STRIVING TO OVERCOME RECURRENT CHALLENGES: QUALICER 1990 - 2008

Commemorative panel session 10thQualicer meeting

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ABSTRACT

Qualicer, the World Congress on Ceramic Tile Quality, has been held on nine occasions – each Congress being extremely successful in several senses. It has literally become THE international forum on ceramic tile. This tenth conference celebrates past achievements, but more importantly, retains its customary focus on the future. In seeking to ensure the continued and responsible growth of the tile industry, we must consider whether tiles can be considered environmentally friendly if tiling systems fail prematurely?

At past Congresses, we have been fortunate to learn from several world renowned experts. Professor Kingery[1] stressed that the ceramic tile industry must make special efforts to benefit from innovative science and new sophisticated science-based technologies. The challenge was to apply the wealth of scientific knowledge of structures, processes and operational principles as tools in solving specific problems facing the industry.

Past papers have reflected some tremendously successful advances in ceramic tile production from a technological perspective, enabling the evolution of innovative products with new characteristics; significant design improvements; traditional products of superior and consistent quality; and improved ecological performance. However, the industry needs to do much more than produce good tiles.

Several papers have considered various types of tiling system failures. Hartog (2000) advised us on "How not to learn from mistakes: recurrent and forthcoming defects in installation of ceramic tiles", as history might suggest an industry incapable of learning from past mistakes. When will we develop the necessary technologies and educational programs to prevent problems?

There have been visionary papers seeking solutions, so ceramic tiling can become universally regarded as a reliable and durable finish suitable for almost any situation, overcoming challenging environments, whilst providing the broadest spectrum of attractive design options.

Qualicer productively focuses on corporate management, social responsibility, environmental issues, tile marketing and new distribution systems. However, has the tile industry globally considered how to ensure superlative tiling system performance? Is the design and installation of tiling systems craft-based or science-based? Should the future of the ceramic tile industry be dictated by traditional experience, or should we engineer systems that will perform reliably, and with adequate safety levels?

This commemorative panel session will re-examine some specific recurrent challenges:

1. *Improving the characteristics of tiling system components*
2. *Providing reliable information to consumers (including architects and engineers)*
3. *Supplying sufficient competent tile fixers to enable the growth of the industry*
4. *Developing installation technologies and ensuring tiling system performance*

This session aims to assess what, if any, progress has been made in ensuring tiling system performance, and what is required to facilitate rapid progress. The challenges are inevitably intertwined, an obvious common thread being Standards and Codes of Practice. Are they fit for purpose to establish fitness for purpose? What simple solutions can we identify? Where should the R&D focus be, from a global industry perspective, rather than a corporate or national standpoint? If we think globally with the aim of acting globally, we might all benefit locally. We might have a landscape of tiled facades inspired by Peixoto[2] (1992).

***CHAIRMAN**:*

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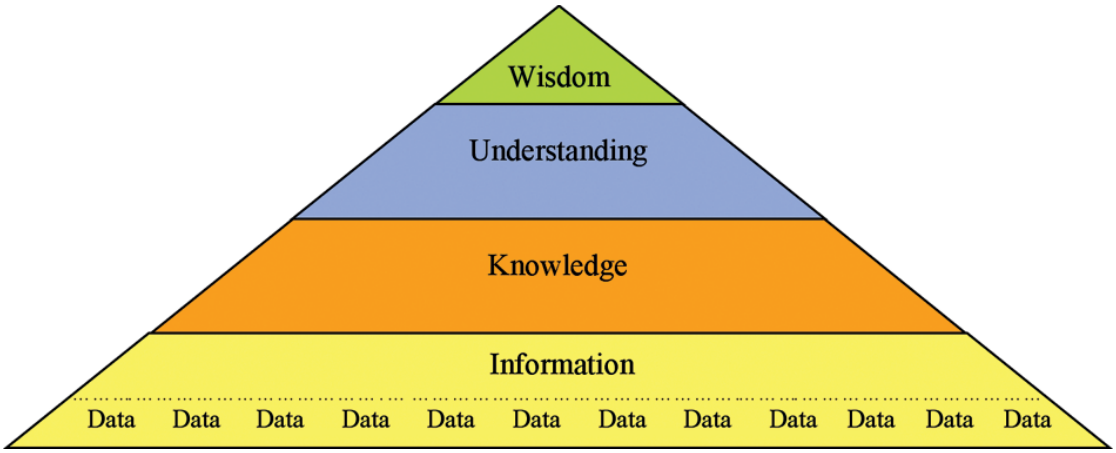

1. INTRODUCTION

"A little neglect may breed great mischief" is the theme for my personal appraisal of the recurrent challenges that face the tiling industry.

For want of a nail, a shoe was lost
For want of a shoe, a horse was lost
For want of a horse, a rider was lost
For want of a rider, a message was lost
For want of a message, a battle was lost
For want of a battle, a war was lost
And all for the want of a nail…

This tale[3] of unintended consequences lies at the heart of chaos theory, and can be used as an analogy for several types of failure, including the failure of tiling systems (and the relative competitive failure of industries). One can immediately appreciate the essential importance of the weak links within systems, and the dire potential consequences of neglect (poor quality assurance). However, it is both simple and difficult to adapt the maxim to tiling systems. It is simple because there are so many potential weak links, possibly starting with failing to fully communicate the owner's needs and expectations to the design professionals. It is complex because so many of the many transactions during the design, procurement and construction processes are based on effective communication between people who require appropriate information relative to their level of knowledge and experience. For want of information, knowledge, experience, etc, any process can be compromised leading to a weak link.

Many failures are due to a combination of causes. The loss of a tiled façade may be largely due to the movement joints failing to relieve differential stresses, possibly due to an insufficient number of joints, inappropriate locations, unsuitable joint dimensions, inadequate preparation of the joint, incompatible materials, improper installation, etc. However, if the design professional team has contributed to the problem, should an experienced builder or a competent tile fixer allow the problem to be perpetuated?

One might simplify the maxim by starting with "For want of knowledge" and ending with "the tiling system was lost". However, knowledge is not paramount, as it is only the mid-stage in the wisdom pyramid. While we all aspire to have wisdom, what we need is understanding of how we should apply our knowledge. Having the correct information is also vital.

I have been fortunate to have attended every World Congress on Ceramic Tile Quality. Since I have raised several issues relating to the recurrent challenges in the papers that I have delivered, I will refer to some of them. They have all fundamentally related to improved tiling system performance based on the provision of reliable information (1990, 1996) and meeting consumer expectations (1994); with particular emphasis on differential movement (1992, 1996) and slip resistance (1998, 2000, 2004). I might summarise them[4] as trying to provide:

1. reliable information about those characteristics of tiles (moisture expansion and slip resistance) that can be blamed for major controversies (delamination of tiling systems and slip and fall accidents);

2. methods of sensibly investigating such situations in order to try to assess the relative contribution of the tile to the problem;
3. improved means of measuring moisture expansion, slip resistance and other characteristics that will influence how tiling systems perform; and
4. enhanced ways of specifying ceramic tiles and tiling systems in order to ensure improved tiling system performance and the fulfilment of consumer expectations.

2. APPLYING KNOWLEDGE (BASED ON RELIABLE INFORMATION)

My Qualicer 90 paper "Possible uses of a Computer-Based Expert System to Ensure Quality of Ceramic Floor Tiling Installations" is still relevant today, as we have the same fundamental problems associated with a fragmented building industry, the management of change, planning for whole building quality, and management of building information. I wrote:

> *"While tiles are frequently selected on the basis of aesthetics and cost, too little regard may be paid to pertinent technical considerations. Computer-based systems, that respond to the answers of a series of pre-programmed questions with respect to the intended use of an area and its basic structural details, can provide architects and specifiers with data on appropriate floor finish materials, possible installation methods and advisory comments. Enhancement of the system can allow material requirements to be quantified, the various options to be costed, and job specifications to be issued with additional detailed instructions to tradesmen, building supervisors and others. When the expert system is linked to a product data bank containing the characteristics of tiles of certified quality, architects and interior decorators will be able to select tiles secure in the knowledge of their quality (fitness for purpose) and value (life cycle cost benefit), while making a decision based on aesthetics and initial cost".*

Was suggesting **industry could provide reliable information to architects** too optimistic?

By 1995, there were a number of computer-based specification and selection systems available to the ceramic tiling industry. These varied dramatically in terms of their scope, capacity, capability and performance. The first generation of adhesive manufacturers' computer-based specification systems essentially duplicated manual procedures, but without adding significant value. The DEA system, a cooperatively developed European product, comprised many elements within the one package, where the user could buy only those modules that they required. Most of the individual tasks that the DEA system could fulfil could be accomplished by other systems, but it was essentially a single integrated tool for creating, coordinating, controlling and carrying out marketing strategy.

At the same time, CompuTile Pty Ltd (a wholly owned Australian owned company led by Colin Cass) had created an interactive system called TileWriter. This concentrated on the needs of design professionals and the process that they follow to produce the best possible tiling specification for any given situation or project. TileWriter initially took the design professional through a series of technical selection options where information about the particular project was sought. This information was then

used to identify suitable tiling systems and to select appropriate tiles, adhesives, grout and other supporting products, where specifiers could choose between competing manufacturers. TileWriter allowed an aesthetic selection of tiles to be made from the qualified products. It overcame the problems of recycled generic specifications. These loosely worded documents are frequently peppered with the term 'or equivalent', and thus allow the subsequent substitution of lower cost products, which are often of lower quality, and less suited for the purpose.

TileWriter delivered an up-to-date, accurate and specific specification for the tiling system and each component, written in a uniform format, which could be compiled readily into the project documentation. It provided a verification function that allowed the designer to cross-check compliance of the recommended system with the regulations. It provided a genuine choice of products that were guaranteed to perform in the designated situation, based on the criteria-based selections. However, the system ultimately failed due to a lack of qualified products, which would enable a sufficiently broad range of choice. This was simply due to the cost associated with entering all of the product data onto the expert system. Too few manufacturers and retailers were prepared to participate, where the small number of Australian tile manufacturers was a telling factor.

