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A STUDY ON PAPER STRUCTURES AND RECYCLED MATERIALS

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ABSTRACT

Nowadays the design quality and the type of utilized building materials have a vital role in bolstering building's energy and to accomplish this task, architects and engineers' minds have been preoccupied with finding more available, feasible and permanent alternatives. Along with this line of thinking, the ever increasing world population necessitates pondering on recycling wastage especially in building industry in recent decades, to name a few of these thoughts we can consider: utilization of raw materials such as paper and paper waste that is very economical and of course environmental-friendly. Thus today in modern architecture, the quality of materials, utilization of recycled and environmental-friendly materials, using progressive methods of production and installation, modular production and speed in performing tasks, being economical in expenses, light weight of materials and facilities to transfer them and ... are inevitable and necessary to be taken in consideration. This study aims at studying properties and potentials of paper and recycled materials of paper waste and considering it as an option to be used in low-rise constructions as a structural component and also to be used in mid-rise and high rise constructions as a non-structural component. This study target at studying architectural qualities of such constructions, therefore the initial introductory part of this research is about paper and its history, paper materials structures, important experiences of paper utilization in constructions and successful instances in this ground. The second part is all about the necessity of green materials, introduction and recognition of paper materials that are non-structural and recyclable, properties of such materials and the production methods. Finally the last part discusses and concludes the potentials and possibilities of utilization of these materials in constructions and the perspective of such utilization and its role in architecture.

INTRODUCTION

According to ever increasing growth of infrastructural projects and also the problems and difficulties of implementation of building projects and the statistics that report on long implementation time of a project or lack of green materials in a project, architects pay enormous attention to new modular materials, using new building technology and materials which are cheap, simple, environmental-friendly, recyclable and easily implementable and constructible. The new form of today buildings are in accordance with modern human requirements and this distinction is not only because of the different design but also because of implementation problems and used materials in constructions. Human beings are entering a new era of life and due to this fact they are more sensitive to a number of issues as compared to the past. Human beings considering environment maintenance and economical use of energies seriously.

To elaborate on this we must say that our future environment depends on matters like less usage of fossil resources, more usage of clean resources, usage of recycled materials and life cycle and the reversibility of materials. The recent experiences have shown that paper that appears weak and unsustainable has many potentials be applied as a structural and non-structural materials that can meet a part of demands in construction and architecture. We continue with answering the questions that must cross our minds in this matter. Can we use paper and paper materials as a basic material in construction? Can we tackle weaknesses and lacks of paper materials? Can we replace recycled materials with raw materials?

This research has been conducted based and descriptive-analytic method of written and collected library documents, that after amalgamation and collecting has been presented as this essay.

STRUCTURAL PAPER MATERIALS

The history of using paper and cardboard in Japan is pretty old. Considering the earthquake-prone qualities of this area from the ancient times the design of the buildings was done in a way that the least possible harm occurs during intense earthquakes and it was the first target of their architecture. One of the best ways to diminish the amount of destruction of buildings during earthquakes is lightening the building and utilization of materials with lower weights. In architecture paper, cardboard and such materials are being used.

Traditional Japanese architects used to utilize paper sheets called shoji as a divider in different architectural environments. These paper sheets in addition to their light weight and plying the role of divider have an aesthetic aspect to offer to the architects. But what we study in this paper is way beyond the use of paper in Japanese architecture. Nowadays the paper is used as the most significant structural element of the building so that a particular form of paper has been able to replace steel, concrete and other building materials. It happens a lot that we throw away the core cardboard of toilet tissue papers or fax papers and plots but we never could imagine that all these materials can be used as structure elements in buildings.

KEY WORDS

key structures, material recycling, sustainable architecture medicine, *Mus musculus*, *Toxoplasmosis*

Published: 10 October 2016

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Two recent decades witnessed considerable achievements in development of paper utilization in building equipment and tools, constructing permanent or non-permanent structures such as houses and exhibition halls. These varieties of paper usage is due to its potentials to take different shapes, raw materials, modern additives and the facilities that have been created by new production technologies. Geometric shapes and sections of paper in the form of pipes, folded sheets, honeycombs and crust grant us this capability to use them in architectural environments. The feasibility of creating different geometrical shapes with high resistance and slight mass provides its ground to be used in architectural environments. Because the raw material of paper is wood then its technical properties are similar to wood and a certain qualities of wood is concealed in paper. Pipe shapes of paper that resembles the wooden houses is one of the strongest geometrical shapes to be used in building construction and architecture. Form and shapes of paper usage in houses can be similar to the form and shapes of wooden houses.



Fig. 1: The machine which turns paper sheets into paper pipes.

