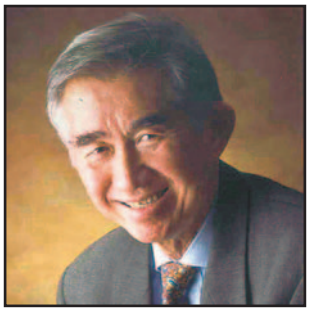
# CHALLENGES OF EXTERNAL WALL TILING IN SINGAPORE



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## 1. BUILDING CONSTRUCTION IN SINGAPORE

As one of the four small Asian Dragons (Korea, Taiwan, Hong Kong, Singapore), Singapore experienced one of the highest levels of construction, if measured on a per capita basis. 25 years after its independence in 1965, the Island-City-State had moved from a developing to a developed status. Housing estates, industrial premises, commercial centres are complemented by roads, expressways, MRT, buses, telecommunication, air and seaports, other infrastructure and a comprehensive range of amenities. In the next 15 years, until today, having provided the basic needs of the city and her people, the construction volume has gradually declined. However, the increasingly cosmopolitan Singaporeans have become much more demanding in the Science and Art of the buildings in which they occupy. The emphasis has shifted from quantity to more than basic qualitative considerations, as well as from meeting basic needs to more sophisticated needs such as improved educational and cultural institutions.

The following three tables provide quick glimpses of the levels of activities during the last 4 decades.

### 1.1. SCALE OF THE CITY

Singapore is a relatively small Country in land and population size. Even so, in order to conserve natural environment and heritage, less than five-seventh of the land is set aside for current and long term future development. The urban density therefore is relatively high.

| Items | Units | 1970 | 1990 | 2000 | Year X * |
|---|---|---|---|---|---|
| **Land Size **** | $Km^2$ | 586 | 633 | 682 | 800 |
| **Population Size** | Million Persons | 2.1 | 2.7 | 4.0 | 5.5 |
| **Urbanized Area** | $Km^2$ | 190 | 312 | 324 *** | 569 |
| **Density, Island wide** | Persons/$km^2$ | 2,580 | 4,814 | 5,885 | 6,875 |
| **Density, Urbanised Area** | Persons/$km^2$ | 11,059 | 8,665 | 12,346 | 9,666 |
| **GDP** | Million S$ | 5,804**** | 66,464 | 139,840 | - |

*(*) Based on 2001 Concept Plan, (**) Size increases through reclamation, (***) Based on 1999 Figure, (****) Based on 1979 figure - Source: URA*

### 1.2. VOLUME OF CONSTRUCTION

In term of building types, construction activities cover all categories:

Residential, Commercial and Industrial.

| Items | Units | 1970 | 1990 | 2000 |
|---|---|---|---|---|
| **Permanent Residents** | '000 | 201 | 274 | 326 |
| **Population in Public Housing** | % | 32 | 87 | 86 |
| **New Towns Lived In** | Towns | 1 | 16 | 23 |
| **Commercial Floor Space** | Million $m^2$ | 0.6 | 5.2 | 9.3 |
| **Industrial Floor Space** | Million $m^2$ | 1.7 | 13.3 | 24.0 |

## 1.3. SPEED OF CHANGE

The transformation of the city has been rapid and orderly. This was accompanied with an ambitious resettlement programme. Based on the land set aside for future population growth and accompanying activities, there will still be ample scope for development.

| Items | Units | 1970-1990 | 1990-2010 | 1990-2030 |
|---|---|---|---|---|
| **Residential** | '000 | 2.5 times | 2.5 times | 1.75 times |
| **Shops, Office & Hotels** | % | 5 times | 1.8 times | 2.5 times |
| **Industrial** | Towns | 9 times | 2 times | 2.5 times |
| **Squatters** | Million $m^2$ | 0.04 times | 0 | 0 |

*Source: URA*

Besides quantity, close attention has also been given to quality and research.

## 1.4. QUALITY ASSURANCE

Despite the haste, quality of buildings has been ensured by clear, up-to-date environmental, planning and building regulations. Building designs are prepared only by registered architects and engineers, and built by contractors classified according to their track records. Safety, durability and defects-free are not compromised. The overarching idea is to build to keep and therefore not to waste precious resources.

