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The Improvements of Building Materials Innovation: A Review for The Future Architecture Concept

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***Abstract*—** The aims of this study are to evaluate the trend of innovative building materials used. More than 150 innovative building materials for structural and architectural components are gathered. Building components are divided into materials for structural dan surface components for roofing, flooring, walls, and ceilings. The building materials are analyzed from various design considerations including its physical properties including its appearance and performance, environmental properties for energy saving, installation and maintenance factors. This study also evaluates how the materials can meet the requirements to elevate the creativity of the design process and its influence on future architecture by exploring these innovative materials.

Keywords—innovative material, material consideration, future architecture.

I. INTRODUCTION

A. Background

Creativity and innovation are among factors that influence designer ideation, building appearance and choice of building material in architectural design (Idi & Khaidzir, 2015). The characteristics, advantages and constraints awareness of the building materials help the architect to optimize the use of the material. Choosing a building material in architectural design includes many considerations, including physical conditions (visual appearance and material performance), consideration of environmental factors, installation, and the maintenance. Site context, including its geographical and natural condition is one of the indicators in the material selection, where the use of local materials becomes important to accommodate energy saving issues and involving the local community for building construction.

Building materials as it first generally used natural materials from wood, bamboo and other earthen material according to its natural potential where the building was constructed. Based on the environmental issues, the use of solid wood for structural materials is currently reduced. The use of processed wood is increasingly a solution to utilize wood waste for building construction. Laminated wood, for example, continues to be developed to allow building shapes to be more flexible, lighter, smaller but with higher strength by modifying its materials, adhesive, and construction systems.

Industrial technology development brings up steel material which is then widely used because of its ability to create a wide-span buildings. Since the invention of steel, every city competing to make the tallest building with the latest technology. The emergence of concrete material then creating the possibility of organic form design for architecture. In the architectural design, the building structures are often exposed and has an aesthetic value. Glass and plastic material then developed from what was originally used only as building accessories, then became a major element in the architecture. In its current development, the basic ingredients are mixed with additives to increase their strength and durability. Strength and durability considerations are the main considerations in choosing building materials for structural components.

For surface component selection, the purpose is not only for room or building appearance, but also has the material able to provide user comfort. As a surface element which separates interior and exterior, walls and roofs have an important role in creating comfort for the room. Walls and roofs have a function as a barrier to extreme weather conditions (heat/cold, wind, rain, etc.) and the ability to reduce noise. As a non-structural building components, ceiling has a function as a space-forming element, utility pipes cover, heat insulation, and sound absorbers from the roof. The choice of material for flooring is adjusted to the room function and needs. Materials for exterior floor must have a weather resistant and safety specifications. Rooms that require high floor strength, such as drop off area or basement also need distinctive specifications for its selection. Texture, color, pattern, and size of surface materials will create the room image that is adjusted to the Building design concept. The emergence of new material certainly aims to improve one or several aspects of the previous material design. Innovative building materials that appear also have the potential to present new trends in built environment design.

This research will examine the innovative material trends that were already available on the market, both those that have been implemented and those that are either still in the research process. The study is conducted based on the material characteristics mentioned above. Material selection was based on a literature research on trends in innovative building materials that were applied over the past 10 years. Materials collected are classified into materials for structural components and materials for architectural components (including materials for roofing, flooring, walls, and ceilings).

Nearly 150 materials were reviewed based on various aspects of material selection considerations. Each new material is compared to its predecessor material to assess the improvement of material quality. The results were analyzed by evaluating the consideration aspects of material selection which experienced a significant increase from diverse material classifications. Researchers will also examine current material trends and their possibilities in presenting various design trends in the architectural design.

II. LITERATURE REVIEW

As a designer, architects must study building materials and monitor their development. This knowledge will be one of the tools to improve design creativity. Based on its application, building materials can be divided into architectural materials and structural materials. Architectural materials are surface materials that cover up a building component and bearing a structural load, such as roof cover elements, ceilings, walls, and floors. Structural materials are materials for building structural components, such as a foundation, columns, beams, and roof frames.

Classification of building materials based on the raw materials can generally be divided into metal, non-metallic, and composite materials. Metal materials include ferrous metal (iron, steel, etc.) and non-ferrous materials (aluminum, copper, zinc, etc.). Nonmetallic materials include organic materials (wood, plywood, bamboo, etc.) and inorganic materials (cement, sand, bricks, tiles, glass, plastic, and other synthetic materials) (Frick & Koesmartadi, 1999). Composite materials include particulate composite (concrete, conblock, etc.), fibrous composite (asbestos cement board, glass reinforced concrete, etc.), and laminated composite (plywood, etc.).