If the paper sheets be cut into strips, smeared with glue and wrapped around round rods in a spiral form, a paper pipe with the cross section of tree trunk would be made. Paper pipes according to their expected functions can be made in varieties of diameter, thickness and length. The possibility of making a paste of paper again and its recyclability give us the opportunity to use it over and over again. Cheapness, facilities to change, simple technology, long lasting natural colors that's has been possible with new additives and having no wastage and debris have increase the utilization of these pipes. [8].

In Australia this pioneering act of using paper in architecture was implemented by a number of architecture students and their head Adriano Puppilli in Sydney University. They started their survey to target at making a two-story building with structural and non-structural paper products. Initially they designed structures in varied shape and with different experiments tested their mechanical strength. [Fig. 2].



Fig. 2: Examining mechanical strength of structural paper components.

Researchers finally concluded that the strongest and the most applicable of all was winged circular cross section rod. As we can see in the figure the extra edge that is put in the middle of the circle in addition to enhance resistance of the rod, has provided a good position for couplings. [Fig. 3].



Fig. 3: Final cross section of structural paper component.

Researchers have examined building materials on their resistance to fire and with adding flame-proof materials have increased the resistance of these materials. After different tests and experiments they finally were able to make a pure paper two-story house. [Fig. 4] structural and non-structural elements of this house is completely made up of recycled, designed and constructed paper. (Papilla, 2003)



Fig. 4: The final structure made up of structural or non-structural paper components.

Shigeru Ban, Japanese architect, has used flat and piped cardboards extensively in building houses, urbanizing, big exhibition halls and emergency shelters. This architect has understood the potentials of paper materials and is one of the pioneers in constructing paper buildings. He has started using paper materials in his works since 1989 and has presented a number of valuable art works so far. [5].

Cardboard cathedral in 2002 was one of Shigeru Ban's famous buildings. Christ earthquake in February 2011, invaded a paralyzing damage to Christ cathedral in New Zealand- it was the symbol of town. To respond to this condition building of the cathedral ignited by the well-known artist of paper materials. Paper pipes with the length of 20 feet incorporated a triangular form. [Fig. 5].



Fig. 5: cardboard cathedral in New Zealand.

This model has been adopted the same geometrically plans and perspectives but there is a gradual modification in the angles of paper pipes. This cathedral has a capacity of 700 persons. It can be used as an event venue or a concert hall. The target of the architect was the exact opening of the building on the same date of earthquake incident i.e. February 2012.

One of the latest paper constructions so far is the temporary pavilion of world cup 2014 in the embassy location of Brazil in Japan Tokyo. To present a place to executing different activities of Brazil embassy in world cup 2014, Shigeru Ban designed a temporary pavilion in the opposite patio of the assistance building of this embassy in Tokyo. This strong construction has been made of very firm recycled cardboard and at the opposite side of this beautiful structure there is another magnificent building designed by the famous Brazilian architect Ruy Ohtake [Fig. 6].



Fig. 6: World cup 2014 temporary Pavilion at the arrival place of the Brazilian embassy in Tokyo.

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This pavilion was constructed by a group of Brazilians in Tokyo and was removed after world cup 2014, the structure of this cardboard building was based on a big pillar and thin rods on top of it that buttresses the translucent and plastic ceiling. This pavilion displays a porous wall from the street view that is filled sporadically with balls. Benches and tables of this place invite various social events. (Ban, 2014)

In our country in 2011 a small house was made with using a factory products of paper pipes in architecture faculty of Shahid Beheshti University. Even though these pipes were made for non-construction targets and basically do not have the necessary applications but have shown the potentials of paper and its hidden qualities in this sample. In Iranian sample two kinds of paper piped were used with the diameters of 17 cm for the walls and 10 cm for covering and ceiling. To couple and connect the walls, ceiling and floor together hemp ropes were passed through these pipes and connect these parts with stitches or pegs together. [Fig. 7] (Sartippour, 2012)



Fig. 7: The implemented sample of paper house, designed and engineered by Saeed Mashayekh Farid.

RECYCLE NON-STRUCTURAL PAPER MATERIALS

All the solid wastes (corruptible or none) which are produced in houses, the centers of production, distribution or selling food products, industrial, agricultural and commercial institutes, hospitals and treatment places are called debris. Throwing these debris away in addition to environmental pollutions will destroy a major part of reversible resources. Recycling industry nowadays is supposed to play a vital role in value added and better utilization of resources in the society.