Recognising this, CompuTile sought to develop a system for the US market in conjunction with the Tile Council of America (TCA). However, the TCA elected to develop its own system. Unfortunately this lacked the sophistication of TileWriter and seems to have sunk without a trace. The TileWriter program was fast, accurate and easy to navigate through. It provided the information that was needed, when it was needed, and in a format that allowed junior staff members to compile a specification for subsequent approval. Bowman and Cass[5] wrote at the time:

> *"Given the present emphasis on quality assurance issues and the development of computerised workflow solutions, the building industry is slowly moving towards the paperless office. The tiling industry will be inexorably drawn along, but if it wants to expand at the expense of other finishing materials, it will need to be at the vanguard. While architects and engineers will continue to manage the design process, it is likely that change will be evolutionary, rather than the revolutionary process that brought us CAD. The current generation of CAD-based software programs will assist in visualisation and as a sales tool. Upmarket retailers may find that visualisation packages, such as the DEA system, will become an item that they have to have. However one must remember 'All that glitters is not gold': failures will occur unless appropriate products are properly installed using suitable systems. This requires further R&D on installation methods, incorporation of innovative installation methods within the specification framework, and attention to the quality training of sufficient installers. In the interim, affordable user-friendly intelligent specification software, such as TileWriter, will assist design professionals to specify more appropriately, more efficiently and less stressfully".*

Jones[6] (1996) in "Powerspec, an electronic specification for ceramic tiling" presented details of software developed by an adhesive manufacturer in conjunction with a leader in constructional specification systems. This enabled complex specifications, involving wall and floor tiling to different surfaces. However, such proprietary systems do not seem to have been widely successful, particularly where they have merely automated the previous practice, but have not eliminated the need to make some educated decisions.

Prof Enrique[7] (1994) reviewed tile requirements in terms of specific applications in "Technical requirements of ceramic tiles for specific uses". This was one of a number of important Spanish initiatives to enable the selection of appropriate and compatible tiling products and systems. José Luis Porcar[8] presented details of "The Spanish tile installation project" in 1998, in order to improve tile-fixing quality in a country with high tile consumption and notable shortcomings in tile installation. Unified documentation was presented on selecting tile, grout and bonding materials, with background diagnostics and treatment, tile installation systems and techniques, as well as other subjects. Porcar also proposed a training model for tile fixers, accompanied by methods for assessing the professional competence and training of tile fixers, as well as the use of multimedia tools. The Instituto de Promoción Cerámica published "The Tile Installation Project Documentation" together with a CD-ROM edition. This documentation provided the collected professional knowledge, and represented an instrument of universal dissemination, that provided the basis for a quality spiral to develop throughout all sectors of the industry. I trust that this project will be further developed; it has the potential to be converted into an expert system, which might then receive the support and endorsement of expert specifying bodies.

There have been tremendous increases in computing power in the 18 years since I proposed that the tiling industry needed an expert system. **For want of an expert system**, what have been the consequences? Probably more of the 'same old same old': the dissemination of product data literature that is not as 'fit for purpose' as it might be; the continuation of poor specification practices, where recycled specifications have sometimes been a principal cause of failure; the continued reliance on traditional solutions that may have been somewhat modified in an attempt to accommodate change, thus considerably reducing the safety factor of the system; the lack of a defined structure to assist education throughout the industry, including a demand for higher quality inputs that better identify the characteristics of tiling system components. Expert systems can eliminate some of the problems that derive from the human element.

Blake[9] (1998) concluded his invited paper with the sentence "I put it to you that the human element is the prime factor in the chain of events leading to failure and this is where the industry's greatest challenge lies". He listed the main causes of tile installation failures as: differential movement not catered for in the system; selection of inappropriate products for the conditions; and poor workmanship on site. While he provided some simple rules for the successful installation of ceramic tiles, he also revealed a promotional campaign run by the South African Ceramic Tile Manufacturers' Association (SACTMA). SACTMA had produced a series of simple handouts titled "Successful Ceramic Tile Installations", where each handout commenced with the question "Do You Know?" For example, Do you know:

- that there are different types of tiles for different applications, both glazed and unglazed?
- that you will enhance the appearance of the installation by using the correct techniques and finishing materials?
- that correct cleaning and maintenance will prolong the life of a tile installation?
- that surfaces may need special preparation before tiling?
- that sufficient time must be allowed between building operations to allow elements to cure before proceeding?

Each question was followed with a simple diagram, table or some statements that facilitated the achievement of a successful ceramic tile installation. This is an excellent example of delivering the appropriate information in the right format. In 2008, industry organisations may be less willing to publish details of how to install products, or how to clean and maintain tiles, as such generic guidance might contradict proprietary guidance or not anticipate a particular combination of circumstances. As such, the guidance might be inappropriate, and cause the organisation to be liable for any failure. It is often considered preferable to alert consumers, tile fixers and industry professionals to aspects that they might need to consider, thereby minimising the risk of failure, rather than to provide specific step by step instructions.

Any campaign that helps to educate the public is a useful adjunct to the development of expert systems. If the public start asking the right questions, showroom staff might need to use the expert system to ensure that they are providing the correct answers. Minimising failures at the design stage is a great way of ensuring consumer satisfaction and being environmentally friendly.

3. DELAMINATION FAILURES

The loss or debonding of tiles normally result from a failure to manage information and to apply knowledge. In 1992, I addressed the problem of tiles being automatically blamed for tiling system differential movement failures in "The need for establishing a moisture expansion convention for the analysis of tiling system failures". This paper outlined such a convention, partly based on the draft ISO moisture expansion test. It presented a constructive approach to the handling and analysis of such failures, covering relevant aspects of site inspections, information gathering and laboratory investigations. It also contained an analysis of moisture expansion techniques and results. I still use this approach when working on such failures, although using upgraded moisture expansion techniques. While such a convention might not have been adopted elsewhere, the lessons learned enabled the reformulation of Australian ceramic tiles, so that such failures now predominantly involve foreign tiles, particularly if the tiles have been fixed in accordance with the tile installation Standards.

There have been several papers at Qualicer on tiles delaminating from the facades of Brazilian high rise buildings. In 2007, in response to such failures, I gave an invited paper at Revestir: "Moisture expansion and tile detachment from facades". This could not address all the issues or provide all the answers. One needs to derive test data on the extruded tiles concerned in order to develop an understanding of their natural moisture expansion kinetics, as well as their behaviour on reheating, and any subsequent natural and accelerated moisture expansion characteristics.

In 2007, I also investigated differential movement failures of Italian and Malaysian tiles, where the problem was not the moisture expansion of the tile. In such situations where the tile is exonerated, there is a tendency to blame the design of the system (characteristics of the specified materials, and detailing of the movement joints); performance of the adhesive; workmanship (preparation of the surface, application of the adhesive, installation of the movement joints, etc); and compliance with published codes of practice. One must still determine how much movement occurred, in what time frame, whether there was adequate provision to accommodate such movement when the first failure occurred, and whether any subsequent remedial works improved or worsened the situation.

Although there is still a need to establish a moisture expansion convention for the analysis of tiling system failures, we also need to better understand the long-term behaviour of adhesives, and the development of stresses and how they can be safely relieved in tiling. There have been several outstanding contributions at past conferences.

Riunno and Murelli[10] (1992) asked "How flexible are 'flexible' mortars?" when introducing the proposed CSTB deformability method that was adopted in EN 12002 and then ISO 13007. They recognised the need to properly define the term 'flexible' in order to protect tile installers and consumers against its improper use and the misleading advertisements of some adhesive manufacturers. Jones[11] (1992) also introduced the deformability test method in his paper "Ceramic tile adhesives and grouts: a case for quality". He made the point that "Adhesion of a ceramic tile adhesion can be measured in **tensile and shear. Both** are relevant to the integrity of a tiling finish".

In 1996, I drew attention to "The crucial need for computer modelling of tiling systems", where I stated that although there were several different types of tiling system failures, very few were directly related to unforeseen characteristics of the tile; one exception being its moisture expansion, since the accelerated test method may give a poor indication of the likely in-service long-term behaviour. Since computer modelling offers a cost-effective means of determining the stresses and strains that may develop when the system is subjected to specific loading conditions, it provides a logical means of engineering tiling systems. However, there was still a fundamental underlying requirement for comprehensive engineering data in order to determine appropriate compliance limits and to permit the development of engineering design codes that can support the project decision-making process.

Since finite element analysis (FEA) is highly dependent on the assumptions that are made, the results have associated limitations. "One must complement the FEA with tests to failure of a physical experimental model, but such procedures have still to be fully developed. FEA can assist in product development as it provides a means of rapidly and cost-effectively determining the relative effect of modifying a system parameter, prior to confirmatory testing. A better knowledge of the time-dependent behaviour of the system components will allow development of more reliable models, assisted by the continued development of more powerful finite element software."

I stated then that "FEA indicates that there is a potential deficiency in draft European Norms for ceramic tiling adhesives since they do not require the determination of the shear strength of cementitious adhesives, or the tensile strength of dispersion adhesives. The logic for this is hard to determine given some of the conclusions that can be drawn from the modelling of tiling systems". Despite several concerns over aspects of the ISO 13007 ceramic tile adhesive test methods, they have been adopted in Australia. US adhesive interests would like the ISO standards of tiling systems that incorporate membranes to include more shear testing, but the debate seems to revolve around whether tensile or shear testing gives the most reproducible results, rather than the utility of the resource that any result may represent.

FEA generally indicates that tiling systems are under greatest stress in the proximity of the movement joints. This highlights the need to take particular care when installing movement joints. We concluded that "Analysis of the stresses in adhesive joints is essential for efficient design, particularly if realistic factors of safety are to be

used. In the design process it is important to know unambiguously the mechanical properties of the materials used. Adhesive manufacturers' product literature often extols their technical virtuosity. Sadly, their contributions to the scientific literature are inconsistent with these raised consumer expectations. If consumers are to realise their expectations of improved life cycle performance, more information must be made available to designers. This should instil greater confidence in architects, and enable tiles to be more widely used in applications such as high-rise external facades". Although adhesive manufacturers may be conducting extensive internal research, the situation does not appear to have changed, except that mechanically clad external façade tile systems are becoming increasingly popular.

Miguel Abreu[12] (2004) presented an excellent paper "Modelling the behaviour of ceramic tile coverings", which was based on his thesis. While he was interested in continuing such work, he was unable to find an employer with a similar ambition. When people have the necessary skills to help solve recognised problems, it is most unfortunate when they are not used.

FEA has its limitations. It is based on several assumptions, including those of the characteristics of the materials. The outcomes can also be influenced by the size, shape and number of the elements that are used to model each material, the choice of boundary conditions, etc. Furthermore, there are some subtle aspects that are very difficult to include in such models. For instance, Jose Pascual Pitarch[13] (1996) investigated the "Effect of different ceramic tile characteristics upon its adhesion strength to cement mortar substrates", considering how the water absorption and the geometry of the back of the tile affected the shear bond strength of different adhesives. Sufficient surface roughness of the back of the tile was also found to play an important part in the adhesion of tiles with low water absorption.

Considering other notable contributions, Feliu et al[14] (1992) included a most practical questionnaire, for use in gathering data for the analysis of tiling system failures, in their paper "Methodology for diagnosing pathologies in installed ceramic tile".