Choosing material in architecture includes numerous design considerations. Physical characteristics, including its performance and visual appearance, are one of the main considerations in choosing building materials. The material chosen must be able to produce the visual appearance in accordance with the concept of the building. For physical appearance, a material has a different performance depending on the raw material, additive material, and the manufacturing process. Along with structural importance & constructional behavior, visual impact with the historical value of particular materials gives an essence of built environment (Mishra & Das, 2015). In addition, the designer needs to adjust the material to be used in the context of the location of the building including climate considerations. Careful selection of materials can be improved the comfort level of the building by improving the energy efficiency as well as the visual appearance of the building (Tweed Shire Council).

Consideration should be paid to the assembly and maintenance requirements of particular materials. For example, some metal will rust and corrode very quickly within a coastal context. Similarly, a hardwood which is exposed to the elements (salt, sea, sun, and wind) will require regular maintenance to avoid cracking and disintegration (Tweed Shire Council). Materials that are not difficult to install and do not require experts will be more desirable because they can reduce labor costs. In addition, costs can also be reduced if the material does not prescribe periodic maintenance.

For environmental considerations, minimal energy use is an important aspect of choosing building materials. One crucial factor in creating sustainable architecture is the selection of ecological materials. Ecological building materials are materials that have the least transformation (Frick & Koesmartadi, 1999). Classification of building materials can be categorized as follows (1) building materials that can be re-cultivated such as vegetal and animal ingredients (2) building materials that can be reused such as soil, clay, lime, stone, etc. (3) building materials that has a simple transformations change such as clay tiles, concrete blocks, concrete blocks, etc. (4) building materials that experience several levels of transformation changes such as plastic and other synthetic materials (5) composite building materials such as reinforced concrete, fiber cement, chemical paint, etc.

New technologies and high-performance materials are designed to enhance environmental sustainability, the cost-effectiveness, and security (Mohamed, 2017). Minimizing the number of raw materials and energy used, processing used materials into new materials, and creating non-toxic materials are several ways to reduce the negative environmental impacts of building construction. Another innovation is the development of material that is more aesthetic and presents a unique psychological effect. For example, the development of translucent material that can penetrate the light and have a glowing effect, making a different and attractive room atmosphere (Brownell, Transmaterial: A Catalog of Material that Redefine Our Physical Environment, 2006). New material trends also modify many vernacular materials with new, more contemporary forms. The responsive material system develops with the ability to transform and respond to changes in environmental factors. This leads to a more attractive and interactive building surface design while saving energy (Brownell, Transmaterial 3: A Catalog of Material that Redefine Our Physical Environment, 2010).

New materials cannot transform the design and construction industry in a day, or even a decade. Scientific research has produced materials that more durable, waste reducing, change form and adjust to an environmental condition in a different context. Architects and designer should have the knowledge, ethics, and creativity to transfer these technological innovations developed by other industries into the built environment (Klassen, 2004).

III. DISCUSSION

Details of the aspects examined in this study include material characteristics as in table 1.

TABLE I. MATERIAL PROPERTIES

Material properties	Variable
Physical characteristic	Appearance (color, texture, pattern, shape, gloss/matt) Transparency Luminosity Weight Flexibility
Physical performance	Durability (resistance of water/ fire/ weather, chemical, etc)

	Strength Soundproof/ acoustical properties
Environmental properties	Green material Thermal insulation Increasing indoor air quality (non-toxic, anti-allergy, etc) CO_2 reduction
Installation & Maintenance	Simple assembly & low maintenance

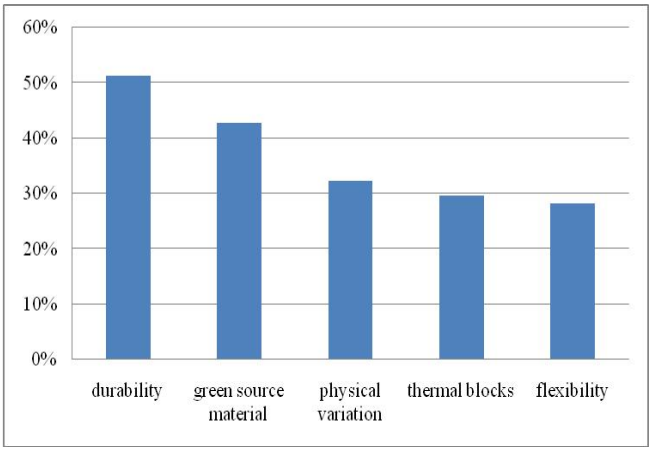

Fig. 1. Innovative building material properties (overall result)

