MODULAR CONSTRUCTION AND THE FUTURE OF CERAMIC TILES IN BUILDING

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ABSTRACT

Tile is a unique material that provides beauty and durability for building when used as covering both for inside and exterior finishing. After having been installed through adhered water-based techniques for centuries, tile has finally been recently applied through more efficient and sustainable methods, such as the well-known ventilated façade. The new construction prefabrication volumetric approach requires more than one-by-one installation methods to address the challenges of today's

productivity levels. Industrialized modular building projects sometimes have to deliver in just a few weeks and need materials that are light, easy to handle and rapidly installed. Moreover, tile must compete with panelled materials, which are also offering architectural features that were only recognized in tiles in the past. This paper discusses the role of tile in this new scenario and what the challenges are that need to be faced by tiles as a covering material for building surfaces.

1. INTRODUCTION

Ceramic tile is one of the most amazing materials to build with. It has changed the history of construction since it was introduced thousands of years ago. Quite interesting examples of glazed mosaics and tile applications that have lasted for centuries can be seen in several countries like Morocco, Spain and Portugal.

Tiles have been used for floor and wall coverings, mostly because they are beautiful and durable. They have also been widely used for façades in low-rise to high-rise buildings in countries like Brazil and Japan for decades. (MEDEIROS et al., 2016a)

However, as buildings became higher and higher, other materials have arisen as strong competitors to tiles, such as aluminium and glass. In particular, the use of glass curtain walls has introduced a new installation method, where prefabricated panels are assembled to build a building façade envelope without the use of scaffoldings or any other exterior access equipment for workmanship. The response of tiles came about two decades ago with the introduction of the ventilated façade, which was developed to allow large-sized tile to enter a shared high-rise modern building market. (MEDEIROS et al., 2016b)

While on the one hand ceramic tiles gained a great advantage with the introduction of large-sized porcelain tiles, on the other, many other materials have been introduced to compete with it. One of the most notorious examples has happened in the interior floor market, where melamine laminate and vinyl floorings have increased their market share very fast in the last two decades in Brazil. Although tiles are still a first choice mostly in hot climate areas, laminate and vinyl floor coverings have become natural options for both residential and commercial buildings, especially in temperate zones. (AECWEB, 2013)

For building façades, aluminium composite material and glass have become the strongest competitors to tiles, while painting and decorative cementitious and polymeric coatings play an important role where tile is not mandatory in terms of culture or where tile traditional adhered installation defects have become a significant issue. Figure 1 summarizes the main material now available in the Brazilian market for building façade finishes.

Source: Inovatec Consultores Associados (not published).
***Figure 1** – Types of other materials available for façade cladding in the Brazilian market.*

Construction has lagged behind other sectors of the economy in productivity performance for decades. Nowadays, modular construction has appeared as an opportunity to completely change this scenario. At the same time, digital tools have improved the design process and optimized delivery logistics, creating a new understanding of priorities and investment. It has only been in the last few years that the construction industry has experienced a giant transformation through what is called now "modular construction". Very much restricted to Japan over the last decades, this kind of prefab building technology can now be seen worldwide, but especially in Europe, Asia and North America. (MCKINSEY, 2017) (JOHNSON, 2007)

Modular construction can provide a series of benefits over traditional construction, such as reducing building costs and overall lifetime costs, accelerating schedules and improving quality while saving energy. Additionally, the presence of more material choices can improve the aesthetics of prefab buildings, changing consumer perceptions of prefab as a source of standardized products. (MCKINSEY, 2019)

Prefabricated modular systems are advancing faster and faster all over and it has become a target to achieve industrialized construction in many countries. But what changes could it bring to the market of building finishing materials and how can ceramic tiles take part on this new construction era?