Goldberg, an architect by training, who has specialised in the design and specification of tile and stone installations, has made several outstanding presentations (1994, 1996, 1998, 2002). In 1994[15], he concluded "Every ceramic tile façade system requires a unique approach to the control and remedy of the effects of moisture penetration. An understanding of the concept of moisture movement and control, together with a logical application of sound engineering and architectural principles, will result in a beautiful, problem and maintenance-free ceramic tile façade". This reinforces the relative individuality of facades, where there may be very few with the knowledge and experience necessary to confidently specify facade tiling systems, as well as a comparatively small pool of tilers, who are well qualified to work on facades.

In 1996[16] Goldberg promoted a better understanding of the different types of building movement, and sought to begin the process of promulgating mandatory standards for the design of movement joints. In 1998[17] Goldberg considered some further related aspects of exterior wall construction assemblies, the function and performance of other façade building elements, the criteria for design of movement joints, and other architectural and structural detailing considerations. Sitzler[18] (1996) also indicated how the success of an installation can depend on the correct detailing and installation of movement joints. An appreciation of these papers should enable most architects to specify sufficient appropriately located functioning movement joints.

Medeiros, a civil engineer, who has specialised in the design and installation of ceramic tile facades, has also made several excellent presentations at Qualicer. Medeiros and Sabbatini[19] identified the importance of having the right information at the right moment on the job site; and that rather than having a well-defined tile façade system with all the necessary details, builders and contractors often had to deal with confused and incomplete information. They discussed the most important design parameters, including building movements, control joints, and the flexibility of mortars[20]; and proposed a design method, presenting the guidelines and parameters necessary to organise the tiling work on the façade, and to avoid poor decisions being made on the job site.

There have been several proprietary products[21] developed to assist with crack suppression, water drainage, acoustic insulation, etc. The relevant tile installation standards normally use a phrase like "Follow manufacturer's instructions" to defer to these, whereupon such instructions take precedence over the otherwise accepted standards. It is up to the manufacturer to ensure that there is no potentially adverse conflict between their instructions and the otherwise accepted practise. Carty and Neilsen[22] considered how stress built up in tiling systems and showed how stress could be reduced using a proprietary de-coupling layer, where the 'weak' interface acted as a forgiving shear plane and how this was effective in maintaining crack-free tiling, rather than having to use a system with extremely strong bonds.

The Tile Council of North America continues to establish the pace in providing guidance on proven methods of tile installation in its annual *Handbook for Ceramic Tile Installation*. It has introduced a multitude of new installation methods in the last four years, providing improved guidance on the generic use of various membranes, radiant heating, shower receptors, etc.

The TCNA Handbook recommendations for movement joint spacing were changed in 2005. The recommendation for the maximum spacing of interior expansion joints decreased from approximately 7.3 to 11.0 m in each direction to 6.1 to 7.6 m; and the exterior recommendations were changed from 3.7 to 4.9 m in each direction to 2.4 to 3.7 m. The Terrazzo, Tile and Marble Association of Canada Manual 2006-2007 adopted an evener stricter 4.9 to 6.1 m internally, and 2.4 to 3.7 m where exposed to sunlight. The TTMAC Manual also used the same 2.4 to 3.7 m externally, but increased the minimum joint width from 6 to 10 mm generally, and to 13 mm where there are extreme temperature variations. I understand that these tighter recommendations reflect the fact that there tends to be less grout (fewer and thinner grout joints) in tiling systems where larger rectified tiles are laid.

There is a new BS 5385 Part 2, Design and installation of ceramic and mosaic wall tiling in normal conditions – Code of practice. Although there have also been public comment drafts for other parts of BS 5385, these have not sought to vary the movement joint guidance. While such guidance was not varied when AS 3958.1 was revised, it probably should have been. The TCNA Handbook is far more amenable to progressive updating than the parts of BS 5385 and AS 3958. Since we have global (ceramic tile and ceramic tile adhesive) products, we should be considering adopting global standards for ceramic tile installation. The TCNA Handbook conferences have worked successfully, whereas standards committees in other countries may be struggling due to lack of critical mass and dedicated resources.

The Tile Council of North America provides installation guidance across a geographic area that includes most climatic extremes. There will inevitably be some

variations in local building materials, regional practices, and national building regulations, but the TCNA Handbook does not purport to include all possible building methods, merely some of the good ones that have been proven to work. It should be feasible to produce global guidance, where countries might adopt local variations to facilitate best available practice.

4. IMPROVING THE CHARACTERISTICS OF TILING SYSTEM COMPONENTS AND THEIR ASSESSMENT

To try to understand our universe, we must first be able to measure it, in order to be able to interpret what we see or what might happen. In order to manage something, like the performance of a tiling system, you must be able to measure it. To measure something you have to be able to define it. In composite (tiling) systems, we need to determine what can meaningfully be measured, how to make measurements, and how the measurements made reveal how individual components will affect the performance of the system if it is subjected to a range of potential environmental situations and physical loadings. Does our industry have the right metrics to ensure the long-term integrity of tiling systems?

The moisture expansion of ceramic tiles is evidently one characteristic that needs to be better understood within the context of all the other reversible and irreversible movements that occur in tiling systems, together with the characteristics and capabilities of adhesives. The slip resistance of tiles is another characteristic that needs better understanding. The coefficient of friction (COF) for any two materials depends on system variables like speed, temperature, pressure, as well as on geometric properties of the interface between the two materials being measured, and the characteristics of any third material that is interposed between them. COF is both a 'material property' and a 'system property'. Ceramic tiles do not have a single COF, but several depending on the choice of footwear, its characteristics, and the extent of contamination. Slip resistance is a highly complex system, where we take one or two measurements in order to try to characterise the likely performance of a product.

4.1. SLIP RESISTANCE

One improved tile characteristic that the property industry desires is the development of moderately slip resistant tiles that are easy to maintain in a clean slip resistant condition. This recurrent challenge seems to have been consigned to the "too hard" basket.

Some tile manufacturers believe that Australia has unrealistic expectations when it comes to slip resistance requirements for floors. Most Australian tile merchants would agree. However, who can dispute that "Any workplace death or injury is one too many"? South Australia has a new offence of reckless endangerment, which will apply to any person or business that demonstrates a conscious or reckless disregard for workplace safety that creates a substantial risk of death or serious harm to others. The reckless endangerment provision can attract fines of up to €700,000 for corporations and public sector agencies while individuals face a maximum fine of €233,000 or imprisonment of up to 5 years. Failing to clean up a spill that causes a floor to become slippery is reckless endangerment. Specifying a floor that has poor wear resistance characteristics, such that it is likely to become slippery after normal use if an accidental spill occurs, might also become a case of reckless endangerment.

In "Assessing the relative contribution of ceramic tiles to slip and fall accidents", Bowman (1998) took a multifactorial approach to the problem of slips and falls, where tiles are often blamed for accidental slips even though slip resistance is a complex multifactorial area. There are generally factors, other than the slip resistance of the tile, that contribute to any specific incident. While individual slip resistance measurements taken in isolation can be misleading, one also has to question the relevance of the test method, how the test was conducted, and on what surface. There may be no simple general solution to assessing the relevant contribution of a ceramic tile to a specific slip and fall accident, but the industry needs to be asking the right questions and obtaining the necessary information in order to protect its long term interests.

In "Where to next with slip resistance standards" Bowman (2000) reviewed some of the legislative requirements driving the adoption of slip resistance standards. Bowman considered some of the options for developing future standards, with particular reference to adoption of requirements within mandatory building codes and enforceable occupational health and safety legislation. Where standards are adopted, the inherent limitations of the test method should be recognised, and appropriate cautionary advice should be provided somewhere in order that the results can be analysed within a responsible framework.

In "The future of the ceramic tile sector in the XXI Century", Bowman (2002) considered why there had been so many difficulties in developing an ISO standard for the slip resistance of ceramic tiles, and reported on some difficulties with the ASTM standards. He identified the variability of the slip resistance as a problem, where the architect was often provided with inadequate information, and particularly that product literature provides no indication as to how the slip resistance is likely to vary with wear. He reported that "CSIRO has been using the ISO 10545-7 surface abrasion test to prepare worn areas on tiles to assess how their slip resistance may change with wear over time. The slip resistance has been assessed using a laboratory based SATRA STM 603 device since it can make measurements on the small (80 mm diameter) abraded surface".

In 2004 Bowman[23] concluded that an initial ISO standard, based on a revision of the Australian slip resistance standards, could be introduced quite soon, where the use of national variations could overcome past European difficulties. While Bowman outlined some other proposed initiatives, the intended revisions of the Australian slip resistance standards were unexpectedly postponed by three inappropriate minority votes. While these senseless objections have been overcome, promulgation of the new standards has been intentionally delayed pending an Australian Building Codes Board review of the "relationship between slips, trips and falls and the design and construction of buildings". The ABCB writes the Building Code of Australia and can mandate slip resistance in areas as it determines.

It is anticipated that a series of new Australian slip resistance design recommendations will be issued in 2008, based to a greater extent on pendulum results, where the pendulum test method has been modified to enable better discrimination between the wet slip resistance of products at the slippery end of the spectrum. The guidance will also recognise the need to be aware of the potential loss of slip resistance with wear.

In "Sustainable slip resistance: an opportunity for innovation", Strautins (2008) reports an accelerated wear test method that will be considered for future adoption

as a preparatory step for slip resistance testing. However, correlating changes in slip resistance (due to accelerated wear with that which the changes that occur over time in a variety of end use situations) will inevitably cause some time delay. In the interim, we need to recognise that test results obtained on factory fresh surfaces may be illusory, possibly misleading designers into specifying products that may be potentially hazardous within weeks or months of installation, thereby endangering users. However, we need to also ensure that use of the accelerated wear procedure does not lead to over-specification of products, which might be very difficult to clean using the methods that are typically used in specific scenarios. Should an accelerated wear test be applied to all products or only those that appear to have adequate slip resistance? What are the limitations that should be advised to designers? One needs to consider the total impact of introducing any major changes and to risk manage their introduction in order to ensure their optimum beneficial adoption.

Strautins' noteworthy paper should raise several questions. It again positively discriminates towards use of the pendulum, rather than ramp tests although. In Spain, the pendulum has been adopted by the March 2006 Basic Safety in Use Document provisions, according to ENV EN 12633, which uses the CEN rubber rather than the traditionally used TRRL or Four S rubbers. While the CEN rubber is similar to the TRRL rubber, industry knowledge is principally based on results obtained with the Four S rubber, and to a lesser extent the TRRL rubber. Perhaps the findings of CEN/TC 339 will determine which rubber should be adopted, but one often needs to question how well informed Governments have been when making decisions about the adoption of slip resistance test methods (see Appendix 1).