Result shows (see Fig.1) that the most emerging characteristic appears in innovative building materials seem to be more durable, more green, architectural variation, and higher capability for a thermal insulator. These materials are more durable, especially in weather resistance (resistance from water and heat). 43 % of materials are using local sources or recycled material for its main material or additive formulas. This shows that the ecological issue becomes a major consideration in creating new materials and these materials have a big role to reduce building energy. The material's ability to reduce heat for cooling effect and increasing energy efficiency also has a high percentage of the result (30%). Physical appearance consideration shows that the building surface becomes more interactive, thinner, flexible and dynamic with various shapes, color, texture, pattern, transparency, light expression, etc.

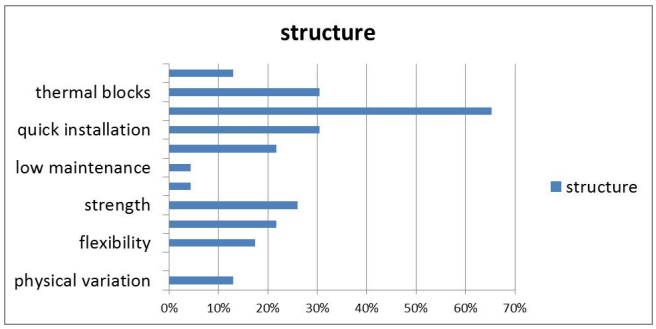

Fig. 2. Innovative building material properties (materials for structure)

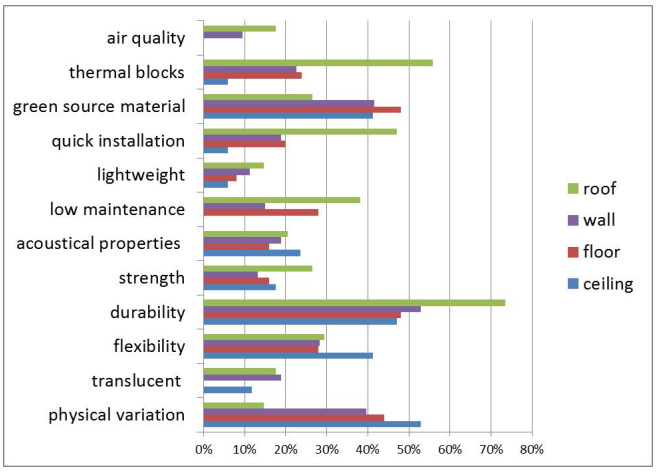

Fig. 3. Innovative building material properties (materials for surface components)

Materials for structural elements

Fig.2 shows that 65% of materials for structural components are using the local material or recycled materials as their raw material. Waste material, e.g. wood, can, concrete, ash, paper, etc and renewable material such as organic fiber, bamboo, etc. is mainly used as a material for a structural component. The latest material for structural components has several improvements that complement the previous materials. This study found that those performance improvements include (1) lighter weight with higher strength (2) faster installation process because it was made in prefab and modular shape (3) more environmentally friendly because it can be recycled and derived from recycled materials or has the ability to absorb pollution, and (4) higher weather resistance such as moisture, heat, water and fire resistant. In addition, in terms of design possibilities, the innovative materials for structure increase the potential for building buildings with organic shapes with curved and thin structures. Structure form potentials to be exposed and creating a delightful impression.

Materials for surface components

Materials for walls, ceiling, roofing, and flooring (see Fig. 3) have more varied in architectural appearance. Building materials have a large selection of colors and patterns that allow a more varied design. The material becomes thinner and more flexible so it is easy to bend, simplify the design with organic forms.

Materials for roofing

Materials for roofing have more improvements in its durability, especially weather resistance and thermal blocks. The roof is the most exposed weather building components that require a higher resistance. New materials for roofing increase the material performance so that space becomes more comfortable. Roof coverings are further combined with the use of renewable energy such as the solar roof to reduce energy use in buildings. A Another characteristic that stands out is a roof covering material is lighter, which reduces the structural load of the building. Another characteristic that appeals is its fast installation. Roof installation must be done

as quickly as possible, so that the interior construction can do immediately when the building has been protected from the weather. The green roof development is also varied, with the improvement in the drainage system and the wide range of vegetation types that can be planted.