## 1.5. BUILDING RESEARCH ACTIVITIES

Despite the decreasing volume of domestic work in recent years, there is a corresponding increase of opportunities, for Singaporean consultants, contractors and suppliers, for the markets around South East Asia and North Asia. Construction in Singapore has a proven track record in both quantity and quality. And while those involved may capitalize from the good Singapore brand name, they and the rest of the Country cannot afford to stand still. Improvements through research are necessary. Not to duplicate the good works in countries in the temperate zone, Singapore could position itself to be one of the leaders in research on construction issues related to the Tropical Belt. In fact, to reach this goal, an informal Steering Committee for Construction Technology was formed about 2 years ago to bring together all the building research centres in Singapore.

It is with this frame of mind, that we come to this conference to exchange knowledge and experiences with you. In particular, while external wall tiling is discouraged in Singapore today, this material, with both merits and demerits, deserves another closer look through research, with the view of bringing it back as one of the alternative finishing materials.

# 2. LONG ASSOCIATION WITH CERAMIC TILES

The use of tiles, from ceramic to natural stone, in Singapore dates back to the early 1900s. The old quarters of Singapore are distinguished by the ubiquitous presence of

mainly 2 or 3 storeyed shop houses. These are townhouses with shops and covered walkways on the ground level and residences on the upper floors. Many of them are decorated on the external walls with charming pastel shade decorative ceramic tiles. These, together with an eclectic combination of other design elements, in different materials painted principally in pastel colours, make the buildings look distinctly "Delicious". Indeed we have had our early romance with decorative ceramic tiles. The main sources of supply in those days were Europe.

In the early years, tiling finishes were also generously applied to the interiors of houses, mainly in bathrooms and kitchens where they provided attractive finishes with little maintenance. The maintenance aspect is particularly important for Asian domestic kitchens where heavy cooking is a daily affair. Today, some of these finishes remain sound and visually stunning. Recent new housing developments have in fact incorporated both dry and wet kitchens to cater to the Asian life-style.

With the advent of high rise buildings in the early 1970s, tiling onto the building facades and envelope was then considered an attractive method for cladding due primarily to its wide variety of colours, designs and textures. Besides requiring little maintenance, it also provides a durable skin that protects the external walls, and insulates the indoor environment from the elements of the Singapore hot and wet tropical weather. Given good workmanship in those days, it is not surprising that water seepage through the façades of buildings was hardly heard of.

Initially mainly mosaic was used but was subsequently overtaken by ceramic tiles. This was due partly to some mosaic failure and partly to change of fashion. In later years, stone tiles especially marbles, made its way onto building facades but such tiles were then bedded with adhesive.

Tiling of facades was highly popular in commercial, public buildings and higher end factories. These include Landmark Tower, Singapore Power Headquarter, Shaw Tower, DBS Building, Beauty World Shopping Centre, Parkway Parade Shopping Centre, Ministry of Environment Building, Changi Airport Terminal 1 and so on. Some residential apartments were also tiled. To name a few, they are Holland Hill Mansion, Nassim Mansion and Maryland Park Condominium. Many of these buildings have withstood the elements for many years after construction. On many of them, the external tiling has remained sound and well bonded. Where, in some cases failures of the façades were reported, they were often caused by structural problems. The relatively high rate of success of these earlier examples is probably due to more ready availability of experienced skilled workers, given adequate time to carry out their craft. These buildings clearly attest to the potential viability of tiled facades to buildings.

In the 1980s, following the successful implementation of prefabrication and pre-cast concrete for public housing, the Singapore Housing and Development Board (HDB) began incorporating clinker tiles with pre-cast concrete panels. This process, carried out in the controlled factory environment, assures good bonding.

## 3. ENCOUNTERING PROBLEMS

Increased incidents of debonding failure of tiles on facades in Singapore took place mainly between late 1980s and early 1990s. From the early 1990s, the use of tiling

as an exterior cladding finish has come under intense scrutiny from the public and the authorities, after a series of widely publicized tile failures from prominent buildings [1-7]

Common types of problem associated with external tiled walls in Singapore include staining, delamination, cracking, efflorescence and joint failure. However, delamination and falling tiles receive the most attention, as it is a serious public safety hazard issue. A survey of tiled buildings in Singapore conducted by Ong and Alum [8-9] in 1994 reported that 42% of surveyed buildings by the study suffered from some form of delamination problems. No details on sample size were given in their report.