The researchers of Jean University in Spain have taken another step in environmental-friendly aspects and have been successful to produce bricks from the paper waste. In this process they have produced brick from the wastage of paper factories with less cost and expenses. The wastes of paper factories is along with sludge and mixed with clay from the process of water waste treatment and then will be compressed and exit the machine in the form of paste and used for building materials. [Fig. 8]



Fig. 8: Produced paste from recycled materials.

The pieces of paste that are similar to sausages are cut according to the brick's size and measures and put in the furnace. This process demands less time as compared to traditional brick production. The paper bricks that are produced in 3*1*16 cm are transmitting temperature rather low that is considered of one of their greatest properties. The other merit of invention of this method is reduction of refuse in the place of refuse burial. [Fig. 9] [3].

Although these bricks have less pressure resistance as compared to traditional ones but they have considerable adherence and plasticity qualities and these properties are acquired by mixing a lot of paper refuse. These researchers are hopeful that adding barely, olive and bio-diesel refuse or sewage sludge to this mixture would make these bricks able to overcome their limitations and shortcomings.



Fig. 9: Produced bricks of recycled materials in Spain.

According to the priority of recycling refuse and wastage to their removal or burial, Indian researchers have also made paper bricks out of recycled refuse of paper. This was done by Professor Rahul Raleganokar from Visusavaria national technical institute in India (VNIT). The material used in these bricks was 90% from the recycled paper refuse and 10% cement. These combination was implemented mechanically and then the mixture was poured into the mold and compressed under pressure. After taking out from the mold the mixture is exposed to sunlight for some time. This recycled materials is of low cost production-wise and their light weight make them ideal and precious material to be used in buildings. [Fig. 10] [4].



Fig. 10: Brick production from recycled material and their trial by Indian researchers.

Chemistry researchers of one of the developmental technologies in Eastern Azerbaijan science and Technology Park were successful in producing super-light cellulose bricks from recycled paper fibers. In the production of this super-light brick they used cellulose recycled paper fibers that is considered to be a kind of natural polymer so that after mixing these materials together and molding them, these bricks can be used without any mortar or material added to them. Papers of dry cellulose refuse or newspaper and cartons enter the recycling line and after recycling they turn into paper paste they will be mixed with materials like polymers, Resins and others. Then they are put in contraction molds. Due to existence of humidity in paper structure of these bricks they will be exposed to a flow of dry air or driers to become as designed blocks. [Fig. 11]

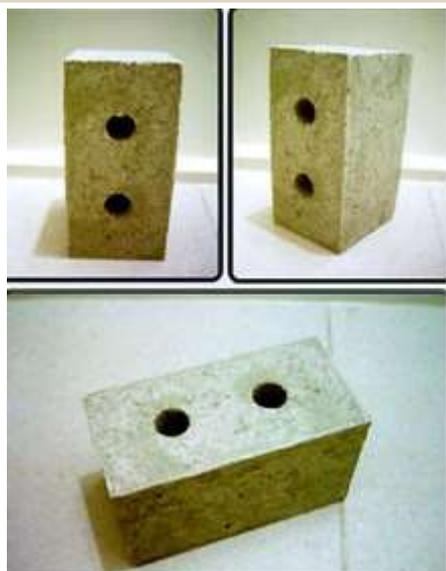


Fig. 11: Production of bricks from recycled materials by Iranian researchers.

Because these bricks do not require any mortar or added materials, for installation they connect together like pieces of puzzle and then a number of rods are passed through them and couple the bricks to the main structures of the building. These bricks can be used in non-porter walls, blade wall and interior parts of the building like EPS walls, and the mixture of these bricks are of ultra-light materials that their density is 0.5 g/cm^3 or 500 kg/m^3 , if we compare these numbers with building materials and structures similar to them the number will rise to $900\text{-}1700 \text{ kg/m}^3$ and because in construction the lighter the weight of the materials the safety of the building is higher this makes the product superb. If you utilize these bricks in the building there is no need of painting because these bricks can be produced with any color and the fire-proof property of these bricks is another merit that makes them superior to easily-catch-fire EPS walls. These bricks can be resistant to fire to 500 centigrade degree. After production of these bricks, their samples were given to Tabriz University students of civil engineering and the results were positive and after being approved by authorities and grabbing enough financial supports the mass production would be triggered very soon. [1].

Practical utilization of this product have been implemented in false ceilings and partition walls. These bricks with their ultra-light weight can be really economical and can decrease the cost of building to 30% of the total cost of construction.

