CERAMIC TILE AT THE FOREFRONT OF ARCHITECTURE

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INTRODUCTION

The maturation of ceramic tile art and technology has created vast new opportunities for architects to expand their design vocabulary. Exciting new design applications, ranging from cladding of modern amorphous building façades , to technologically advanced prefabricated tile clad panels, have put ceramic tile at the forefront of modern architecture.

Architecture is currently riding the wave of 21st century technology, and once again, architectural fashion is firmly entrenched in a modern design movement. The tenets of the first generation of architecture's modern movement that occurred in the mid-20th century remain intact, most notably, the modern architect's disdain for non-functional ornamentation. However, with the rebellion against ornamentation, architects lost one of their traditional tools for expressing emotion and establishing character in architecture. Many feel that the lack of character and human scale was responsible for the failure of the first generation of modern architecture, and resulted in the trend back to post-modern and traditional design concepts that occurred in the last two decades of the 20th century.

The resurgence of the modern movement of architecture in the 21st century is the result of architects' success with re-defining and transforming the modern movement design vocabulary. Architects have developed new strategies for expressing emotion and character, such as sculpting striking computer-generated forms with advanced technology materials, articulating and expressing structural elements, and creating dramatic spaces which respond to all levels of human scale and spirit. The underlying reasons for ornamentation did not disappear, but were simply transformed and manifest in new ways, most notably through the use of advanced technology building materials. The American architect Frank Gehry is probably the most well known example of an architect who, through experimentation with the metal titanium, has re-defined architectural character simply through the use of a high-technology material in a very sophisticated manner to capture one's imagination and wonder of the power of architecture in our lives and society. Architects have found that the expression of advanced technology materials and methods are the carved mouldings and ornaments of our generation.

Advancements in computerized design technology have lead the way in the latest version of modern architecture, not so much in the development and production of new building materials, but more so in the capabilities to generate, study, and determine the technical requirements necessary to construct complex, sophisticated architectural forms, especially building façades. Whether they are the amorphous skins found in Gehry's style of architecture, or the intricate geometric facade patterns of architects Renzo Piano or Richard Meier's styles, buildings employing advanced technology design techniques and materials will be the focal point of modern 21st century architecture.

THE EVOLUTION OF CERAMIC TILE IN ARCHITECTURE

Ceramic tile has historical roots in architecture. The development of ceramic tile can be traced to ornamentation of architectural elements as early as 4000 B.C. However, it was not until the 13th century that tile was used extensively in the Middle East as both a decorative and functional architectural cladding material. Islamic architecture, with its conceptual basis in highly geometric intricacies, lent itself to expression with the small scale geometric patterns that could be crafted in ceramic tile. The influence of Islamic architecture gradually spread to Spain and Italy in the 16th century, where tile was used extensively as an external cladding on prominent public buildings.

Until the mid-20th century, ceramic tile technology did not permit mechanically resistant and affordable products for floors and pavements, and therefore ceramic tile was used primarily as a wall cladding until that time. It is ironic then, that with the significant developments of new ceramic tile technology over the past fifty years, that the bulk of modern day ceramic tile production has been employed primarily as a floor finish, and not true to its historical roots as a cladding material for building façades. Ceramic tile has enjoyed limited success to date as a true architectural material used conceptually to influence architectural spaces and forms. Despite some aesthetic and technical failures of the first generation of tile façades, tile is now on the verge of bursting into the mainstream of architectural consciousness.

An interesting analogy can be drawn between the current evolution of ceramic tile and the recent evolution of another architectural material, glass. Over the past twenty five years, glass has been transformed into a revolutionary architectural material that today is the driving conceptual force behind many of the best examples of late 20th and 21st century modern architecture. Glass historically was utilized primarily as a functional architectural material until the latter half of the 20th century, when it underwent a technical revolution that has now made glass the most important and influential material in modern architecture today. There were notable exceptions ahead of their time, such as the glass and iron experimental structure of Paxton's Crystal Palace, built in London's Hyde Park in 1851. The design for the Crystal Palace, or perhaps the Galleria in Milan, pushed the limits of glass and iron technologies of that era to the limit. Those pioneer buildings continue today to serve as prototypes and inspiration for modern glass architecture, such as Sir Norman Foster's British Museum renovation in London or his Reichstag Parliament addition in Berlin, both of which prove how a simple architectural material used in daring and innovative ways can influence the essence of architecture.

Glass has always been the modern architect's favorite material, but most of us are all too familiar with the disastrous "glass box" style of modern architecture of the late-20th century which was devoid of human character. Similarly, there were many technical failures of first generation glass architecture, one of the more prominent examples being I.M. Pei's John Hancock Building in Boston, USA. However, modern material and computer design technologies, together with the unlimited imagination and perseverance on the part of architects, engineers and glass manufacturers, have transformed a relatively unsophisticated functional material into a material that today is the conceptual basis for prominent architecture around the world. Studying the evolution glass in architecture provides a valuable lesson for the ceramic tile industry, and should serve as inspiration as to the enormous possibilities of architectural expression with modern ceramic tile technology.