Given that the SlipSTD European collective research project (Tari and Engels, 2008) seeks to establish knowledge concerning the relationship between the surface characteristics of tiles and their slip resistance, it would seem logical that they should determine what surface changes occur during Strautins' accelerated wear test. This should promote a better understanding of slip resistance issues for tile manufacturers, and allow them to improve the surface characteristics of tiles.

4.2. ABRASION RESISTANCE AND STAIN RESISTANCE

At Qualicer 90, there were only 18 open papers. These included "Analysis of some factors related to the degradation of glazed ceramic tiles through abrasion" (Felíu et al); "Practical analysis of the influence of wear resistance of ceramic materials in relation to their use destination (Lorici and Bresciani); "Study of porosity in single firing glazes for floor tiling" (Aparici and Moreno); and "Physical-Chemical characteristics of ceramic glazes and their influence on the quality of ceramic surfacing and flooring" (Garcia). In various ways these papers are linked: they related the glaze composition and the porosity of the glaze to its abrasion resistance and its visual appearance, and the inability of the EN 154 glazed surface abrasion test (now ISO 10545-7) to provide a realistic appraisal of abrasion resistance.

Palmonari and Timellini[24] discussed the abrasion resistance of glazed tiles, where the problems of change of colour, loss of gloss, and increase in surface porosity were recognised. They also recognised that dark coloured tiles were more likely to change colour due to wear, while light coloured tiles were more likely to change colour due to the soiling of pores that are opened by abrasion. Although they concluded that the information derived from the ISO standards was "intended to aid the designer in choosing the most suitable material for specific applications" how can this occur if the

tendency of lighter coloured tiles to stain is only assessed if they show no change of colour, and there is no assessment of the loss of gloss?

Escardino et al[25] (1992) provided quantitative evidence of the soiling problem in their paper "Using the roughnessmeter for the quantitative study of ceramic glaze degradation by abrasion". Pascual et al[26] (1992) studied the "Influence of the composition of fritted ceramics on the resistance to abrasion", and there have since been several studies linking glaze composition to wear resistance, and the improved characterisation of the tile surface as it is progressively worn. Much of this work has been conducted at ITC, principally by Felíiu and Silva. I should also recognise "Effect of the volumetric fraction and particle size on the abrasive mechanism in ceramic glazes" by de Oliveira, da Rosa and Alarcon[27] (1994), as the first of several excellent Brazilian open papers; and "Durability prediction of ceramic tile subject to abrasion processes from pedestrian traffic" by Barbera et al[28] (1996). This introduced the Tribopod apparatus for simulating pedestrian abrasive wear, where the associated limits of visual perception of colour change and gloss change were also established for some different types of floor tile.

Qualicer 96 was the first Congress where posters were presented. Feijao et al[29] "Study of the wear mechanism in glazed tiles by scratching tests"; Escardino et al[30] "Reversible dirt retention in glazed tile surfaces"; and Escardino et al[31] "Variation of roughness and gloss in glazed tile with the intensity of the wear produced with a standard abrasion tester" were all relevant to developing a better understanding of the problems of the abrasion and soiling of floor tiles. In 1990, Lorici and Bresciani[32] concluded that the surface abrasion test had to be conducted under reflected light so that loss of gloss could be observed, as such wear is observed in real world conditions. In 2008, Ilha et al[33] are the latest in a series of researchers to conclude that "The PEI method does not represent the real conditions of ceramic tile abrasion and leads to misinterpretations of the obtained results". Although Palmonari, the convenor of ISO/TC 189 WG1, recognised the problems with the PEI method in 1992[34], ISO 10545-7, *Determination of resistance to surface abrasion for glazed tiles*, has still to be significantly revised.

At the time of Qualicer 90, the ISO ceramic tile standards were still being developed. Harrison[35] criticised the EN 122 standard cleaning agent being much weaker than typical cleaning agents found in homes. Many glazed tiles inappropriately failed the potassium permanganate stain test due to the weakness of the mandatory cleaning agent. Harrison concluded manufacturers should still realise what specifiers required, eg, slip resistance, even though some such tests were not a part of the formal quality assurance system.

In another invited paper, Palmonari and Bauer[36] discussed some of the thinking behind the draft ISO stain resistance test, and the advantages of exposing the tiles to a new and greater range of "staining agents", recognising that the cleaning procedures would determine the test outcomes. The eventual standard was not as "open" to new solutions as they seemed to predict. Perhaps Palmonari was thinking of the extended cleanability test method developed by the Italian Ceramic Center, which Timellini and Carani[37] subsequently discussed, when they also considered chemical resistance and wear resistance. Importantly, they recognised that the chemical and abrasive wear test conditions only allow a very general (and abstract) representation of what actually occurs; chemical and wear attack often occur simultaneously, and there can be a synergetic effect. Their new approach on the simultaneous application of chemical and mechanical actions better represented what actually occurs in working

conditions. This approach was recommended for the study of soiling and cleaning of tiles, and the assessment of cleaning agents. I have conducted some similar tests, but am unaware of any subsequent published studies. There are other in-house test methods that can be more useful than the standard tests when comparing products for specific use in circumstances.

Caridade et al[38] compared ISO 10545-14 and ASTM C1378, *Determination of resistance to staining*, and generally found that ASTM C1378 provided a more realistic interpretation, although the best test would combine aspects of both staining test methods. While the US tile industry might be criticised for not adopting the ISO ceramic tile, adhesive and grout test methods, ASTM C1378, includes methylene blue and $KMnO_4$, other nominated staining agents, as well as any staining agent deemed appropriate for the service conditions. It better fulfils consumer expectations than ISO 10545-14, so perhaps we should be critical of other countries for not being prepared to adopt a more comprehensive test regime. With the benefit of hindsight, there was probably too little comparative testing when the ISO standards were being developed (and too much national/ regional pride associated with the ASTM/ CEN standards) so that they were never as fit for purpose as they might have been.

ASTM C1378 uses a contrasting (fine) unsanded tile grout as a paste rather than the ISO 10545-14 chrome oxide paste. However the chrome oxide paste is used in ASTM C1027, *Determining visible abrasion resistance of glazed ceramic tile*. Since the ISO 10545-7 and ASTM C1027 test procedures are technically equivalent, one must ask why ASTM or ANSI has failed to adopt ISO 10545-7, even if it was to include some minor national variations. Is there an inability due to copyright problems? If so, why does ISO not insist that the problem is resolved? If not, is there an enduring reluctance, in order to protect American manufacturers? If so, should ANSI continue to hold the ISO Secretariat for the Committee?

By contrast, the Australian national variations to ISO 10545-7 permit reporting of **loss of gloss** and staining of the tile surface after any abrasion stage, not just 12,000 revolutions. AS 4459.7 is to be revised further to allow the test to be conducted on **unglazed** porcelain tiles. The intent is to provide consumers with better quality information, in order that they can make better informed decisions. There is also a generally unrecognised need for the development of test method to measure the gloss of polished porcelain tiles.

4.3. TILING SYSTEM TESTS

Walters[39] (1996) outlined the development of the ISO 10545-5 impact resistance by coefficient of restitution test method. This showed how the initial impact resistance of the tiling system was a function of the curing of the adhesive. While British Ceramic Research Ltd proposed a tentative classification of the impact resistance of floors, this has not been widely adopted or used. Walters indicated that the test was a means of differentiation of tiles for various (end use) environments, but that it was not sensitive enough to differentiate between two equal thickness fully vitrified tiles from different manufacturers. This might be so, but the test method also requires the reporting of any visible damage that is produced, such as Hertzian cracks or chipping of glazed tiles. I have yet to see a manufacturer reporting such damage in any of their product literature. Even manufacturers who produce extensive technical literature might simply explain the impact resistance test by "Rebound measurement with 5 samples".

The impact resistance test method enables some comparisons of different possible tiling systems, similar to the proposed ISO/TC 189 adoption of the UPEC test methods for determining the resistance to impact loads and rolling wheel abrasion. Adoption of these test methods had been rejected in the 1980s, but French use of these methods required that exporters of tiles must conduct the test. Although the tests specify adhesion of the test tiles to a dense concrete slab with a thick-bed two component cementitious adhesive, the results will depend on the adhesive selected.

There is nothing wrong in introducing test methods that might assist in optimising selection of compatible tiling system components, but there should be a defined strategic rationale as to what test methods should be adopted, whether there should be compulsory requirements, and if not, how the results can or should be productively used. Introducing new test methods because some manufacturers have to undertake a test to satisfy national requirements is not sufficient justification. Testing is expensive, and tests should be undertaken for constructive purposes. The ASTM C627, *Standard method for evaluating ceramic floor tile installation systems*, is an excellent test method for simultaneously assessing the performance of different combinations of tiling system components.

5. ENVIRONMENTAL STANDARDS

There are both compulsory and voluntary environmental standards. Manufacturers must comply with environmental regulations when producing tile, but may elect to have tile assessed according to other criteria in order that the contribution of the products to the environmental impact of the works can be evaluated. Such data is required for the design and construction of high environmental quality buildings, which are being increasingly recognised as also providing optimum return on financial investment and improved worker productivity.

At Qualicer 98, Prof Enrique[40] presented an invited status quo report on "Integrated pollution prevention and control in the ceramic tile industry – Best available techniques", while Probst[41] presented information on the initial development of "International, European and National Standards for the protection of the environment and their impact on the European ceramic industry". The European Ceramic Tiles Manufacturers' Federation (CET), recognising the importance of environmental care, recommended targets for maximum levels of emissions into air and waters, specific energy and water consumption, and recycling rates. While various production integrated technologies have been introduced to reduce pollution and minimise environmental demand, there are other aspects that must be considered.

When promulgated in 2002, the EU Eco-Label Award Scheme[42] for hard floor coverings adopted tighter requirements than the CET recommendations. These manufacturing requirements should be expected to become more demanding each time they are revised. The tiles must also be fit for use. "According to the Council Directive 89/106/EEC a product is presumed to be fit for use if it conforms to a harmonised standard, a European technical approval or a non-harmonised technical specification recognised at Community level". According to the User Manual[43] "The applicant shall provide test procedures and results together with a declaration that the product is fit for use based on all information about the *best application by the end user*. The testing shall be performed according to ISO, CEN or equivalent test methods, such as national or in-house test procedures".

The following information should accompany the product: "recommendations for the use and maintenance of the product". This information should "highlight all relevant instructions particularly referring to the maintenance and use of outdoor products. As appropriate, reference should be made to the features of the product's use under difficult climatic or other conditions, e.g. frost resistance/water absorption, stain resistance, resistance to chemicals, necessary preparation of the underlying surface, cleaning instructions and recommended types of cleaning agents and cleaning intervals. The information should also include any possible indication on the product's potential life expectancy in technical terms, either as an average or as a range value". The User Manual includes some 2001 German Guidelines for Sustainable Building, which indicate that ceramic tiles have a life expectancy of 50 to 70 years, slightly less than soft natural stone. Hard natural stone has a reported life expectancy of 80 to 150 years. This is much shorter than the known age of several tile and stone installations.