As these failures could affect a building's image and value, these incidents were usually not reported unless human injuries or fatality is involved. As a result, no comprehensive and accurate statistical data on the extent of the problems are available. Even for those publicized, findings of the causations were usually kept confidential, save for those involving full litigation proceedings or public inquiry. While the sensitivity of the cases to the owners of the building is understandable, the invaluable learning experience and lessons were wasted.

Although the first traceable published record of external tiling failure was in 1987, public attention was drawn to a short spate of 3 months in 1990, during which debonding of tiles was reported from 3 buildings, i.e. Ministry of Environment Building in September, PUB Building and Yen San Building in November. Two of them were public buildings. Slightly over a year later, in 1992, tiles falling from the 10th storey of Parkway Builders Centre injured a pedestrian at ground level.

Such events had led the then Public Works Department (now Building and Construction Authority, BCA) to issue a memo, discouraging the use of tiles (ceramic and stones tiles bedded with adhesive) on the facades of buildings exceeding 4 storeys. This virtually limited the use of tiles on facades to low-rise buildings. The supply of ceramic tiles thus took a setback. Confidence among professionals on tiled façade was low. While the use of tiles on façade was significantly reduced on new buildings, further reports of failure of bedded tiles on external walls of older buildings were heard from time to time. The tiled façade failure at the Haw Par Techno centre within 1 year after construction in 1993 then almost marks the demise of bedded tiles on building facades.

This unfortunate turn of events was not helped by a common misperception that ease of maintenance equates no need for maintenance. Hence, tiled façades are hardly inspected or checked in the life of a building unless there is failure, often at a level which causes public alarm. This resulted in an over reaction to tiling as a system for external façades.

The phobia of using tiles on facades conversely facilitated easier entry of other façade systems. Other options were considered, like glass, aluminium and stone cladding and curtain wall, which began their market entry around the same time, in the late 1980s. These were very well received and popular in high rise commercial buildings, of course at a cost. For low rise buildings like factories, cement board and rendered finishes were the other cheaper options. These alternatives and cheaper options were not without problems like higher maintenance expenses due to the need for regular repainting or replacement and lower durability. Failures of mechanically fastened stone cladding, spontaneously shattering of tempered glass and debonding of cement sand rendering are known to occur subsequently. Meanwhile water seepage through these building façades becomes a new concern. That goes to show that while

ceramic tiles have their unique problems, other materials are not problem-free. At the end of the day, the choice depends on how effectively and easily can any of these materials contain their problems. This is a challenge for all of us.

## 4. EARLY DIAGNOSES

Experiences gathered from the many failure cases in Singapore and neighbouring countries indicate clearly that failure can occur at any part of a tile system, at or within various interfaces. The problems could be mostly due to a combination of the various stages in the whole building delivery process, from design, detailing, workmanship, materials, specification and maintenance. These issues are further elaborated hereunder.

### 4.1. DESIGN

Design errors include incorrect, inadequate or inappropriate detailing specification. The more common design errors are the lack of or poor provision for movement joints for aesthetic reasons. Where provided, they were often wrongly positioned.

Tile-to-tile joints were traditionally thought as only to accommodate size variations of difference types of tiles. But a well and adequately dimensioned joint allow for proper grouting to prevent water ingress and help accommodate movement of the tiled system. Again, similar to movement joints, practices in Singapore had been to use narrow joints for aesthetic reasons.

There has been a lack of attention paid to proper specification and preparation of plaster. Inadequate consideration to embedment of services and other metals within the tiling system or behind the tiles has also frequently caused failure of the tiles.

### 4.2. WORKMANSHIP

Workmanship together with design is perhaps the main contributing cause of tiling failures. In a number of cases, the presumed tiling failures were actually failure of the plastering works. The plasters applied to receive tile finishes though hidden are no less critical than the tiling installation itself. But they always receive little attention. Lack of protection and curing of the plaster especially under tropical climatic condition, erroneous application of excessively thick plaster and the use of rich mix to increase adhesion, are typical recipe for failures.