The remainder of this paper is devoted to an informal chronology of empirical experience with tile building façades and other architectural applications of ceramic tile. The examples depicted are not intended to be representative of the most dramatic design with ceramic tile. The intent is to be more representative of the evolution of ceramic tile in architecture over the past twenty years through the study of technical challenges and solutions.

CERAMIC TILE BUILDING FAÇADES

Building façade applications offer perhaps the greatest potential for expanding the use of ceramic tile in architecture. The resurgence of a new generation of the modern movement of architecture has provided the perfect opportunity for architects to exploit tile's highly technical and aesthetic characteristics. Architects are looking for ways to stretch the capabilities of materials and discover new ways to use them. One of the ideas that intrigues architects today is the engineering and use of materials in ways that they have never been used before. Architects have now recognized that ceramic tile has the potential to be utilized as the skin of buildings in even more creative, or perhaps more economical ways than the most sophisticated glass or metal panels available today. Architects are beginning to discover that ceramic tile is not just a decorative cladding material, but can be a conceptual design tool for creating forms and surfaces that are integral to the skin of a building (figure 1).

Figure 1 - Example of ceramic tile as integral to the concept of building façade design composition.

The most common method for cladding façades with ceramic tile in the 20th century relied on direct adhesion of tile cladding at the building site to traditional cementitious or masonry surfaces. One of the most famous 20th century examples of experimentation with ceramic tile as a material integral to architecture is the Casa Batllo in Barcelona, Spain designed by architect Antonio Gaudi in 1905. It is ironic that almost a century later, the amorphous forms of Gaudi's architectural style are in vogue again and serving as inspiration for a new generation of architects to consider use of ceramic tile as the cladding or skin of buildings.

While in-situ adhesion of ceramic tile on façades remains technically viable and desirable under certain conditions, architects have gravitated to exploring other methods of tile cladding. The reason most architects cite is that the tile industry has not provided reliable tile products and construction methodologies specifically engineered and tested for building façades. The first generation of in-situ adhered tile clad façades produced some promising architecture, but many projects were functional and aesthetic disasters. Many other projects were never realized, as regulations did not permit construction due to lack of demonstrable compliance with engineering regulations.

While there has been a vast improvement in both the technical and aesthetic quality of the new generation of tile clad buildings using the in-situ method of adhesion, the lack of systems and products engineered and tested specifically for building façades will continue to limit the architect's consideration of tile clad façades using this method. Nonetheless, architects continue to explore design concepts and produce exciting architecture which derive from the use of in-situ adhesion of ceramic tile.

The residential project at 3 Babington Path in Hong Kong, PRC (figure 2) is an example of the continued popularity of ceramic mosaic tile as an in-situ cladding material for high-rise structures which employ reinforced concrete structures and clay / concrete masonry infill walls. In this project, 45 x 95 mm glazed mosaic tiles were installed in-situ using latex cement adhesive. In many parts of the world, the lack of tested and engineered tile cladding systems has prompted regulatory agencies to limit the tile module size for cladding façades of tall structures, as these types of systems typically do not employ engineered fail-safe mechanisms against falling tile. The lack of a demonstrable factor of safety for in-situ adhered tile cladding systems make them dependent solely on the quality control of installation labor, a somewhat risky endeavor, despite good intentions. As a result, these safety concerns dictate small tile modules as well as height limits for tile clad façades in many countries.

Figure 2 - 3 Babington Path residential high rise project in Hong Kong clad in-situ with ceramic mosaic tile adhered with latex cement adhesive.

Despite safety concerns and regulations, there are many successful high rise building façades clad with larger module ceramic tile. The 28 story Housing Development Board Building, located in Singapore and completed in 1986 (figure 3) , was clad with 30,000 square meters of 150 x 150 mm ceramic tile.

Figure 3 - The Housing Development Board Building, Singapore, clad with 150 x 150 mm ceramic tile and installed in-situ with latex cement adhesive.

The residential development project for the Cloudlands and Cliff at the Peak in Hong Kong, PRC, completed in 1998, is a good example of the continued evolution of the in-situ adhered method of construction (figure 4). In this project, the architectural concept for the façade composition was influenced by material characteristics and their differing expressions and effects on human sensibilities. The architects chose to expose and express the concrete structure as a modern means to provide architectural interest, ornamentation and human scale. Over 8,000 square meters of 300 x 300 mm porcelain tile was installed in-situ with latex cement adhesives. This construction method allowed the architect to simultaneously reinforce and diminish the repetitive pattern and rigid geometry of the structure with the juxtaposition of fluid curves. The expression of structure as ornamentation and as a scale-giving element is further accentuated by the use of dark gray color for the structure against the light gray porcelain stoneware tile. This simple technique enhances the depth of the façade composition and accentuates the fluidity of a porcelain tile skin weaving through the concrete structure.

Figure 4 - Residential project at the Cloudlands and Cliff at the Peak in Hong Kong, PRC, an example of an in-situ tile clad façade, adhered with latex cement adhesives.