2. MODULAR CONSTRUCTION

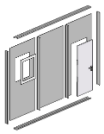
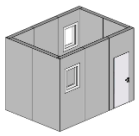
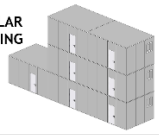
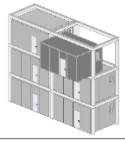
For more than a century, steel and concrete construction methods have played the most important roles for high-rise building construction. For dwelling housing and low-rise buildings, however, masonry and wood frame are still the most widely used material for construction. In Japan, on the other hand, another kind of construction method has played quite an important role, especially in the housing construction market. Since 1959, the Japanese started to produce prefabricated houses as a result of government and private enterprise working together to enhance the productivity of the prefabricated home (MATSUMARA, 2004).

The Japanese succeeded in introducing this transformation in their building market with a sophisticated approach of prefabrication based on the automobile lean production philosophy .also known as the *Toyota lean production system*. Nowadays, about 20% of all dwelling housing construction in Japan is made in factories. (MATSUMARA, 2004).

There are two main definitions for the term "modular construction". McKinsey (2019) defines modular construction as a process that "involves producing standardized components of a structure in an offsite factory, then assembling them onsite." Also, Generalova *et al.* (2016) define modular construction as a group of various technologies based on rapid construction principles, including "the use of separate elements of a frame system that are produced offsite and assembled onsite; and the use of 3D elements."

For Lawson and Richards (2010), "modular construction comprises prefabricated room-sized volumetric units that are normally fully fitted out in manufacture and are installed on site as load-bearing 'building blocks'".

The first two definitions generalize modular construction, making it synonymous with prefabrication or off-site construction. The last one restricts modular construction to volumetric units, which is more accurate in regard to the new practices of the industry. Based on this, Figure 2 shows an illustration and the various approaches of off-site construction terms and strategies.

OFF SITE STRATEGY						
		NON VOLUMETRIC PRE ASSEMBLY		VOLUMETRIC PRE ASSEMBLY		
				ON SITE FINISHED	PLUG IN	
PREFAB STRATEGY		MODULAR COMPONENT 	PANELLING (2D) 	VOLUME (3D) 	MODULAR BUILDING  MOBILE UNIT 	
PROJECT DRIVERS	FLEXIBILITY IN USE	↑	=	↓	↓	
	CUSTOMIZATION	↑	↑	↑	=	
	QUALITY	↑	↑	↑	↑	
	SCHEDULE	↓	=	↑	↑	
	COST / UNIT	↓	=	↑	↑	
MAIN APPLICATION		ANY BUILDING / PART	FACADE PARTITIONS	MASS CUSTOMIZED HOUSING	RESIDENTIAL BUILDINGS COMMERCIAL BUILDINGS	
MAIN MATERIAL	STRUCTURE	STEEL FRAME	LSF WOOD FRAME	LSF STEEL FRAME WOOD FRAME	STEEL FRAME + STEEL / CONCRETE CORE	
	WALLS	ALC DRYWALL WALL BOARDS	CONCRETE GLASS EIFS / METAL DRYWALL	WALL BOARDS TILED BOARDS METAL DRYWALL	WALL BOARDS METAL GLASS DRYWALL	

↑ Increase ↓ Decrease = Irrelevant

Source: author's figure.

***Figure 2** – Forms of Prefabrication According to the Building Production System.*

There are several variations in terms of solutions and materials used by the industry, but the main principle is the same: make a complete house in a factory in a few days and assemble it in less than 30 days in the field, according to the client's wishes.

While in Japan the concept is mostly applied to dwellings, other countries have moved modular construction forward to building. England, USA and Singapore have arisen as leaders of this new movement, which can finally move the building construction industry from its 50's productivity level to another age. (BCA, 2017)

Most modular construction methods use lightweight elements. Light steel frame and wood frame are usually combined with gypsum drywall instead of masonry or concrete walls to facilitate handling and transport. (MATSUMARA, 2004)

Recently two high-rise modular building have finished, one of 32 floors in New York - the world's tallest building built through off-site modular construction (BERG, 2017) - and another one of 29 floors in London, as shown in the following pictures.