Contrary to expectation, all of the essential information (as detailed above) does not seem to be in the product literature of some products that have received the EU Eco-Label. This may be due in part to the difficulty in interpreting what *"the best application by the end user"* means, as well as interpreting some of the ISO 10545 test results. In the context of ISO 13006, some products with a modulus of rupture of 30 MPa are first quality; others are not. In this context, the compliance criteria might appear to have been arbitrarily chosen. However, the classification criteria were based on a lowest common denominator approach, recognising the strengths that were typically attained for products of certain porosity ranges for given methods of manufacture.

Some of today's second quality products would have been regarded as premium first quality products by past generations, and might have survived centuries of use in cathedrals and other monumental buildings had they been available in past times. It is important to recognise that life cycles are a function of the construction system used, and that second quality products can have extensive life cycles when used in appropriate situations. One of the prime ways of caring for the environment is to reduce the amount of manufacturing, and the amount of construction, and to recycle as much building product as possible for high level use, rather than as benign hard land fill. This should be advantageous for mechanically clad tile systems, where the tiles can be reused. Intelligent tiles that serve multifunctional purposes should also benefit, but the industry should start to consider the potential consequences of a global downturn in demand in some market sectors.

ISO 13006 confirms that a product meets the minimum agreed criteria, and provides an indication of some other measures that may or may not be useful for determining whether a product is best suited for a specific purpose. ISO/TC 189 should consider whether test method variations might provide more useful results, and/ or enable the tests to be conducted in a more environmentally friendly manner, i.e., less use of energy, water, chemicals, etc.

However, it is the voluntary environmental standards that require the manufacturer provide assurance that the product is suitable for use. This seems to depend upon individual manufacturers' interpretations of the test data, unless the product is submitted for independent technical assessment or approval (where variability exists between such certification schemes within and between counties). It would seem necessary that ISO/TC 189 should be providing further guidance on the interpretation of the ISO 10545 test data. Such interpretation would normally best be undertaken with respect to specific usage scenarios and given tiling systems. Unless global guidance

is prepared for codes of ceramic tile installation, the any ISO guidance to enable consistent universal interpretation should recognise various potential limitations.

Since the EU Ecolabel certification scheme was approved in 2002, only seven ceramic tile manufacturers have obtained the label[44]. The requests for environmental labels usually arrive from overseas markets (especially North America and Australia). There is no equivalent Green Seal standard in the United States.

Good Environmental Choice Australia, the Australian Member to the Global Ecolabelling Network (GEN), is drafting an Australian Environmental Standard for hard surfacing finishes. Since the GEN has mutual recognition arrangements, the Australian Standard will contain production environmental requirements similar to those of the current EU Eco-Label for hard floor coverings. It should also recognise that second quality tiles can be successfully used in installations that have low anticipated stress performance levels. A new Standards Australia Handbook might be required to provide the necessary guidance on interpreting various test data when assessing best fitness for purpose.

Not only do materials have embodied energies and emissions, but the way they are used by designers contributes to reductions in net emissions, as well as the need for maintenance, and any associated environmental consequences.

6. ROUND TABLE DISCUSSIONS AND PANEL DEBATES

The introduction of a round table discussion in 2000 marked an important phase in the development of the Congress. Such panels have become an increasingly vital aspect as they allow attention to be focused on specific areas of concern.

José Luis Porcar[45] chaired the first round table discussion on "Professional qualification in the ceramic tile sales and installation process". It featured Michael Byrne (USA), Colin Cass, Luigi Puce (Italy) and Paul Uth, and reinforced several papers that Uth, Cass, Tarver and others had presented at previous Congresses. While there was a unified global perspective on the problems arising from a shortage of skilled tile fixers, and there had been some isolated action at the national level, there has been not been any subsequent concerted global action to overcome these well recognised problems, or might one dare say that they have become "accepted problems"? However, there have been some rays of hope: Velez and Escovar[46] reported that despite an initial lack of knowledge about porcelain tiles and their installation, implementation of quality assurance greatly improved the quality of tiling, the productivity of relatively unskilled tile fixers, whilst minimising the risk of subsequent failures in a large (70,000 m^2) Colombian project.

In 2002, Bowman chaired a round table panel discussion on the "Ceramic Tile Sector in the XXI Century". Goldberg[47] identified shorter, aggressive construction cycles as a significant cause of problems in the construction industry, which the tiling industry would have to accommodate: "The tiling industry must be more proactive in promoting engineering models for tile system installations in order to minimise the negative effects of failures caused by aggressive construction schedules". Architects had problems in specifying proper installation of tiles and insuring the suitability of the tile for the intended use: "The tile specification process can be simplified by developing standards based on intended applications or performance, rather than

a prescription of technical characteristics". "Tile manufacturers must take more responsibility for insuring long term performance of tile products through increased involvement in developing both installation recommendations and procedures, as well as determination of suitability for intended uses". In his invited paper Goldberg[48] gave examples of the evolution of mechanically anchored and ventilated ceramic tile technology, as well as prefabricated tile panel construction technology. He concluded that while architects had unprecedented design and technology at their disposal, the uses for ceramic tile could be limited by the tile industry's willingness to support architects with sufficient imagination and technical innovation.

Within the round table, Bowman[49] considered "Standards" and found that there were significant problems with many standards that had long recognised weaknesses, which had resulted in some national variations. "Change is continuous, and ISO/TC 189 must become more reactive so that the standards can be modified in a timely manner to reflect recent developments, such as the evolution of new products. There is an immediate need to provide architects and specifiers with better guidance. In the longer term, ISO/TC 189 must also tackle how to revise the test methods and compliance requirements in order that the results might provide better service life predictions, in line with the need for sustainable development". Bowman has considered[50] some further aspects, and subsequently asked ISO/TC 189 the following questions when trying to ensure that the ceramic tile standards were fit for purpose.

1. How do we enable the standards to assure consumer expectations?
2. Do we retain the traditional classification system?
3. Do we permit any tile to be subjected to any of the test methods?
4. How do we change the ISO cycle, so that the product standard & test methods can be simultaneously revised?
5. What provision do we make for second quality tiles or is that a national issue?

In order to enable the best use of test results, greater use needs to be made of existing and new classifications. While definitions may be useful for classification purposes with respect to imports and tariffs, they have created artificial boundaries from the perspective of assessing some performance characteristics. We would benefit from allowing tiles to be subjected to any of the test methods, where there will be a sensible result.

Brazil has published ABNT NBR 15.463, the world's first porcelain tile standard. Australia proposes to publish a porcelain standard, where test methods will be applied without considering whether tiles are glazed or unglazed. While such definitions may be important with respect to trade tariffs, tiles need to be tested according to methods that yield the most useful information from a consumer perspective. ISO/TC 189 recognises that it has been moving too slowly and needs to improve its ability to update standards in a timely manner. This is inherently difficult, given the timing of the cyclical review process for each standard, and the need to simultaneously change the product requirements whenever there is a significant change in test methods.

In October 2007, Bowman was appointed to lead an ISO/TC 189 task group that will develop a database, which will document national variants of each ISO ceramic tile standard, highlighting key differences, which will then be used as a guide in

revision of the standards. Some variants are regarded as being positive progressive developments of the standards, while others are considered to unnecessarily restrict free trade.

Mondini[51] and Stefani[52] (2002 round table) both indicated the need for the design of facades and development of specifications where large-size porcelain tiles and thin panels were to be used. There was broad agreement for the need to develop tiles that had a wider range of functional performance characteristics, allowing invention of new horizons of use.

Michavila[53] considered internal and external threats to the industry, and concluded that there was a need for close co-operation within the ceramic tile sector and that company size was becoming more critical: "Big companies usually bury their errors, but small companies are buried by them". Boschi[54] foresaw the growing need to add value to products being achieved through design of increasingly advanced ceramics that had improved technical properties. Marti[55] recognised that tile manufacturers should be protected against consumer claims where tiles were properly chosen and installed.

In 2004 there was a well staged round table discussion on "Ceramic Tiling Pathologies", chaired by César Díaz[56]. This consolidated the earlier findings of Bowman, Cass, Felíu, Goldberg, Hartog, Medeiros, Porcar, Walters, Wong and several others. Sitting in the audience, I was reminded of the unsettling phrase, "Houston we have a problem". While experts on the panel and in the audience might be able to get their clients out of trouble, or prevent them from having problems, how can the isolated knowledge of a few be distilled into a suitable format to prevent problems on a wider scale? Relevant information has been published, but it has not been packaged in a format that would enable its ready adoption by university architecture lecturers.

In 2006 there were five panel debates. The debate[57] on "The challenges to the growth of the United States ceramic tile market" identified several objectives including improved training of the installation workforce. "A substantial portion of the cost of training and education, recruitment and retention and advertising may need to come from the international sector that enjoys a majority of the market share in the United States". While Australia would also enjoy such funding, it is unlikely to occur, given the high penetration of Asian tiles into the market, replacing European tiles. The panel recognised that the tiling installation methods and materials may need to change in response to changing U.S. home construction practices, but did not identify who should ensure that the engineering detail is correct. The panel recognised that there are numerous explanations for very costly installation failures including improper specification, inadequate engineering for the product specified, and questionable construction practices. The relative lack of specialist knowledge by "big box retailers" was also considered a probable contributing factor. There was a perceived role for the ceramic tile industry to take active and aggressive information marketing strategies.

The "Ceramics and architecture" panel debate[58] recognised that ceramic tile manufacturing technology had evolved and that innovative tiles with new special technical characteristics had achieved a prestigious position. They then identified several issues that hampered the full acceptance of tile among architecture and building professionals. They sought new technological properties from tile, particularly those that would contribute to environmental quality, such as climate-regulating tiles. They also sought tiling systems that could be easily disassembled, where products could

be easily substituted. They also believed that the technical information required for specifying tiles and tiling systems should be readily available on the Internet, and that there should be expert consultancy firms that would enable tiling systems to be used in innovative ways on high profile buildings, where the reliability and quality of the end product would be assured.

José Luis Porcar[59] chaired a European panel debate on "Adhesion and deformability of cementitious adhesives and grouts for the installation of ceramic tiles and other modular rigid slabs". The debate was preceded by a paper by Prof Felixberger[60] "Stresses in the composite system: tile – fixing mortar – base", where a formula was used to calculate the shear stress gradient in the adhesive bed in different tiling system scenarios. Such formulae (and finite element analyses) allow manufacturers to determine the influence of various parameters. However, they depend upon assumptions made about the system components and their characteristics, where it is known that some of the characteristics will change with time or exposure conditions. Nevertheless, the analyses could be distilled into a few guidelines for the tile fixer. Prof Felixberger acknowledged that it would take years and years in order to obtain all of the necessary factors, and to correlate them with practice, but a start had been made on obtaining some of the data necessary to provide the critical physical confirmation of the stresses and the amounts of movements that are occurring.