The Team Disney Corporate Headquarter Building, located in Florida, USA (figure 5) is a striking example of the importance of color composition to modern architecture, and the unique color attributes and patterns possible with ceramic tile cladding. Of particular interest is the ceramic tile cladding of the reinforced concrete cylinder. This building form thrusts through a deliberate juxtaposition of disparate geometric forms of differing scales to anchor the façade composition and shape a variety of interior and exterior spaces, including the world's largest sundial in the interior courtyard (figure 7). In addition to taking advantage of the color composition possible with ceramic tile, ceramic tile introduced a more human scale to the huge amorphous shape of the cylindrical concrete structure.

There were several interesting technical challenges presented by this project. Interestingly enough, such a sophisticated project was not immune to the need for solutions to traditional technical problems such as delamination of cement renders, water infiltration, and efflorescence staining of tile. The cylindrical shape required extensive rendering in order to meet the precise demands of the geometry, and there was concern over the safety factor of the adhesion to a complex geometrical shape with tremendous thermal expansion and shrinkage differentials due to the complexity of solar orientation and exposure to weather (figures 6 & 7). As a result, a steel wire mesh was anchored to the concrete structure with stainless steel anchors to provide positive, corrosion resistant anchorage to the concrete structure, and a latex-modified render was pneumatically applied to insure consistent technical characteristics and application technique. The force of the render application with compressed air automatically impacted the material to provide maximum density and contact with the concrete, a common problem with traditionally applied renders (figure 8). The anchored mesh controlled both shrinkage and provided a safety factor in the event of delamination of the render. Another technical innovation of note was the use of a direct-bond latex waterproof membrane, a relatively new technology which permits direct in-situ adhesion of tile, while preventing water infiltration (figure 9). Water infiltration and saturation of underlying cementitious materials such as renders or concrete has been a continuing problem with the first generation of tile façades, and this relatively new product technology has proven to be one of several solutions to the problem of efflorescence staining and water infiltration in in-situ adhered ceramic tile building façades.

Figure 5 - Team Disney Corporate Headquarters facade composition of colored glass, stone, synthetic plaster and ceramic tile installed over reinforced concrete with pneumatically applied latex cement render and adhesive.

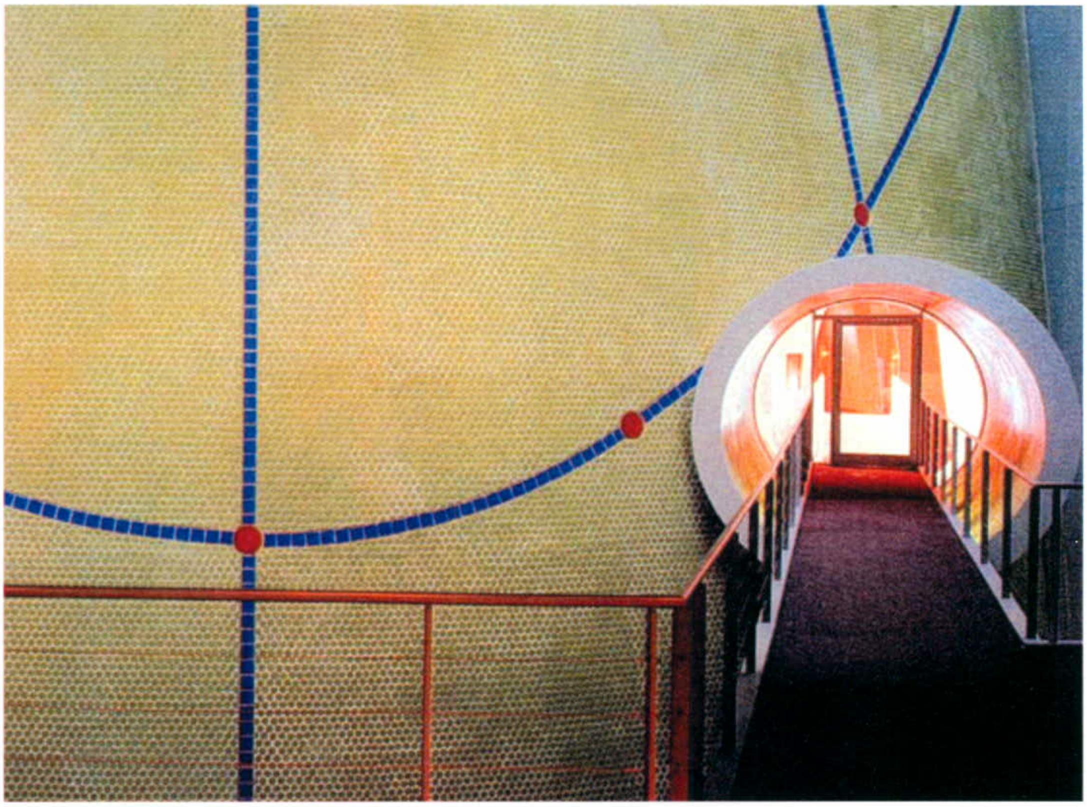

Figure 6 - The external surface of the tile clad cylinder intersects with interior space, creating a variety of thermal expansion conditions.