Source: ***https://www.businessinsider.com/inside-461-dean-modular-apartment-building-2016-11***

Figure 3 *– 461 Dean designed by Shop Architects located in downtown Brooklyn, NYC.*

Source: *https://www.visionmodular.com/portfolio-item/apex-house-wembley-student-accommodation/*

Figure 4 *– Apex House designed by HTA Design LLP located in The North London Wembley Regeneration Area.*

While 3D printing technology is a promise for the near future, modular constructions has already been making a huge difference in more and more countries. Although modular buildings are designed and manufactured with well-known materials and nothing new has been invented in this sense, how should the tile industry and business react to this? Or should the tile industry just wait to see what happens? Are the materials and methods used in ordinary construction enough to suit this new era of construction or it is necessary to come up with more advanced ceramic tiles and installation methods?

3. NEW TILES AND INSTALLATION METHODS

Figure 5, based on available data from Anfacer (2019), shows the relative participation of ceramic products manufactured in Brazil during 2013 to 2018. While ordinary floor tile production has decreased since 2013, porcelain tiles have increased. Wall tiles and façade tile production have been practically constant for six years.

The 8% decrease in floor tile production represents a loss of 115 million square meters of ceramic flooring. This drop indicates that other materials beyond porcelain are replacing ceramic flooring, like laminate and vinyl floorings as stated by AECweb (2013).

The 6% increase in porcelain production represents just 42 million square meters. In other words, porcelain tile production does not offset the decline in the floor tile segment, indicating that the ceramic industry has lost ground to other materials.

The stability of façade tiles, on the other hand, could be explained by the growth of some other materials in the market, like ACM – aluminium composite material – and the introduction of new materials and installation methods, such as high-pressed laminated panel, both phenolic and melamine. ACM, for instance, has been increasing its share in the Brazilian market and reached more than one million square meters according to ABAL (2017).

Another possible reason is the use of painting and other cheaper render materials where tiles are not a requirement for façades in the local market, as has occurred in the major Brazilian building construction market, São Paulo city metropolitan area.