This debate reflected the proliferation of problems associated with tiles fixed by direct adhesion, and much mention was made of the development of the European Norms for adhesives, and particularly the test method for measuring deformability. Prior to the debate, Dr Porcar provided a very useful summary of certain sensitive aspects of the debate forum. Attention was drawn to the poor reproducibility of the deformability test and a number of changes to the standards were proposed. While I do not know what may have since transpired within CEN/TC 67 WG3, there does not seem to have been an European proposal to make these changes to the standards at the ISO level.

Given that recent papers and the round table panel discussions have confirmed that the recognized recurrent challenges still require solutions, where do we go from here?

7. ASSESSING PROGRESS

"How not to learn from mistakes: Recurrent and forthcoming defects in installation of ceramic tiles" could have been a subtitle for this panel discussion. However, it was the title of Peter Hartog's masterly 2000 invited presentation. Hartog concluded that "The defects we repeatedly encounter in ceramic tiling are predominantly shortcomings in design and installation, not in manufacture of tiles and tiling accessories. There are, of course, defective products, but their occurrence tends to be geographically concentrated and short-lived. A sophisticated, well-capitalised and science-based manufacturing industry can respond efficiently to such problems. It can organise world congresses, support research and publish technical journals. By contrast, the service industry that applies the product, at least in the region of my experience, is skill-based, fragmented and conservative, often to the point of obstinacy. Its low entry and exit costs tend to immunize individuals and companies from the ultimate costs of rectifying their errors".

As Hartog stated "In a time of resource depletion and environmental degradation, it is disturbing to calculate the energy embedded in the thousands of metres of

unflawed tiles that have ended up as landfill due to the installation defects I have reported. Education is the only reliable way to pre-empt recurrence of such defects in construction. In the case of installation defects in tiling, the initiative and resources probably have to come from outside the tile-fixing industry, as already seems to be the case in Spain. The same applies to educating architects and interior designers. To protect its own position, the manufacturing industry should be doing more to educate the design professions".

The design professions have indicated[61] (2006) that they require more information from the tile and adhesive manufacturers. More useful information about the characteristics of both ceramic tiles and adhesives is seemingly being demanded from standards writers, but is that message being effectively transmitted? More information is also required about design of tiling systems, but there seems to be a difficulty in incorporating such material into codes in a timely manner, except in the case of the TCNA Handbook. Adhesive manufacturers certainly provide information about how their products should be used, but they must always list several caveats and limitations.

The industry has undoubtedly made progress in improving tiling system components, partly to meet the demands of evolving construction practices, but also to satisfy commercial imperatives: having products with new and enhanced characteristics, particularly those that fulfil previously unrecognised needs.

A few well established ceramic tile manufacturers provide extensive information about their products and their fitness for specific purposes. Many recently established manufacturers provide the absolute minimum data, and often in a format that is almost unintelligible as far as foreign specifiers are concerned. While many manufacturers fall between these extremes, there is an inherent problem in making a consistent universal interpretation of any published test data, because the basis of such data varies. If one assumes that there is consistent universal interpretation of the Standards and that the tests are conducted uniformly and reproducibly, do the results indicate a guaranteed minimum level of performance or do they reflect typical results? There is inevitably some variation between batches of tiles, and often within a range for some characteristics, particularly as a function of colour. This might be addressed within the Standards by requiring a declaration as to the basis on which the results are being published. Such a declaration might also reflect the level of quality assurance testing that is conducted, both in terms of frequency and accreditation status.

While ceramic tiles are finished products, adhesives might be considered to be works in progress, as they have yet to be transformed into their final intended state, and many have a shelf life. Although adhesives are robust, they can be sensitive to the other tiling system components, how they are prepared and applied, and the environmental conditions at the time of their application and subsequently, as well as any cyclical or other imposed physical and chemical stresses. Thus the poor reproducibility that is sometimes associated with adhesive standards testing is not too surprising, even when laboratories strive to use the same techniques, using similar materials and environmental conditions. Such inherent variability also complicates the accumulation of data about the characteristics of adhesives and as to how they change with time as a function of various exposure conditions.

In such circumstances, where manufacturers never know exactly where or how someone might intend to use their products, there is necessarily a broad range of guidance provided. While more specific advice might be given where the details of

a project are well defined, it will be some time before adhesive manufacturers can provide reliable data that will enable the design of engineered facades with recognised factors of safety.

Such facades could be constructed from pre-fabricated panels, but most direct adhesive fixed tiling will be installed by poorly skilled workers, subject to poorly qualified supervisors. The quality of workmanship and supervision can be increased by further training based on recognition of prior learning and existing skills, but tile fixing is unlikely to become an appealing career path until there is appropriate financial reward for master tradesmen. People don't know what they don't know, and there needs to be a groundswell of better informed tradespersons throughout the industry to prevent the misdirection of novices by well-intentioned but misguided workers.

While new installation technologies have been developed thanks to the development of proprietary products, ensuring that such tiling systems perform satisfactorily is predicated upon several factors. The specifier might be able to rely upon the guidance provided by the adhesive manufacturer, but will still have to tailor such guidance to accommodate the specific requirements of individual projects. The location and detailing of movement joints is an obvious example.

Although there are a variety of independent consultants who can assist with various aspects of product selection and tiling system design, their specialist skills are often not called on at the design stage. Architects may be responsible for assembling knowledgeable teams to ensure that their clients' expectations will be realised, but will often permit past specifications to be recycled, being ignorant of their relative suitability. Surgeons might facilitate burial of their mistakes, but distressed tiling is harder to quietly dispose of. The expert that might help to avert failure during the design phase might also assist to crucify the architect after a failure has occurred.

Mechanical cladding systems are likely to become more popular as they are simpler to understand from an engineering perspective, and they enable a greater proportion of the building to be constructively recycled from an environmental perspective.

Given the demand for more environmentally friendly buildings, it is likely that a greater proportion of ceramic tiles will apply for eco-labelling accreditation. It is equally likely that such accreditation will become progressively harder to obtain, given that expectations of improved environmental performance are likely to increase. This will become a recurrent challenge, where the long distances of transporting some raw materials and finished products will need to be addressed.

However, there is also a need to address the issue of second and third quality product. Just because a tile does not comply with an arbitrarily chosen criteria does not mean that it cannot be used to serve a worthwhile functional purpose. Should projects be given green accreditation points if they utilise products that might otherwise be recycled for scrap? The ISO 13006 tile standards need to be revised to allow an alternative recognition of quality when assessing fitness for purpose. Products that might fail to conform to ISO 13006 might receive an eco-label, if any limitation as to use was recognised, and there was adequate guidance as to how the product might be constructively used for best purpose.

The 2006-7 USA subprime borrowers crisis has shown us how fragile the global economic system is. Perhaps we will have a global credit crisis, but if not we have

already had slumps on world share markets, and direct adverse consequences on the American construction sector that affect tile production and investments in other regions.

We have been warned about the potential consequences of inaction on global warming. If we were to accept that this might cause greater devastation than all past wars, what actions should the tiling industry take in order to minimise its contribution to the problem, and to maximise its contribution to creating a sustainable habitat and environment? In order to solve this previously poorly recognised but ongoing challenge, we must first overcome our recognised recurrent challenges.

The tiling industry has much data, ranging from broad empirical experience of failures to unpublished proprietary test data on products and systems. Proprietors, researchers and standards organisations provide a wide range of information of various types and varying levels of reliability and applicability. There is much industry knowledge, but the experts and the extent of their knowledge is sometimes difficult to identify, and the independence of expert guidance may need to be assessed. The extent of industry wisdom is questionable, as industry is rarely heard to comment openly and progressively, other than in a self-serving way.

For want of focused cohesive international industry planning, or a benevolent industry dictator . . . have we lost the opportunity to develop the plans necessary to establish a sustainable industry? We have extensive experience of identifying problems and proposing partial solutions, and then waiting for others to recognise our brilliance and their moral and commercial obligation to assume the significant financial responsibility for remedying the problems, disregarding how this will also advantage their direct competitors. It sounds very idealistic to say that we must learn to help one another because we are all in this together, but is there an alternative truth?

For want of a leader? We have talked the talk; now we must learn to walk the walk. Who, amongst our industry leaders, has the vision and wisdom to take the necessary actions?

> *It is not the strongest of the species that survives, nor the most intelligent, it is the one that is the most adaptable to change*
>
> Charles Darwin

8. ACKNOWLEDGEMENTS

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APPENDIX 1. WELL-INTENTIONED BUT UNPRODUCTIVE BARRIERS TO PUBLIC SAFETY

In Italy, the national provision for the elimination of architectural barriers for persons with disabilities (DPR 14, June 1989, No. 236) adopted the Tortus test method. Bowman used the information in Table 1 in his 2004 Qualicer presentation to highlight the inadequacy of both the Tortus and the ASTM C1028 test methods, based on a presumption that the ramp test methods provide reliable discrimination. Table 1 gives slip resistance data extracted from one manufacturer's technical literature: ordered first according to the ramp classifications and, since no ramp angles were stated, then according to the wet Tortus Four S rubber results.

TILE TYPE	RAMP CLASSIFICATIONS		TORTUS, FOUR S		ASTM C1028	
	DIN 51130	DIN 51097	WET	DRY	WET	DRY
Natural 1	R9	-	0.45	0.48	0.61	0.70
Natural 2	R9	-	0.46	0.56	0.63	0.78
Natural 3	R9	-	0.61	0.65	0.73	0.73
Natural 4	R9	-	0.61	0.67	0.62	0.82
Polished	R9	-	0.62	0.88	0.51	0.78
Prepolished	R10	-	0.41	0.68	0.65	0.86
Structured 1	R10	-	0.49	0.61	0.50	0.77
Rustic 1	R10	-	0.49	0.65	0.51	0.62
Structured 2	R10	-	0.55	0.68	0.62	0.74
Natural 5	R10	-	0.77	0.84	0.74	0.78
Rustic 2	R10	A	0.41	0.60	0.63	0.79
Rustic 3	R10	C	0.52	0.68	0.52	0.80
Rustic 4	R10	C	0.58	0.65	0.66	0.68
Rustic 5	R11	A	0.63	0.75	0.72	0.81
Structured 3	R11	B	0.50	0.61	0.69	0.89
Industrial 1	R11, V4	C	0.54	0.65	0.70	0.70
Industrial 2	R11, V6	C	0.54	0.65	0.65	0.65
Industrial 3	R12, V8	C	0.55	0.64	0.65	0.71
Industrial 4	R13, V10	C	-	-	0.65	0.78

Table 1. Slip resistance data extracted from an Italian manufacturer's technical literature

The Tortus results indicated that the R10 Natural 5 tile had exceptional wet slip resistance, and that the R9 polished tile also performed very well. The ASTM results also ranked the R10 Natural 5 tile as best, but the R9 polished tile performed poorly. The R9 Natural 3 tile also performed well. One has to ask whether the Italian ceramic tile industry is not powerful enough to persuade the Department that there is a more appropriate test method, or is it comfortable with a test method that misrepresents the slip resistance of tile but portrays it in the best possible light?