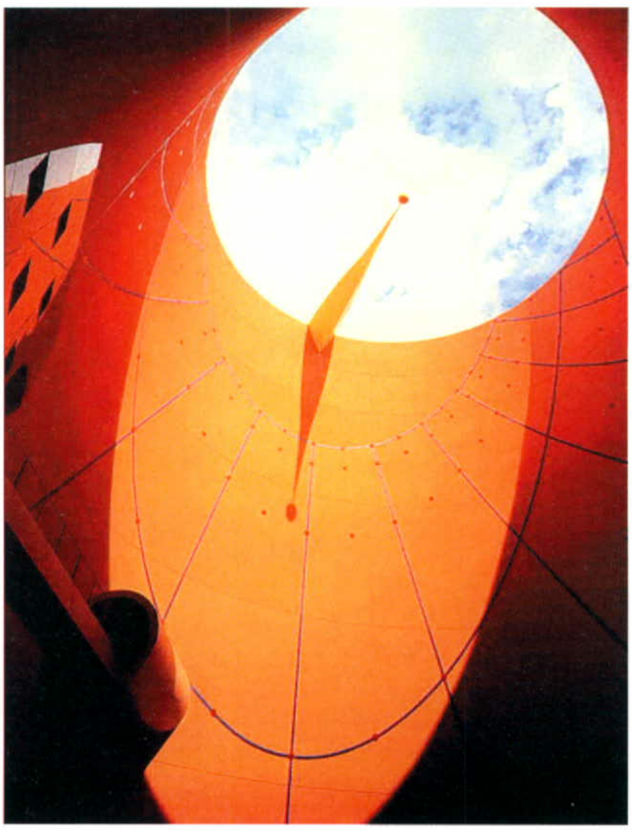

Figure 7 - The internal surface of the tile clad cylinder is exposed to continuously changing solar conditions, creating variable thermal gradients in the cylindrical concrete structure.

Figure 8 - Pneumatic application of latex cement render over steel wire mesh secured to reinforced concrete with stainless steel anchors.

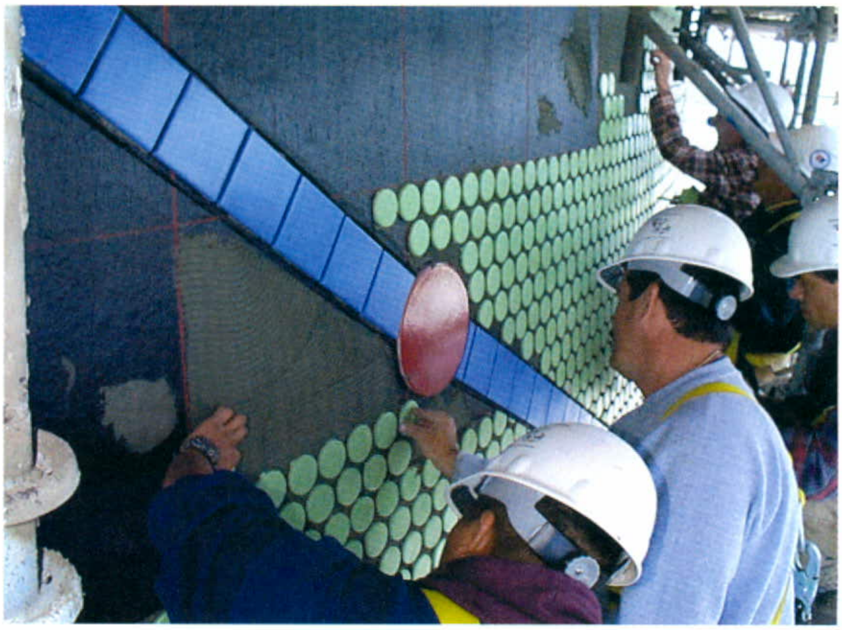

Figure 9 - Installation of ceramic tile over continuous direct bond waterproof membrane across preformed expansion joint (located along both sides of the blue tile) using latex cement adhesive.

The method of utilizing prefabricated ceramic tile panels for building façades has been in limited use for the past twenty five years, and has now become increasingly popular with architects as a result of the resurgence of interest in highly engineered building skins. These tile cladding systems have typically been prefabricated in off-site production facilities, due to the controlled conditions and precise skill required for the construction of both the structural support for the panels, and the installation of the tile. Some systems also use silicone adhesives to adhere the ceramic tile, and this type of attachment requires that the tile be installed in a horizontal position at an off-site production facility until tile adhesion is cured to adequate strength.

Figure 10 - Naval Intelligence Center, Suitland, Maryland, USA incorporating prefabricated ceramic tile clad panels with tile adhered by structural silicone adhesive.