According to surveys in brick production from recycled material and paper refuse, for better utilization of these materials and their mass production, it seems that there are shortcomings in these materials that can limit their usage. One of the pitfalls of paper materials is their low level of strength against humidity. In this field a number of surveys have been conducted that we will consider them. The researchers of Italian institute De Technologika headed by Roberto Singollani have invented a tool to connect cellulose fibers available in paper to nano- particles to create new properties in paper for example paper becomes resistant to water, finds some magnetic properties, becomes florescent or resists against bacteria. The results of this survey were published in Journal of materials. [1].

Researchers of our country have also conducted a number of researches in which they have applied colored coverings based on polymer to make fabric, paper and any kind of building materials water-proof. With utilization of this covering we can make fabric, paper and wood water-proof. This covering penetrates inside the surface and the polymer covering permeates slightly inside the crust while a thin layer of Nylon also covers the surface and make it perfectly water-proof. Because this covering is polymer, it has a great deal of resistance against acid, alkaline and also environmental changes and also is strong against friction and color peeling and chipping. These polymer coverings suggest a wide range of colors from colorless and lucid layers to other colorful spectrums.

The low resistance against fire is the other shortcoming of paper materials. Thus we can add chloride ammonium to the mixture in initial production stages and it makes the bricks more resistant to fire and incineration process starts with delay and difficulty. Or we can add Silicate sodium solution to the mixture to make it fire-proof. Of course the detail of applying these materials demands more field and operational work. (Najafi, 2007)

Thus with fundamental studies regarding block and brick production issues with the use of refuse and wastage and removing their shortcomings, we can achieve a new generation of green and sustainable materials in our country. Now we elaborate on the merits and qualities of prominent properties of bricks produced from recycled materials. Maybe the most significant property of these materials are the light

weight of them compared to their counterpart materials with the same shape, because the ultra-light materials are applied in their production. Resistance to fraction and chipping is one of the other merits of these bricks. The possibility of collapsing due to earthquake or temperature changes in these materials are pretty low in these blocks. This characteristic does not exist in gas blocks of concrete. These materials due to pores and bubbles existing in their structure are considered to be the best materials which are insular to temperature changes. Due to plasticity of these blocks they can be made in the form of tabs and crotch to make an appropriate coupling in the connection points of different blocks. The lack of crotch or tab in the materials can create a lot of problems in the implementation process and it uses more mortar to couple and connect the blocks and this adds to the cost of construction. In mass production of these materials they can be easily sawed, nailed, pierced and slotted and the place for mechanical and electronic equipment can be embedded. The feasibility of this block is really high in its transportation as compared to other products it has less weight and can be transferred in higher volumes. Because of the possibility of mixing these materials with Nano-particles and anti-bacterial materials they do not decay and the growth of mold or other micro-organisms on them is impossible and no insect can lay eggs in it. Due to available materials, the block can be a long lasting product and its properties would not change. The other merit of these materials are their characteristics of being environmentally-friendly. Studies prove that these materials and their production process due to the utilization of green energy is adaptable to environment fully, it does not only prevent harming the environment but also because it cares for refuse and recycling processes, the life cycle of environment can be damaged far less and also can be protected. With more studies this product can be produced according to national standards of construction and make it aligned with the section of 18 and 19 in technical qualities and strength.

CONCLUSION

According to what we mentioned earlier and the fact that today the design quality and consumed materials play a vital role in increasing the energy of the building and considering this fact that in our country one of the main problems is the lack of recycling technology for refuse and spending enormous expenses to refuse reduction and removal and environmental pollution and on the other hand no progress in prefabrication technology and lack of green material usage have created problems in urbanizing and construction. We can conclude that pondering on and investing in the field of optical materials of building using recycled materials is of grand importance. The experiences of using paper in architecture are of beauty, strength, simplicity and elegance. The humble sense of paper; and the capabilities that the new production technologies have created make it possible to shape the paper in varied forms such as pipe, box and sheet, and this plasticity have suggested paper materials as structural materials and non-structural materials like dividers in the buildings. Due to the industrial production of these materials in modular forms, we can witness in future the fast, easy, cheap and sustainable production of these materials in low-rise constructions as structural components with this method. In high-rise construction we can take advantage of non-porting members made by recycled materials.

Even though some part of paper materials merits were revealed, the construction based on them is still in its beginning. To develop and promote construction capabilities as we promoted the use of steel and concrete before we have to educate people about these materials as well. Repetition and sustainability of rational and justified experiences for paper technology application especially building temporary spaces can play an important role in introducing hidden and obvious effect of paper in construction and architecture. Even though paper material potential and capabilities have been proved to be able to create and architectural space in short-term and limited constructions, the utilization of it in permanent constructions demands more time and trial and error.

CONFLICT OF INTEREST

There is no conflict of interest.

ACKNOWLEDGEMENTS

None

FINANCIAL DISCLOSURE

None

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