TCNA has recognised[62] that (1) the ASTM C1028 method provides a measurement of static coefficient of friction (COF), which is but one of many criteria that should be considered when evaluating the slip potential of a surface; (2) it is also useful to evaluate the dynamic COF when determining slip potential; (3) the C1028 measurement does not provide a measurement of dynamic COF; and (4) the C1028 method can over-

report the highly polished surfaces. TCNA is evaluating the potential of the BOT 3000 tribometer as a potential replacement for the C1028 method. The BOT 3000 is a motorised drag sled device, similar to the Tortus. It can make both static and dynamic COF measurements.

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DEVELOPING INSTALLATION TECHNOLOGIES AND ENSURING TILING SYSTEM PERFORMANCE

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1. INTRODUCTION

At this commemorative X WORLD CONGRESS ON CERAMIC TILE QUALITY we will try to discuss the advances and recurring challenges in floor and wall ceramics production technology that we have witnessed over the last 18 years. Many articles and posters have been published and much has been learnt from the exchange of ideas and practical and theoretical experiences. But can we really say that the global ceramic industry has evolved as we might have hoped in this area in a period of nearly two decades?

Most of the articles published in the QUALICER Proceedings for the 10 congresses that have been held have constituted a series of different ways of presenting the recurrent problems associated with floor and wall tiling. Defects in wall and floor tiling of practically every type and from various parts of the world have been presented. The serious problem of adherence failure in which tiles come unstuck has been a constant feature of the *presentations and posters* submitted by authors from various continents. The majority were sent from parts of the world where they use the most ceramics on building facades.

From everything that has been published and discussed during this time it seems that one truth emerges clearly: the behaviour of bonded ceramic tiling does not only depend on having a good product and good *workmanship*, as the practices employed in the recent past might suggest. The recurring defects of nearly two decades demonstrate that both are necessary but they are not in themselves sufficient to meet the requirements of more modern applications.

To cite a few examples, engineering work, such as the facades of tall buildings, industrial flooring, public pavements, the frontage and flooring of external, prefabricated structures like those of shopping centres, demands a series of requirements over and above those usually met by our domestic "recipes".

Also, there is a consensus on the part of the ceramics industry and research institutions in general that there is virtually no research which attempts to arrive at a better understanding of the behaviour of bonded cladding systems and the numerous factors that influence their performance.

Even with apparently simpler applications, situations arise which demand specialized technical expertise and detailed construction work. Porcelain tile floors in apartments in tall buildings, for example, need to be applied on top of thin concrete slabs, which are often subject to movements that are incompatible with the conventional solutions we use.

Also, in relation to ceramic products, very basic questions arise on a daily basis for specification writers. In the II QUALICER congress, the delicate question of defining specification criteria with a product-purpose focus was already the subject of discussion, PALMONARI; TIMELLINI (1992). In the same event, BOWMAN (1992) looked at the subject of humidity-induced tile expansion in depth, demonstrating how an aspect which is given little thought when selecting tiles can generate uncertainty. Or is it the case that an architect has all the information he needs to enable him to choose the ceramic tiles for a facade with confidence solely on the basis of tile standards, without having ceramic tiling standards specifically designed for the project in hand to guide him from a product-purpose perspective? Are there criteria in the project specifications which restrict one particular type of tile or another to specific situations

in which they can be used? Is there a recommended technical limit for hygroscopic movements – in the case of characteristics which today are determined by standards, this is called humidity expansion – to which tiles can be subjected and which can have consequences over time, such as a decrease in adherence between tiles and adhesive as a result of fatigue? Are there differences between glazed and non-glazed tiles in these cases? Can cracks in tile glazing have deleterious consequences, even when they occur long after a cladding system is applied? Are the characteristics of current ISO standards sufficient to act as guidelines for informing choices made the world over?

2. EVOLUTION AS AN ESSENTIAL REQUIREMENT

On the one hand, there were plenty of studies demonstrating the defects of applied ceramic tiles at several congresses, for example the studies presented by FELIU et al. (1992), SITZLER (1996), WONG, C. W. MEDEIROS (2000), HARTOG (2000), GOMES (2004) and WAN (2004), but technical and institutional solutions to prevent them were harder to come by. In general the causes of the defects discussed tended to converge. The same cannot be said of the origin of the problems and their probable solutions. The reality is that few studies discussed what needs to be done to ensure the performance of bonded ceramic cladding systems in any depth. Studies by GOLDBERG (1996), PORCAR (1998), and MEDEIROS and SABBATINI (1998) addressed the subject from different viewpoints. However, questions we regard as basic remain unanswered from any angle of application technology we might care to adopt.

Most of the articles that propose solutions for defects in cladding systems dealt with the materials of which they are composed, particularly adhesives. A series of articles, such as those by RIUNNO and MURELLI (1992), PITARCH (1996) and HAROLD (1998), dealt with the characteristics of cement-polymer based adhesives when used for the application of ceramic tiles. With the arrival of porcelain tile the international market for mortar adhesives advanced a great deal in this respect.

New adhesive mortars showed that they were capable of ensuring the adhesion of large-scale tiles and became directly responsible for the stable performance of numerous bonded facades in many parts of the world, especially Brazil, where large-scale tiles and tall buildings are a common combination. The work of MARANHÃO, COSTA E SILVA; MEDEIROS (2006), published at the IX QUALICER congress, showed how their use evolved and how the level of performance obtained in practice by builders improved.

At the II QUALICER congress RIUNNO and NELLI (1992) presented an interesting study on the flexibility of adhesive mortars and indicated a method for measuring it effectively. Other studies also addressed the subject up until the publication in 2003 of standard EN 12.002 (2003), which determined how to measure the transverse deformation of adhesive mortars. Even so we still need to respond to basic and highly relevant questions in order to understand the behaviour of bonded tiles. Basic research will involve demonstrating the importance of the adherence of the various cladding layers comparatively, using a deformation or flexibility modulus for each material of which the system is composed.

With respect to the effects of polymers and other chemical agents in adhesives, it is still the case that little is known about certain variables or at least that they have not yet been used when adopting specific criteria for codes of conduct in building, and

performance and project standards. One of the variables which are of most concern is durability. There are so many different contexts in which ceramic tiles are used that we are uncertain about the durability of adhesives under different conditions.

It is likely that the adherence between a ceramic tile and the adhesive which is employed is impaired over time, depending on the conditions they are exposed to, and the stress levels and fatigue the layers of bonded cladding are subjected to. But what will this impairment consist of? How long would it be before it became significant and how could this be predicted in a project in order to establish cladding maintenance criteria? The same applies to flexibility. All these questions need to be clarified. In this field basic research would be research which clarifies *the long-term performance of the bond strength of ceramic facade cladding systems – the correlation between laboratory conditions and practical design criteria.*

To know the durability of these materials would be a real starting point for defining the lifespan of a project and the maintenance requirements that need to be established for the end user of the building when it is completed. However, with the exception of the odd definitive so far unpublished or internal study conducted by laboratories within the industry, we still do not know the true performance and lifespan of the bonding between the adhesive and the ceramic tiles, and between the adhesive and substrate render.

In practice we have witnessed the behaviour of the materials of which facade cladding systems are composed in the hundreds of buildings with bonded ceramic facades that we have designed, although some types, such as porcelain tile facades are too new for general conclusions to be drawn.

Neither have there been any studies so far that have conducted in-depth analysis on how flexibility and other physical characteristics of adhesive mortars or grouting materials might contribute to avoiding problems. With regard to this particular question, investigators generally opt for the use of mathematical or simplified behavioural models, an area in which research efforts need to be continued in order to ensure wider applications, as shown by BOWMAN and BANKS (1996), ABREU et al. (2002) and FELIXBERGER (2006).

If, on the one hand, we have doubts as to whether advances in polymer technology will make the production of deformable adhesive mortars viable, on the other there has been little progress in scientific knowledge related to the design of bonded ceramic facades and flooring.

To cite three aspects essential to the stability of bonded tiling, we still need to identify the premises of cladding application and establish criteria for substrate reinforcement, the selection of *adhesive and grouting material*, and expansion joint projects. We still need to understand how the size and physical characteristics of ceramic tiles influence the selection of *adhesives and grouting materials* and the properties of normal mortar substrate, given that in practice it has been shown that nothing is gained by using the best adhesive available and then applying it to a substrate unsuited to the situation for which it is intended. We also still need to understand how climatic characteristics and application conditions affect the selection of *adhesives and grouting materials*, and the criteria for sizing, positioning and locating expansion joints.

We are not aware of any plans to revise ceramic cladding project and application standards so that they correlate with reliable parameters, for example, the height of

building structures, their type and ceramic cladding joint distribution. Nor do we know how to determine with sufficient confidence the levels of internal stress in the layers that constitute the cladding system applied to a facade or floor surface and the effect of the flexibility or adherence of adhesive mortars and grouting materials on the system as a whole.

The influence of the substrate base and layers of cladding systems is a variable which as yet has been little explored. We know that concrete foundations shrink as a result of flow and creep and we can determine these values, but we still have no models to show us how they can affect the performance of bonded cladding.

When it is a question of the safety of vertical bonded cladding – the safety of floor tiles and aspects related to slippery horizontal surfaces will be covered in another module – one question emerges: why do we not simply abandon or even ban the use of bonded ceramic tiling and adopt mechanical approaches to achieve the performance we require?

This would be perfectly reasonable, were it not for the fact that mechanical anchoring systems cost three or four times more than adhesive solutions. In countries which use ceramics on the facades of thousands of buildings – right now we estimate that there are at least 2,000 buildings over 12 floors in height being built simultaneously in Brazil, nearly 500 of which have ceramics on their facades – the adoption of mechanical methods that perform well would not be viable either economically or from the point of view of the sector's infrastructure.

Although there are numerous problems, the many buildings of high quality and performance which exist tell another story. They show that, from an engineering perspective, we need to improve our understanding of how bonded ceramic cladding systems perform in order to determine the conditions limiting their use, and the criteria and parameters which apply. We need to organize this information as a systematized whole to permit our specification and project technical standards to be revised so that the quality of building work can be reproduced on a large scale.