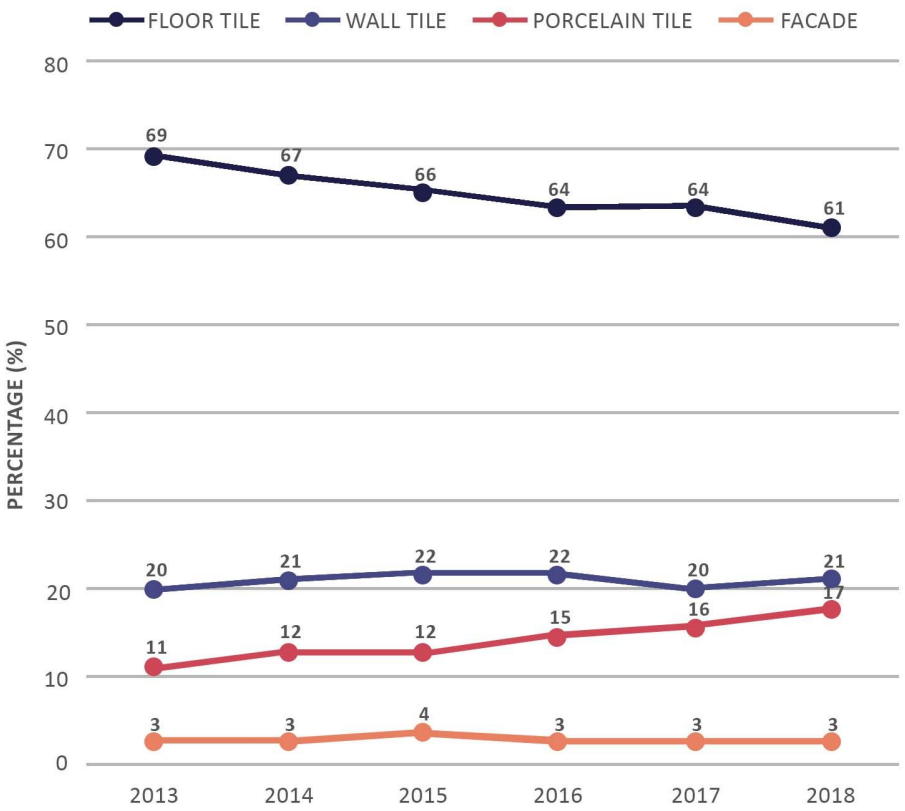


Figure 5 *– Percentage of ceramic products manufactured (2013-2018) in Brazil based on ANFACER data. Source: https://www.anfacer.org.br/brasil?lightbox=dataItem-jz8zn5yh*

Although tile has changed a lot since large sized porcelain tiles were introduced into the market, it seems that a point has been reached where one should question the role of tiles in the era of modular construction by asking what could really change in terms of tile design, manufacturing and installation technology. Being large does not appear to be enough to make tile compete against other materials in this new prefab world where houses and apartments can be delivered almost 100% off-site built and customized. The construction industry appears to be searching for good quality lightweight materials that can last, be easily installed and recycled at the end of the building life cycle. So, maybe the main question that arises is how can tiles meet those new requirements?

Such new perspective introduced by modular construction clearly demands a different response from the ceramic industry. Here are some general initiatives to implement the use of tile under this new perspective:

a) High performance low modulus resin-based adhesives (Figure 6) – new adhesives for tile installation are already being widely used in Japan and allow tile adhered system to achieve a whole new era in terms of safety, combining water tightness, crack bridging resistance and high bonding strength. Besides, it is not necessary to use any grout material, which allows the development of a new style of tile that does not require grout material;

b) Mechanical fixing methods for façades, walls and floors (Figure 7) – ventilated tile façade systems are available in most markets but dry fixing methods for interior walls and floors are still not popular;

c) Self-adhesive installation membrane instead of cementitious mortar (Figure 8) – many other covering materials like high-pressed laminate floors boards come in a way that can be easier and faster than ceramic tiles when installed with adhesive mortars;

d) Development and improvement of decoupling membranes (Figure 9) – these membranes are becoming more and more popular in a few countries. They avoid crack propagation and debonding, turning tiling system into high-performance crack-free systems;

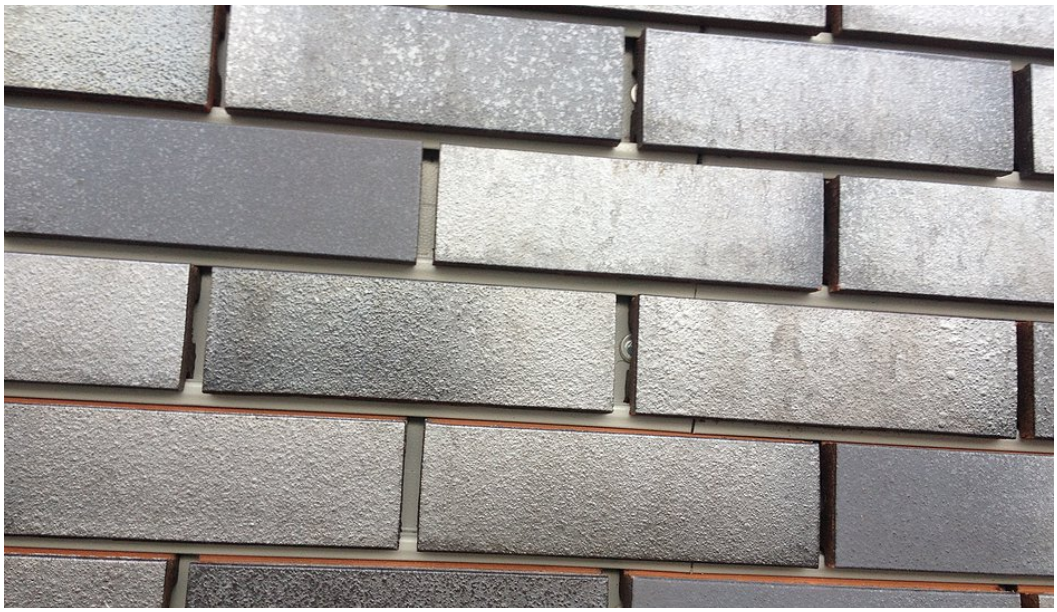
e) Development and improvement of finishing accessories profiles (Figure 10) – metal profiles for corners and balconies, metal and PVC joint profiles, shelves and lightning elements can also improve the quality and durability of finishing tile installations.

