardwalk (Malecón de La Habana). Sourc`pin/440930619742221705/?d=t&mt=signupOrPersonalizedLogin

Sources

1. Wortbedeutung.info [Definition]: https://www.wortbedeutung.info/filigran/, [07.01.2021]
2. Duden [Definition]: https://www.duden.de/rechtschreibung/Filigran, [07.01.2021]
3. Baumgart, Fritz: DuMont´s kleines Sachlexikon der Architektur. Köln: DuMont Verlag, 1977
4. Dregischer, Hans P. ; Lüftl, Sigrid: Leichtbau: Prinzipien, Werkstoffauswahl und Fertigungsvarianten. Weinheim: WILEY-VCH Verlag GmbH & Co.KGaA, 2009, S. 9
5. Wiedemann, Johannes: Leichtbau: Elemente und Konstruktion. Heidelberg: Springer-Verlag Berlin, 2007, S. 3, S. 5
6. Harder, Nadine ; Schlegl, Friederike ; Albrecht, Stefan ; Park, Sumee ; Leistner, Philip: Bauphysikalische und ökologische Potenziale von adaptiven Leichtbaukonstruktionen. In: Bauphysik 40 (2018), Heft 5, S. 307-318
7. Klein, Bernd ; Gänsicke, Thomas: Leichtbau-Konstruktionen: Dimensionierung, Strukturen, Werkstoffe und Gestaltung. 11. Aufl. Wiesbaden: Springer Vieweg, 2019, S. 31-40
8. Material, Structure and construction, Dr Belakehal, [course] http://cours-examens.org/images/Etudes_superieures/Architecture_et_urbanisme/2eme_annee/Architecture/Theorie_projet_S1/Cours_s1_8_2eme_annee_LMD.pdf
9.Bambou house in Bali, [article] https://rencontres-woodrise.ch/architecture-en-bambou-renouveau-global-a-bali/
10. Mein Traum von der Grünen Schule TED ideas, [video] https://www.youtube.com/watch?v=HD4bpztESWw
11. Case study Bambou in Cuba, [book] UNDP
12. Numerical fabrication for light construction, [thesis], https://www.archdaily.com/952445/the-master-of-advanced-studies-in-architecture-and-digital-fabrication-at-eth-zurich-unveils-its-latest-thesis-achievements/
13. Beton Wiki: Geschichte des Beton. https://www.beton.wiki/index.php?title=Geschichte_des_Betons, [08.01.2021]
14. Rempel, Sergej ; Will, Norbert ; Hegger ,Josef ; Beul, Patrick: Verstärken mit Textilbeton: Filigrane Bauwerke aus Textilbeton. In: Beton- und Stahlbetonbau Spezial, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2015, S.83, S.86-87
15. Wikipedia: Textilbeton: https://de.wikipedia.org/wiki/Textilbeton, [08.01.2021]
16. Hanses, Katrin: Basics: Stahlbau. Berlin, Basel: Birkhäuser Verlag GmbH, 2015
17. Engelsmann, Stephan ; Peters, Stefan ; Dengler, Christoph: Filigrane Sporthallenüberdachung mit futuristischer Kunststoff-Gebäudehülle über der dreifeld-Sporthalle der Friedrich-Ebert-Schule in Pfungstadt. In: Stahlbau 89 (2020), Heft 9, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2020, S.780-S.784
18. amerika 21: Kuba produziert Öko-Zement für den Weltmarkt. https://amerika21.de/2015/10/133892/kuba-zement-produktion, [08.01.2021]
19. Matamoros M., Álvarez A.E., Rojas M.P., Pérez B., Fonseca J. P. (2018) "Bamboo Tourist Village. An alternative for Hotel Development in Cuba?" [article] http://rau.cujae.edu.cu/index.php/revistaau/article/download/519/490
20. Pascual J. M. (2008) "El bambú, una alternariva sostenible en la solución de la vivienda social". [article] https://www.redalyc.org/jatsRepo/3768/376859616006/html/index.html
21.. Cubadebate (2018) "Cuba produce cemento ecológico menos costoso y más resistente".
[article] https://www.google.com/amp/www.cubadebate.cu/noticias/2018/03/31/cuba-produce-cemento-ecologico-menos-costoso-y-mas-resistente/amp/
22. Martínez J.J., Wainshtok H.R., Córdova L.F (2018) "Desing of the wall of Havana seafront armed with polymers reinforced with fiberglass". [article] http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382018000200003
23. Carneiro J. A y Wainshtok H. R. (2015) "Empleo de barras y telas de malla de PRF como refuerzo del hormigón y el ferrocemento. Diseno estructural" [article]