The Naval Intelligence Center (figure 10) is one of the largest building façade installations using prefabricated ceramic tile clad panels. The project consists of over 16,000 square meters of tile cladding installed on over 900 prefabricated panels. The panel structure was constructed of galvanized steel decking attached to light-gauge steel stud structural framing. Over 200,000 ceramic tiles in three sizes and shades of gray were adhered with structural silicone adhesive. The different shades of gray were intended to blend with, and reinforce the colors and textures of the aluminum, glass and stainless steel to express the highly technical nature of the building.

While vehicular tunnels are not typically considered architecture per se, they in effect are an inverted or internal façade that encloses space for human activity, although in most cases human activity at a relatively inhuman scale. Nonetheless, ceramic tile clad tunnels have spawned many new ideas and technologies for the use of ceramic tile in architecture.

One of the most technically challenging architectural projects employing ceramic tile cladding is the Central Artery Tunnel project, currently under construction in Boston, Massachusetts, USA. The Boston Tunnel project employs a total of 120,000 square meters of ceramic tile, of which 89,000 square meters is adhered to prefabricated precast concrete panels. The panels are assembled in a production facility and shipped to the site, ready to be anchored to the structural tunnel walls (figure 11). In addition to providing the substrate and structure for the tile, the tile-clad precast concrete panels act as an inner curtain wall by creating a cavity between the tunnel's outer structural wall and the inner tile clad precast concrete panel. This design provides for the dissipation and drainage of infiltrated water from hydrostatic and vapor pressure differentials present in a tunnel wall, without affecting the performance of the tile cladding. Similarly, this design concept facilitates maintenance of the structural tunnel walls by allowing removal of panels and minimizing damage to the tile cladding.

The ceramic tile-clad panels for this project utilize many advanced construction techniques and materials. The tile is cast integrally at the time of concrete forming and placement, using the negative-cast method. The negative cast method of cladding precast concrete panels with ceramic tile has been used extensively in Japan for many years, where the majority of tile clad building façades employ this method. This method utilizes a key-back tile (figure 14) which is placed finished face down in a mold with steel reinforcing, with the concrete panel cast over and integral with the tile (figure 15) . A latex or epoxy bonding agent is sprayed over the tile and steel reinforcing prior to the concrete placement to insure maximum adhesion strength as well as corrosion protection.

Once the concrete panels are cast, they are steam cured to accelerate and maximize the concrete compressive and adhesion strength. After curing, the joints between the tiles are grouted with epoxy grout. The controlled conditions of the production facility allow the use of epoxy grout, which ordinarily would be prohibitive to use at the construction site on a large scale basis. The epoxy grout has the same rigidity and low maintenance as the tile, and in effect, creates a monolithic cladding surface with durable and low maintenance characteristics. The epoxy grout is also immune to carbonation from vehicle exhaust, and immune to efflorescence, both of which are significant problems in traditional tile clad tunnels with exposed cementitious materials in a continuously damp environment.

The Central Artery Tunnel is projected to carry 245,000 vehicles per day once it is complete in 2003, at a total cost of US$ 16 billion.

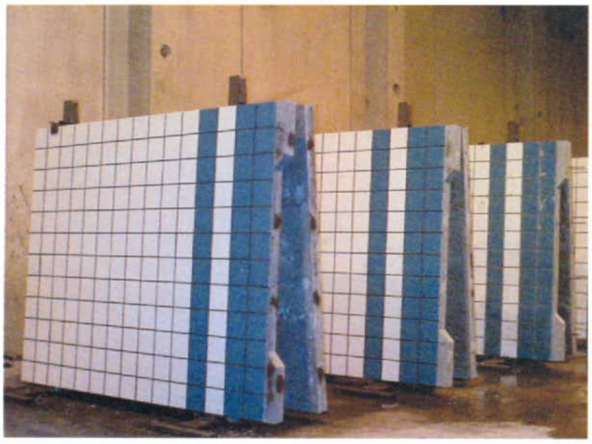

Figure 11- Completed tile-clad concrete panels ready for shipment to the tunnel.

Figure 12 - Placing key back tile face-down into the precast concrete panel mold.

Figure 13 - Panels hoisted into place at site.

Figure 14 - Close-up view of tile bonding surfac.

Figure 15 - Placement of concrete over tile and steel reinforcing.

Figure 16 - Large-scale production capabilities for tile installation.

The development of a new generation of engineered systems for the construction of tile façades will be the driving force behind growth in this sector in the 21st century. Direct adhesion of ceramic tile cladding will remain a viable technology, especially for prefabricated or precast concrete panels. One of the shortcomings of in-situ adhered tile façade systems is that structural behavior is somewhat indeterminate, as field adhesion can not produce consistent and reliable structural engineering values. This is the primary reason why the future of direct adhered tile systems will likely rely more so on prefabricated and precast tile clad panels. However, the most promising method of tile façade cladding, known as the ventilated rainscreen method, employs mechanical attachment of the tile. This method lends itself to the precise engineering required for the advanced technology employed in 21st century building façades. This technology utilizes mechanical anchors that are either prefabricated with the tile, or installed as a post-production accessory to tile (figure 17 & 18), and in effect is similar to the technology used in modern glass and stone curtain wall façades. Many of the dramatic glass structures today not only utilize a laminated plastic interlayer for protection against breakage, but in some cases utilize the extension of the plastic interlayer beyond the glass edge to provide invisible mechanical anchorage to the supporting structure. This is a not only a promising new technology for the glass industry, but also an innovation that may be adaptable to ceramic tile technology.