Materials for walls

Overall, the innovative materials for walls has more environmentally friendly characteristics, with the used of natural, non-toxic, and easily biodegradable materials. These green materials are varied, including residual coconut skin, glass remnants, processed wood waste, mushroom ingredients, seaweed, mud, peanut shells, processed waste paper, and other natural ingredients. The new materials also have higher durability and more heat resistance. This is because the wall is a surface Barrier between exterior and interior that needs more protection against weather and impact. The modular systems aplication has also become a trend in the innovation of materials for the walls. The wall is the widest surface coverage area in the building so the need for cost efficiency, quick and easy installation is one of the main considerations. The variety of shapes, patterns, textures, and colors of the wall covering materials are also increasingly varied. For example, the presence of light reflecting concrete material has the potential to provide unique and interesting room ambience besides its safety purpose (Fig. 4).

Fig. 4. The potentials of BlingCrete in architecture, interior design and transport safety (source: www.blingcrete.com)

Material for flooring

Like other surface components, materials for flooring also innovates to improve the lack of its predecessor's characteristics. For example the hydrocork floor that mimics the look of a wood parquet, but it has the ability to reduce sound and increase heat and water resistance. Carpet material tends to catch dust and is difficult to clean, but the innovation of the econyl carpet floor from recycled nylon waste is easier to clean and more waterproof so it is friendly for toddlers and animal care. Despite its aesthetic value, use of wood for a surface material is its difficult treatment. The innovation of conwood materials, composite plastic wood, and ceramics wood increases the durability of the material with a look made to resemble wood fiber. The emergence of porous concrete material (ThruCrete) also answers the need for floor covering material with a large load resistance, but has permeable properties for the absorption of ground water and flood prevention (Fig.5).

Green source materials such as glass, bottle caps, and recycled rubber as well as plant-based ingredients also dominates the characteristics of new materials for flooring. One type of floor covering material that has the potential to support green building trends is Pavegen (Fig. 6). This material has the ability to store electrical energy from stamping pedestrians that cross the floor. The basic ingredients are iron, recycled aluminum, and other composite materials. Besides being able to creating energy, this material is able to store data in the form of patterns and the number of footprints of people who pass it. In architecture this benefit can be used to provide information about users behavior and activity pattern that occur within them.

Fig. 5. Asphalt, ThruCrete, and paving block comparison for flooring. (Source: Holcim YouTube channel)

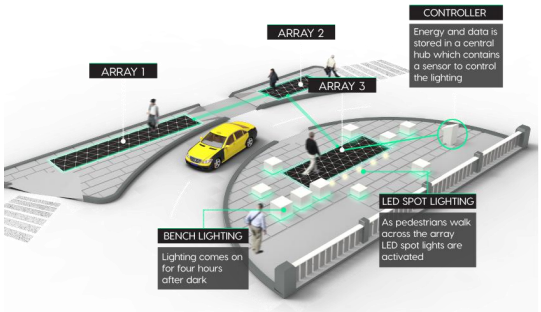

Fig. 6. Pavegen floor tiles. (Source: www.pavegen.com/washington)

Materials for ceilings

Variations in appearance dominate materials for ceiling. The ceiling is not only in sheets, but can also be in the three-dimensional form (3D ceiling pattern). Ceiling cover materials such as luminous textile that can emit light and glass water panels (made from the glass with water movement effect) that are able to reflect a light can create a delightful effect. As an element that is often used to improve room acoustical quality, several innovative ceiling materials also have noise reduction capabilities and acoustical properties. As other surface elements, the use of green materials is one of the dominant characteristics in materials for ceiling. The ingredients come from clam shell waste, banana midrib, rice husk, bagasse, as well as flax, recycled containers, cardboard and recycled plastic. To increase the flexibility of the material and reduce its weight, some ingredients use additional various types of fiber as a mixture.

There are several interesting findings in the innovative materials characterization collected. First, the development of translucent material and self-luminous materials for wall, roofing and structural elements. The main advantage of transparent material is the fact that it can transmit light. There, it can be used to make green buildings. Since it can

transmit light from natural as well as artificial sources, the building can have fewer lights meets its demand for lighting and also saving huge energy cost. Properties of luminous materials open up wide-ranging design possibilities in architecture, interior design, product design, and traffic-safety related areas. Potential applications include the permanent marking of dangerous areas for safety purpose as well as the design of structural-integrated guiding systems and new surface components (facade, floor, ceiling). A translucent material can set up an interesting visual appearance. Design could be more dynamic, rich and flexible. For example, a building with transparent concrete façade can display a massive expression during the day, while at night the building can shine and has a lighter expression with interior lighting design. Another example is the discovery of switchable glass (or often called privacy glass) with the adjustable opacity that allows a space to get privacy flexibility.