f) 3D printed tiles (Figure 11) - 3D-printed ceramic cladding system designed for easy assembly can serve as a rain screen and are made to be hung on a building façade or interior. The surface of each ceramic tile visually emulates a knitting technique called the seed stitch by the author. Figure 4 shows a good example of what is already available.

g) Development of functional tiles to introduce digital solutions for walls and floors (Figure 12) – the Kasita prefab modular house developer predicted a wall of functional tiles to provide a series of features which vary from simple shelves to digital screens, including heating systems, speakers and energy plugs.

Source: author's photo.

***Figure 6** – High performance low modulus resin-based adhesive provides water tightness, crack bridging resistance and high bonding strength. No grout for joints is necessary.*

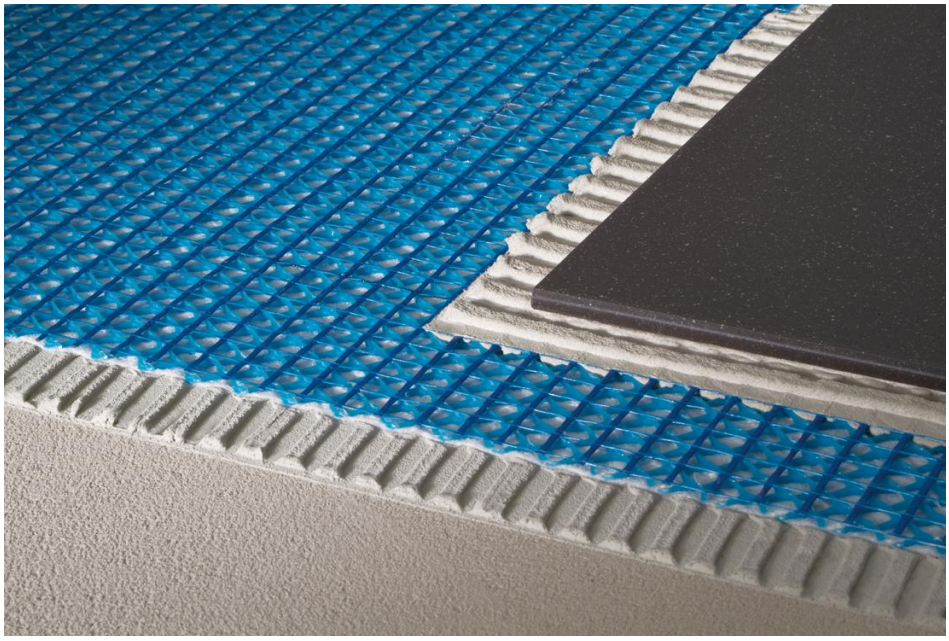


Source: https://interra.smugmug.com/CORIUM-Brick/i-hLSkq3L/A

***Figure 7** – Mechanically installed tiles with no need for adhesive.*

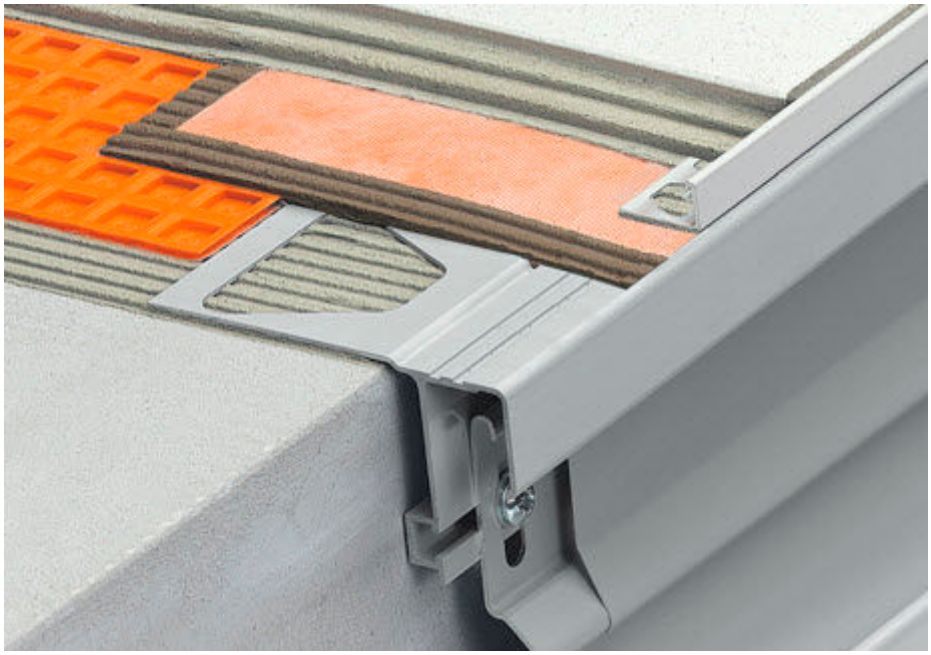
Source: https://www.lowes.com/n/how-to/a-tile-backsplash-without-toil

Figure 8 *– The self-adhesive mat for tile installation replaces water-based adhesive and allows faster finishing.*



Source: https://blanke-systems.com/en/products-for-tile-setting/products/floor-systems/blanke-permat

Figure 9 *–Decoupling and 3D reinforced membranes avoid crack propagation and debonding, improving quality and virtually turning tiling into a more efficient system which behaves well, independently of substrate performance.*



Source: https://www.schluter.co.uk/bara-rake-rakeg.aspx

Figure 10 *–Finishing accessories like this metal edge profile for balconies can take tile systems to another level of performance in terms of quality, design and productivity.*