List of figures

B17 : „Step of porous assemblieswith 3D printing"https://www.archdaily.com/952445/the-master-of-advanced-studies-in-architecture-and-digital-fabrication-at-eth-zurich-unveils-its-latest-thesis-achievements/ 2020. S15
B18. Rempel, Sergej ; Will, Norbert ; Hegger ,Josef ; Beul, Patrick: Verstärken mit Textilbeton: 2019. S4
Filigrane Bauwerke aus Textilbeton. In: Beton- und Stahlbetonbau Spezial, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2015, S.83
B19. Rempel, Sergej ; Will, Norbert ; Hegger ,Josef ; Beul, Patrick: Verstärken mit Textilbeton:
Filigrane Bauwerke aus Textilbeton. In: Beton- und Stahlbetonbau Spezial, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2015, S.86
B20. Rempel, Sergej ; Will, Norbert ; Hegger ,Josef ; Beul, Patrick: Verstärken mit Textilbeton:
Filigrane Bauwerke aus Textilbeton. In: Beton- und Stahlbetonbau Spezial, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2015, S.86
B21. Rempel, Sergej ; Will, Norbert ; Hegger ,Josef ; Beul, Patrick: Verstärken mit Textilbeton:
Filigrane Bauwerke aus Textilbeton. In: Beton- und Stahlbetonbau Spezial, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2015, S.89
B22. deutsche bauzeitung: Beton im Besonderen: Pavillon aus Textilbeton an der RWTH Aachen.
https://www.db-bauzeitung.de/db-themen/technik/hauchduenn-2/#slider-intro-2 [08.01.2021]
B23. Engelsmann Peters: Dreifeldsporthalle Friedrich-Ebert-Schule. Pfungstadt 2018
https://www.engelsmannpeters.de/portfolio_page/fes/
B24. Engelsmann, Stephan ; Peters, Stefan ; Dengler, Christoph: Filigrane Sporthallenüberdachung mit futuristischer Kunststoff-Gebäudehülle über der dreifeld-Sporthalle der Friedrich-Ebert-Schule in Pfungstadt. In: Stahlbau 89 (2020), Heft 9, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2020, S.782
B25. Engelsmann, Stephan ; Peters, Stefan ; Dengler, Christoph: Filigrane Sporthallenüberdachung mit futuristischer Kunststoff-Gebäudehülle über der dreifeld-Sporthalle der Friedrich-Ebert-Schule in Pfungstadt. In: Stahlbau 89 (2020), Heft 9, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2020, S.780
B26. Engelsmann, Stephan ; Peters, Stefan ; Dengler, Christoph: Filigrane Sporthallenüberdachung mit futuristischer Kunststoff-Gebäudehülle über der dreifeld-Sporthalle der Friedrich-Ebert-Schule in Pfungstadt. In: Stahlbau 89 (2020), Heft 9, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2020, S.780
B27. Engelsmann, Stephan ; Peters, Stefan ; Dengler, Christoph: Filigrane Sporthallenüberdachung mit futuristischer Kunststoff-Gebäudehülle über der dreifeld-Sporthalle der Friedrich-Ebert-Schule in Pfungstadt. In: Stahlbau 89 (2020), Heft 9, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2020, S.782
B28. Engelsmann, Stephan ; Peters, Stefan ; Dengler, Christoph: Filigrane Sporthallenüberdachung mit futuristischer Kunststoff-Gebäudehülle über der dreifeld-Sporthalle der Friedrich-Ebert-Schule in Pfungstadt. In: Stahlbau 89 (2020), Heft 9, Berlin: Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, 2020, S.782
B29 : Plan of the plot, Salto y Ganuza. Source: Bamboo Tourist Village. An alternative for hotel Development in Cuba, 2018
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B36 : Arrangement of wall reinforcement. Source: ""Desing of the wall of Havana seafront armed with polymers reinforced with fiberglass"
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