While mechanically anchored and ventilated ceramic tile technology has been in limited use over the past twenty years, there have been many product engineering improvements, especially in the size and technical characteristics of ceramic tiles that are necessary to make this a more efficient and cost effective method. One example is the larger, structural tile sizes up to 900 x 900 mm, some with new tile surfacing technology incorporating titanium dioxide in conjunction with hydrophilic coatings that can oxidize organic pollutants and promote self-cleansing properties. Another example of engineering improvement is that some ceramic tiles are now specifically manufactured for façades, with technical characteristics and anchorage systems routinely fabricated at the production facility and tested to comply with model international building code requirements for wind and seismic loading.

Ceramic tile façades are not typically regarded as compatible with energy-conscious design and conservation of natural resources, but mechanically anchored and ventilated tile systems, when properly engineered, do demonstrate that sustainable architecture can be realized by providing flexibility in control and dissipation of wind, rain, sound and solar radiation. A mechanically anchored ceramic façade offers a very low weight to strength ratio, thus achieving structural safety and stability with a minimum amount of material. A mechanically anchored natural stone would require a thickness of 30-50 mm to have comparable flexural strength to a 900 x 900 x 15 mm thick porcelain tile engineered for façades. Similarly, as an engineered system, a precise safety factor can be calculated, eliminating the overbuilding required with other methods to insure adequate safety under wind and seismic loading.

The cavity created by a ventilated system plays a major role in efficient and sustainable performance of a ceramic tile façade. One of the most common problems with in-situ adhered ceramic façades is the control of water infiltration, especially the objectionable efflorescence staining that can occur as a result of encapsulation of moisture and cementitious materials behind an impermeable porcelain ceramic tile. Ventilated cavities allow wind-driven rain water to pass through the outer ceramic skin and be dissipated by equalizing internal cavity pressure, collected, and then directed back to the façade surface to be drained in a controlled manner. Wind pressure can also be controlled with this type of system. Wind is gradually buffered and then equalized by the internal cavity, and can also be used to ventilate and cool the outer ceramic skin to promote energy efficiency. The cavity allows for a variety of thermal and acoustic insulation, waterproofing and vapor control devices, not only to suit the climate, but even to respond to the micro-climate and conditions of each façade orientation and design configuration. Greater control and flexibility of color, texture, and special coatings on ceramic tile can further enhance the crucial role of energy efficiency required by sustainable architecture.

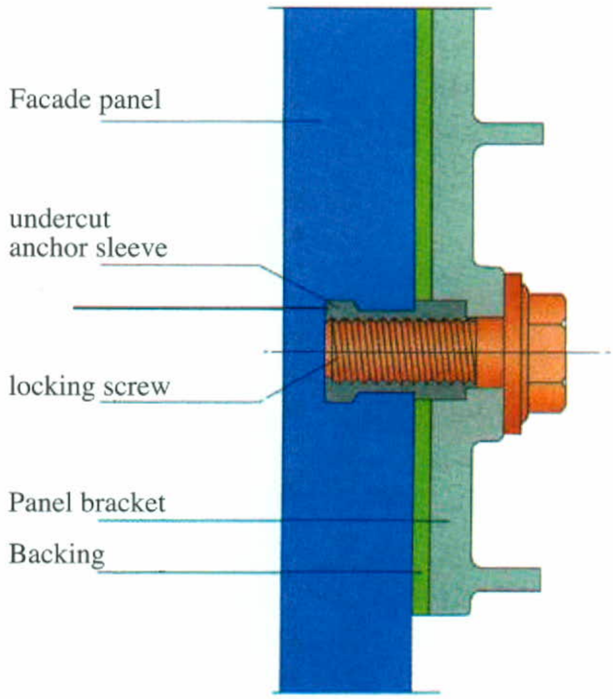

Figure 17 - Diagram of mechanical anchorage of ceramic tile available for tile thickness 10 mm.

Figure 18 - Photo of anchor sleeve which is inserted in precision factory drilled holes.

Figure 19 - Java Coffee Tower, Hamburg, Germany.

In contrast to the engineering benefits, mechanically anchored and ventilated ceramic façades also offer a whole new world of architectural design dynamics which are perfectly suited to the expression of technology so important to 21st century architects. The Java Coffee Tower project in Hamburg, Germany (figure 19) is a simple, yet important representation of the emergence of a new generation of aesthetics for ceramic tile building façades. A ventilated tile façade provides the architect with the technical freedom to express the ceramic tile as a true skin, independent of, or in tandem with the structure of a building. Aesthetically, this relatively new technology provides new design tools for the architect to give a façade a new found depth from the passage of light, and even a sense of transparency that is truly innovative. In some designs, deliberate visual access is provided to the secondary façade layer behind the ceramic tile. In this project, the rigid geometry and differing scales of the tile and the transparency of the blue perforated metal accent strip contrast with the deliberate random window placement in an almost unsettling manner. But it is exactly this type of dichotomy that engages both our conscious and subconscious mind, a quality which distinguishes good architecture.