While pre-cast concrete cast together with tiles is a well-proven trouble-free method, pre-cast concrete with tiles added on in situ, exacerbate the problems. For the use of mould oil and dense higher grade concrete make it very difficult for plaster and some adhesive to adhere to the concrete surface.

Evidences of poorly applied bedding adhesive are abound. Insufficient and inconsistent coverage of the bedding, wrong method of applying the bedding (spreading or buttering), inadequate pressing in of the tiles, and the use of wrong tools (types of trowels) are typical examples. Movement joints have been found to be poorly applied with inadequate depth and adhesion as well as poorly tooled, resulting in a lack of watertightness.

The root cause of workmanship problem is that Singapore has been plagued by a chronic shortage of skilled workers since the late seventies. There has been heavy reliance of unskilled workers from Thailand, India and Bangladesh. Only 7% of foreign workers here are skilled compared to 30-40% for Australia and Japan. (BCA report, 1996)

## 4.3. MATERIAL

Materials follow the law of science. Failure of materials is often due to failure of man to understand the performance and characteristics of the materials, thus leading to the use of unsuitable tiles and adhesive. In the past, there were tiles known to suffer from excessive irreversible moisture expansion. Under tropical climate conditions, the temperature attained by the tile, depending on the colour, can reach up to 70 deg C. Collectively these can give rise to a significant amount of expansion which may induce stress onto the tiled wall.

Another common controversy is the open time of bedding adhesive, usually 20-40 minutes when determined under laboratory condition. However, when subjected to climate conditions like those of Singapore, the open time of the adhesive can be markedly shorter, depending on time of day and temperature, to less than 15 minutes. This will adversely affect the adhesion bond strength of the tiles. Resistance of the adhesive against slippage of tiles after installation is another aspect which traditionally has been neglected by specifiers and contractors in selecting the adhesive.

## 4.4. ENVIRONMENT

Singapore experiences more than 200 thunderstorms a year, each lasting not more than 2 hours [10, 11]. Mean annual rainfall level in Singapore is usually 235 cm. Wind speeds were measured to be between 1.6 to 2.3 m/s [17]. The hot and wet tropical climate in Singapore poses its own challenges to external tiling during construction and performance of the tiled wall thereafter. The hot weather can affect the performance of the materials when in the fresh state like the shortened open time and workable time of the adhesive. Wet weather could delay the drying of the substrate. The consequential shrinkage which appeared later could deleteriously affect the performance of the adhesive and tile. The unpredictable urban showers and North East Monsoon period from November to December is a dilemma for contractors in work scheduling.

Singapore's weather is also characterized by short spells of heavy afternoon tropical downpours. This sudden quenching of the tiled surface by rain after a hot morning induces thermal shock. The frequent and heavy tropical rainfall demand strict quality control and reliable performance from the joints, both movement and tile to tile joints. These factors can reduce the life span of a tiled external wall to an extent not less known in other countries.

## 4.5. MAINTENANCE

Maintenance is probably one aspect which has been most neglected, especially for a tiled façade as it is always assumed that the tiled façade is maintenance free. A newly constructed tiled façade is hardly inspected, partly because it is never easy to do so in a high-rise building. Some distress or defects are expected in newly constructed

building especially with drastically shortened construction time today. During this period, defects in the tiled façade such as failed joints, should be rectified which would otherwise adversely affect the long term performance of the tiled wall.

The movement joints will typically require replacement every 10-15 years. However, there is a lack of awareness of this and some building sealants were virtually unreplaced for more than 20 years.

One of the biggest predicaments in the maintenance of tiled façade in Singapore is the difficulty in assessing the integrity of the tiles. Often, no inspection is being carried out on the façade to check instability and imminent failure. Although it is mandatory for building owners to engage professional structural engineers to conduct a 5 yearly "Periodic Inspection of Building" for all commercial buildings and a similar 10 yearly one for residential buildings in Singapore, under the Building Control Act, the inspection was confined to checking the integrity of key structural members such as columns and beams. The façade is not included despite the hazard and risk involved.