Fig. 7. Italy's Pavilion at Shanghai Expo 2010 was built with transparent concrete (source: www.landscapeonline.com)

Fig. 8. Switchable glass with adjustable opacity creates a flexible private level of space. (source: www.techinstro.com)

Another interesting finding is many of the materials has a self-responsive system. They are also called intelligent material. This term is for materials that are designed to enhance their environment and that often take inspiration from biological systems. It can be actively or passively and can be high or low-tech. Various materials in this category indicate a focus on the manipulation of the microscopic scale (Brownell, Transmaterial 3: A Catalog of Material that Redefine Our Physical Environment, 2010). These products are inherently smart by design. In this research, we found that most of the building materials discussed are categorized as passive intelligence. Many innovative materials that can also respond to the environment so as to generate a non-static appearance. Sensitive glass, for example, will create dynamic room atmosphere by its color changes (stimulates by temperature change). Kinetics elements that react by air movements also can make a dynamic façade appearance. Other assorted lists of benefits provided by these self-responsive materials include pollution reduction, solar radiation and humidity control, natural ventilation, power generation, and less maintenance.

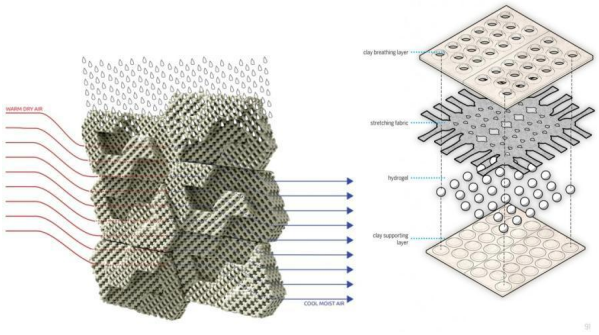

Fig. 9. Hydroceramic and cool bricks– respond to heat and moisture with evaporative cooling. (Source: www. 3dprint.com (left) and www.materiability.com (right))

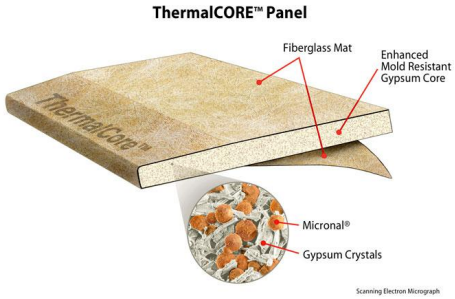

Fig. 10. BASF Micronal PCM (phase change material) – adjust to the material temperature. (source: www.treehugger.com)

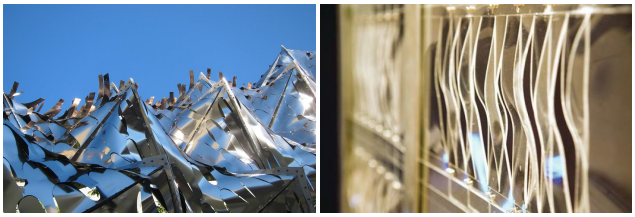

Fig. 11. Thermobimetal and kinetic Glass/ Living Glass as ventilation for a dynamic wall system creating a breathable building. (source: www.materiability.com (left) and www.architectmagazine.com (right)

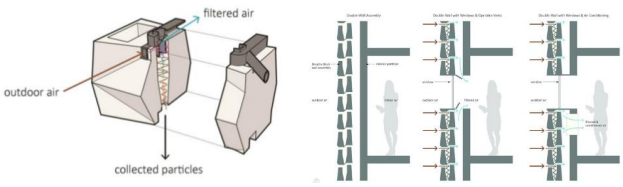

Fig. 12. Pollution absorbing bricks (The Breath Brick) for pollution reduction. (source: www.archdaily.com)

Fig. 13. Self-healing concrete for less maintenance and self-compacting for fast (and precise) production. (source: www.industrytap.com (left) and Civil Engineering YouTube channel (right))

IV. CONCLUSION

Innovative material opens up insights and choices for designers to produce more varied and creative work. This study came to the conclusion that the trend of building materials can form architectural trends in the future that are more sustainable with the selection of ecological materials. Building performance will also increase along with material capability in overcoming various design problems. High/ultra performance building will be a common thing for future architecture. In line with this, the building component will be increasingly multipurpose. Building components are not just for forming a space or aesthetic elements, but furthermore can be integrated as a building equipment to create environmental comfort. With the presence of self-luminous material, the building element has the possibility of acts as lighting and minimizes the energy use of conventional lighting. With this integration, the space design will be more simple and clean. The organic shape will be more developed due to its material's flexibility (thinner and easy to bend to make a curved shape). Some innovative material also can have a different expression with the previous raw material properties. This can make the surprising effect and create a playful building impression.

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