The Service Center Ostkreuz in Berlin (figure 20) is a good example of both the concept of a ventilated tile façade, as well as the economic and aesthetic benefits of panelization to take advantage of repetitive façade elements. Differing tile colors were utilized (figure 22) to respond to differing site conditions.

Figure 20 - Service Center Ostkreuz, Berlin – example of ventilated tile system using prefabricated panels 3 m x 7.5m wide which emphasize technical details of panel frame and tile attachment.

Figure 21 - Example of current trend towards architectural expression of technology using zinc metal and ventilated tile façade mechanically attached in-situ.

Figure 22 - Full story-height prefabricated tile panel integral with windows.

Figure 23 - Mechanical attachment of tile to aluminum sub-structural frame.

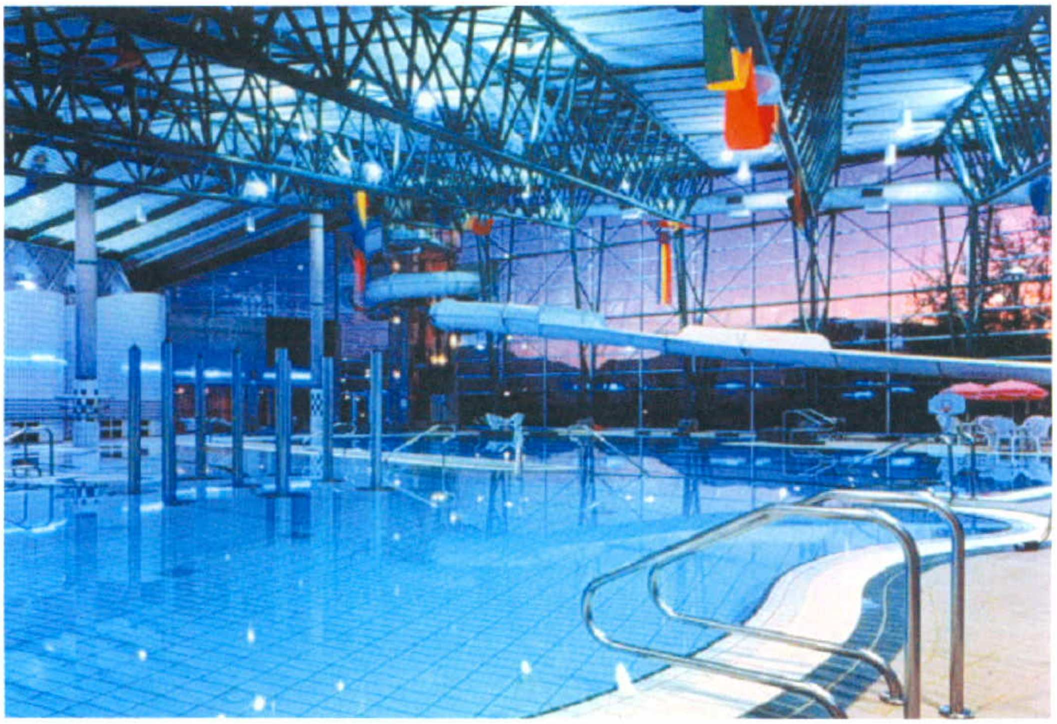

Figure 24 - Eileen Daily Aquatic Recreation Center, Burnaby, BC, Canada.

Ceramic tile traditionally has been the architect's material of choice for the finish of commercial swimming pools, as it is one of the few materials that is both aesthetically pleasing and durable enough to survive the aggressive swimming pool environment. While swimming pools, like vehicular tunnels, are not typically considered as architecture, this building function has been elevated to architectural status through the use of ceramic tile. In some ways, architects are finding design inspiration from their use of ceramics in swimming pools, and are now applying that technical knowledge and creative inspiration to their architecture. As with building façades, new ceramic tile products and installation technologies have given architects the tools to expand the use of tile beyond its functional roots to a more conceptual design level.

The Eileen Daily Aquatic Recreation Center (figure 24 & 25), completed in 1997, is an example of how ceramic tile can be utilized as a conceptual architectural material. Ceramic tile allows creation of undulating forms to express the fluidity of the water and seamlessly integrate a multitude of water features and functions, as well as provide a visual connection and continuity with natural forms through the transparent wall of glass. The ceramic tile also provides human scale and the warmth of color as a perfect compliment to the more rigid and technical expression of the structure. Ceramic tile is unique for this type of architectural application, as no other material possesses both the technical characteristics and human character necessary to achieve this design.

The concept of fluid forms to reinforce the fluidity of water and natural forms associated with water was extended up to the undulating interior tile wall cladding. So in addition to being a traditional decorative and technical solution, tile was used as a conceptual design element to create continuity of architectural forms. This project featured the advanced technology of ceramics designed specifically for water features and pools, and was also one of the first major aquatic centers to utilize new installation technologies, such as epoxy adhesives and joint grouting, as well as direct bond latex waterproof membranes (figure 26). In this project, ceramic tile was the driving force behind the design concept, and not just simply a decorative and functional solution to challenges presented by an existing design.