In summary, there are several major problems in the external use of ceramic tiles in Singapore. The weather imposes a severe demand on workmanship and quality control. Our inability to increase and retain skilled labour from foreign sources with good work ethics is chronic and makes it difficult to ensure good workmanship. On the other hand, the periodic maintenance on high-rise buildings, being costly, is another deterrent to the use of ceramic tiles.

## 5. LIGHT AT THE END OF THE TUNNEL

Experience has shown that a properly designed, constructed and maintained tiled façade or finish system should last at least 30 years, as compared to the current optimistic scenario of 10 to 15 years, before any major repair or retrofitting is needed. As a tiled system is an intricate laminate system, its success depends on the success of each layer and jointing system. It also hinges on the compatibility between the various interfaces of the multitude of materials.

In order to overcome the problems of tiling works, which had transcended the external façade into internal finishes, hypothetically, we can adopt a holistic approach as follows. In some instances, amelioration works have already begun.

### 5.1. LEARNING FROM FAILURES

There is now an increased level of participation among the industry players to examine past cases of failures through proper and thorough investigations of failures and research on maintainability. [12, 13] Two recent research projects carried out by the National University of Singapore deserve special mention. The first one conducted around 1992 with funding from SETSCO is on Durability on Building Facades Under Tropical Conditions. Because of public concern and increased litigation, building owners now became more willing to facilitate researchers to embark on a detailed and thorough investigation into the root causations of failures. The second one, some 5 years later, with funding from the Building Construction Authority (BCA), has produced an interactive expert system on maintainability design and defects mitigation process for building facades under tropical climate conditions.

## 5.2. DEVELOPING NEW PRODUCTS FOR THE TROPICS

Around our region, manufacturers' of materials especially adhesives and grouts for instance are beginning to review their products to cater for the unique tropical climate like Singapore. Even among the specifiers and purchasers such as the HDB, there is an increasing awareness of the specific performance requirements under such environmental conditions in contrast with temperate climate under which most products had been traditionally tested and produced. The HDB for example had established its own set of specifications which better suits Singapore's condition. Through it, new products suitably tropicalised, are beginning to become available, even though rather slowly.

## 5.3. USE OF MORE PRE-CAST FOR EXTERNAL FINISHES

The use of pre-cast construction techniques have been proven to be effective as seen from the incorporation of clinker tiles as part of the pre-cast external walls. This is an aspect to be further explored. With the initiative by BCA on Buildability, pre-cast construction will go a long way towards reducing construction defects not only in tiling works but other trades as well.

## 5.4. SKILLS TRAINING AND DEVELOPMENT

While commendable efforts have been put in by the industry such as the tile adhesive suppliers or tile manufacturers to improve the product to enhance tile bonding, insufficient attention has been given to educate the tilers, builders and architects on the fixing methods and materials. Not only do tilers need to be trained on the use of new generation of adhesives and installation of increasingly larger tiles, but professionals alike need to continuously learn and re-learn material behaviour, adequate specification preparation and installation methodology. Building owners on the other hand, need to appreciate the importance of periodic inspection and maintenance. This issue of training urgently needs to be addressed.

Design and installation of tiles, like any other components in the increasingly complex building construction, requires a team of multi-disciplinary skills and knowledge. There is urgency for the industry to seek out such an approach. Already we are seeing in recent years the engagement of specialists such as independent materials consultants, stone specialists and tiling consultants as part of the construction team to ensure better design, detailing and construction works. Such practice, incidentally, has been long in place for conservation and restoration of historical monuments in Singapore.

Last but not least, in order to pull our limited research resources together in Singapore, the Steering Committee for Construction Technology, referred to at the beginning of this paper, encompasses research institutions, associations and professional organizations to address the future of the construction industry. This committee aims to facilitate an integrated approach towards innovative and quality construction with zero defects for energy efficient, healthy buildings in the tropics. Part of the activities, which this committee has undertaken, includes dissemination of information with regard to past failures, sharing of research findings, strategy planning for future research and studies, as well as development of skills and know-how. The possibility

exists for the issues related to external wall finishing to be holistically addressed through this Committee. Meanwhile, we call upon the international community of manufacturers and researchers to share products and findings with us.

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