Source: http://www.emergingobjects.com/project/cabin-of-3d-printed-curiosities/

Figure 11 *– 3D printed ceramic shingles clad the walls and roof of an experimental cabin.*

Source: https://www.youtube.com/watch?v=oIaVTjwFo_M

Figure 12 *– The Kasita tiny house developer predicted a wall of tiles that could provide a series of functions from shelves to LCD screens.*

4. CONCLUSIONS

Tile is a unique material that provides incredible beauty and durability for building finishing and has been used for centuries. It can cover interior and exterior building surfaces with several advantages. Nevertheless, it has been competing with glass, metal, high-pressed laminates and other covering materials, especially when building architecture requires features that go beyond beauty and durability.

Throughout the world, building construction is moving forward to a new era where productivity is the key word. This movement is now well known as modular construction, a way of prefabricating buildings in volumetric parts, which allows high levels of productivity to be achieved, which sometimes mean delivering a house in one single day to the site.

Modular construction off-site methods are rapidly spreading worldwide and require building materials which are preferably lightweight, durable, sustainable, easy to handle and install, all at the same time.

Tile, though, should be rethought in terms of product and installation technology to meet the construction requirements of modern methods, and try to go beyond the existing solutions of ventilated façades and raised floors to compete with other materials that do not requires adhesive nor grout and whose installation depends less on the quality of available labour.

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