Figure 25 - Eileen Daily Aquatic Recreation Center, Burnaby, BC, Canada.

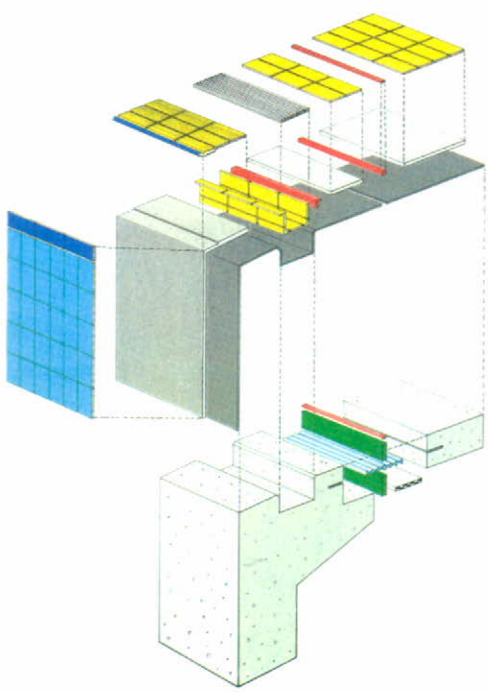

Figure 26 - Exploded isometric view of engineered ceramic tile pool system components, including deck & gutter system, direct bond waterproof membrane (dark gray), expansion joints, and waterstops.

The interior swimming pool at the Intercontinental Hotel in Cyprus (figure 27), built over habitable hotel rooms, employs a contrasting architectural concept compared to the Eileen Daily Center. Here, ceramic tile is used to reinforce and express the formal geometry and rhythm of the structure and glass enclosure. At the same time, advanced ceramic tile and installation technologies allow the pool to be raised and take on the sculptural illusion of a sheet of floating water. The tile module, as well as the lane markings and color variations, contribute to the pleasing scale of the geometric patterns. Ceramic tile is one of the few cladding materials which has both the design and technical characteristics to shape and integrate architectural forms under even the most unusual and harsh conditions (figure 28).

Figure 27 - Interior swimming pool at the Intercontinental Hotel, Cyprus.

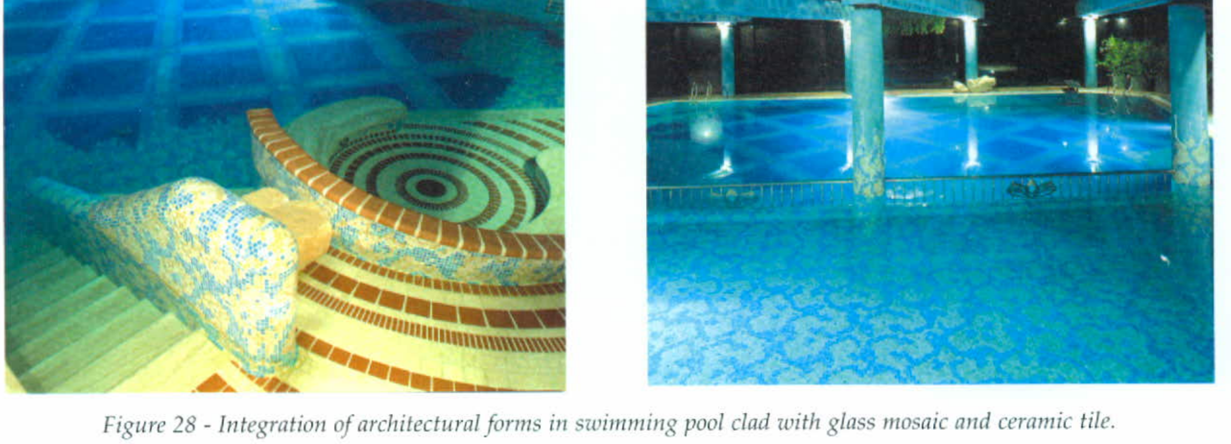

Figure 28 - Integration of architectural forms in swimming pool clad with glass mosaic and ceramic tile.

CONCLUSION

Technological advances both in ceramic tile products as well as new installation technologies have now reached a critical juncture. Architects now have unprecedented design and construction technology at their disposal to explore and stretch the technical capabilities of tile to expand the influence of tile in architecture.

The intelligent and sustainable buildings that will be necessary to allow our society to thrive in the 21^{st} century will be more dependent than ever on materials like ceramic tile, a material that is truly a perfect fusion of art and high technology. The uses for ceramic tile in architecture will be limited only by the architect's imagination, and the ceramic tile industry's willingness to support architects with equal imagination and technical innovation . Ceramic tile technology is in a unique position to evolve and mature along with the technological revolution, and will likely play an important role at the forefront of 21^{st} century architecture.