3. DESIGN AS THE KEY TO PERFORMANCE

One of the most important engineering challenges to making facades clad with ceramics that comply with technical requirements viable, ensuring adequate safety and lifespan, is the elaboration of an executive facade cladding project.

A facade needs to be competent in its function of protecting a building, ensuring its aesthetic quality as far as possible throughout its useful life. To do this an elemental requirement is that the layers of cladding must be designed and executed so that no detachment occurs, even in exceptional cases.

A facade cladding production project must include graphic elements which provide the information required for the building process and ensure that the cladding is adequately produced, minimizing decisions that need to be taken during execution and formalizing decision-making, something which is not usually contemplated in architecture and planning.

These graphic elements should include representations of substrate render and expansion joint reinforcements. Both reinforcements and joints will vary, depending

on the deformations expected of building structures and their cladding systems, as well as the type of tiles to be used, as was discussed at the VI QUALICER congress by GOLDBERG (1998) and MEDEIROS (2000).

A properly designed executive cladding system project permits compatibility between the geometry of the structure and its architecture, optimizing masonry work and the squaring of installations, and creating the conditions required to reduce densities, and minimize reinforcements and joints, which should only be used where necessary.

The compatibility achieved between structure, architecture and the cladding system results in the reduction of building and maintenance costs, and practical experience has demonstrated its importance. It converts the cladding project into a useful tool in planning, and in the process of designing and constructing buildings in Brazil. It has only recently become common practice to elaborate a facade cladding project as an integral part of the process of conceiving building activities, as occurs with other projects.

Reinforcements, membranes and joints are used to avoid the appearance of cracks and inevitable infiltrations, favouring the conditions which ensure cladding remains intact, safe and aesthetically pleasing, despite the wear and tear that occurs over time. Tensile and shearing stresses which cause fissures at interfaces, between layers of cladding and structural elements, such as beams and pillars, can be combated using special metal meshes or dissipated by anti-crack membranes or expansion joints in the cladding system.

Using suitable fillers for tile placement and expansion joints can attenuate these effects but this is not enough to guarantee that cladding will stay in place and remain stable over time. The layers of render and adhesive must be capable of withstanding the internal and external stresses they are subjected to.

Too many expansion joints can also damage the cladding system, contrary to what many claim. As well as their impact on costs, an excessive number of joints makes execution more difficult and tends to cause movements the cladding system may not be designed to admit.

The person who designs a cladding system must know where, how and to what extent – although their determination may not be very accurate – the stresses generated by movements of the substrate significantly affect cladding. These stresses can be minimized, for example by increasing the depth of joints or by reducing the deformation modulus for the grouting material, thereby increasing their capacity to resist stresses. Compensation or alleviation of joint stresses has to be effective when stresses are caused by compression. When tensile stress is at right angles to the principal plane of the tiling system or shearing stresses occur in this plane, the effect must be slight or non-harmful.

This delicate equilibrium, in which, on the one hand, there are the different forces which generate stresses in the cladding system and, on the other, the layers of which the cladding is constituted with their different compositions, resistances and deformation capacities, is what has to be interpreted in the project and must decide the choice of materials, techniques and building details for the project.

As well as providing designs of the positions and details of reinforcements and joints, the project must of necessity specify each material which is to be used, describing its properties and defining its characteristics. This applies to mortar, render, adhesive and grouting material, both in their fresh and hardened state, and specifications must avoid indicating particular brands and simplified typecasting of products.

All the executive procedures as a whole, from the preparation of the substratum to final cleaning and preventive maintenance, control procedures for the reception of materials, the execution process and the approval of each service phase, form part of the project.

When the project is regarded as a production tool, it becomes indispensable to whoever executes the cladding system because it is taken into account in how the building work, building sequence, means of access for production and necessary controls are conceived, meaning that the project previously drawn up on paper and its effective realization bear close resemblance. This ensures the project materializes as the execution team would wish and that it actually achieves results and the satisfaction of the agents involved.

This is why we need to invest in the development of cladding production projects, ensuring better definition of criteria, parameters and methodology, as a way of formalizing the process of achieving compatibility between architecture and the structure of buildings, and supplying the specifications and necessary details before execution.

3.1. USING CERAMIC FACADES IN TALL BUILDINGS (boxed facades)

Two aspects of tall buildings related to their possible effects on facade cladding systems arouse interest: horizontal movements due to wind pressure and the overall shrinking of their structure as a result of the creep and flow of concrete. With respect to the effect of wind, the maximum movements which can cause detectable movements in facades that are most disadvantaged in terms of rigidity are a cause for concern. If these movements are cyclical, they can impair adherence as a result of material fatigue.

With respect to the overall shrinkage of a structure, the regions in the vicinity of the most important load-bearing pillars, where the cladding system may be subjected to shearing stresses, are cause for concern. Perhaps the most significant aspect to analyze in relation to large-scale structures with bonded cladding systems is the load application sequence, including the technical time limits loads must comply with. It is evident that the movements which can interfere with a cladding system are the residual movements that occur after its application, once a significant part of any expected movement has already occurred.

In buildings of slim contours, such as those built in Recife in recent years, we should be more concerned. FONTE et al. (2005) draw attention to the need to conduct other numerical behavioural analyses, as well as traditional overall linear analyses of elasticity, in order to determine service activities, in addition to performing dynamic evaluations of wind load amplification in the direction of wind gusts and the effect of cladding system structure-masonry interactions on rigidity. Many of these buildings are taller than 110 m and at their narrowest point are about 10 m in width. So we would expect these structures to exhibit considerable movement, both vertically (owing to concrete yield and retraction) and horizontally (owing to the effect of wind).

We can add another cause for concern to this question of tall buildings. In cities with a tropical climate, for example on the north-east coast of Brazil, the climate is normally hot all the year round and the relative humidity and solar insolation are high, minimizing the cyclical effects of the dilation and contraction of the cladding systems of these buildings. Meanwhile, although the fact that daily temperatures are not high in tropical regions might be considered an asset, a warm climate favours greater tile dilation and consequently greater internal stresses in cladding systems.

4. MATERIALS AND INSTALLATION METHODS

The production of a facade cladding system is a complicated process that involves making a series of important technical decisions, which cannot be avoided without compromising the final result and safety of the system. A series of different criteria need to be adopted throughout the process of conception, compatibility, design detail, execution, control and maintenance.

The control and responsibility for the cladding system production process require the attention of draftsmen and builders, and often the participation of specialists. This process includes everything from the specifications of materials to the training of the work force which carries out the building work, and aspects related to technical standards and the conducting of tests must always receive due consideration.

Even when applied in a conventional manner, ceramic cladding systems demand a series of special technical procedures, especially in the case of very tall buildings. To facilitate projects and also their execution peripheral beams are a standard height, generally about 0.70 m. This essential requirement is crucial in order to ensure the execution of the horizontal movement joints at the same level. If window spaces are lined up at the top with the ends of beams, this ensures that movement joints are intermittent and as close as possible to their ideal position so they can control any fissures which occur and minimize the consumption of sealing materials.

Adequate execution of the mortar-render system also requires special attention, as the stability and safety of bonded ceramic tiles depends on it. The adherence, surface resistance and deformation capacity of the render layer have to be evaluated by the draftsman and suppliers of materials. A substratum adherence capacity (concrete and masonry) of no less than 0.3 N/mm^2 is specified for the mortar-render system, values of up to 0.6 N/mm^2 being typical. In projects the minimal value permissible for the surface resistance of render systems is 0.7 N/mm^2, the average resistance being 1.0 N/mm^2.

The values obtained for the adherence capacity of blocks of concrete or ceramics to masonry are generally acceptable. The greatest difficulty lies in obtaining the resistances specified for the concrete elements, which require special preparation to permit the anchoring of the mortar-render system that subsequently serves as the substrate for the application of the ceramic tiles.

Cladding systems are generally anchored to the pillars of a structure by means of special metal meshes designed for this purpose. Movement joints are very rarely required between walls and concrete pillars in conventional buildings with concrete structures built *in situ*.

To lay small-size tiles (*porcelain tile* and *stoneware mosaics*) single-component adhesive mortars with direct tensile strength values of from 0.7 N/mm^2 to 1.5 N/mm^2 are normally recommended, the value which is most commonly used in practice being about 1.0 N/mm^2. Values can vary widely, depending predominantly on the size of the building, and the type of structure and cladding system, their dimensions and properties, and how the ceramic tiles are applied.

Two-component adhesive mortars with an acrylic latex adhesive are normally used to lay porcelain tiles. This permits an adhesive strength of about 2.0 N/mm^2 and high flexibility under laboratory conditions. The flexibility of this mortar can be determined using the transverse deformation test in accordance with the EN 12002 (2006) European standard, opting, for example, for the Class S2 one, which has a transverse deformation value of over 5 mm.

For porcelain tile and all formats over 200 x 200 mm, the buttering and floating technique is recommended. Mortars compatible with the types of tile used and the joint widths are employed as grouting material. All the materials are specified in the cladding project and evaluated under conditions of use during the building process.

Hot-dipped wire mesh is used for the reinforcements envisaged in projects, but membranes made of materials other than polyester applied with acrylic resin can also be employed.

Horizontal movement joints are executed to a final thickness of 15 mm to 25 mm and are nearly always lined up along window spaces, very close to the ends of beams and where indicated by the cladding project. High performance polyurethane sealers with properties which meet international standards are employed for the treatment of movement joints.

5. MATERIALS PROPOSED TO IMPROVE CLADDING SYSTEM BEHAVIOUR

In Brazil facade cladding systems for buildings constructed in a conventional manner, using a succession of bonded layers, and in which cement materials are used, have frequently been subject to criticism, doubts and questions, particularly on the part of builders (CICHINELLI, 2007).

This is justified, basically owing to the relatively high incidence of problems, particularly with certain specific types of ceramic tiles. Naturally builders are aware there is a lack of information on which to base their decisions so that they can avoid problems, and that technicians have little or no institutional help in finding technical solutions founded on in-depth knowledge to reverse this panorama of insecurity.

It is also the case that, in an attempt to follow the Brazilian standard which regulates external ceramic tiling procedures – the NBR 13.755 – more explicitly, both the draftsman and the builders involved monitor construction inconsistencies, not only because there is a lack of sufficiently detailed criteria for the reinforcement and joint project, but also of proper parameters for material specifications applicable to the range of different situations in which they are currently used.

This lack of information, in addition to a lack of action in the technical sector, has systematically induced defects in cladding systems and has had a negative effect on

the expansion of the use of ceramics for facades. These cladding defects, especially at the project stage – when the main technical decisions need to be made – lead to errors in execution and, unless the matter is studied in more depth, regulations on use are revised and awareness is fostered in the technical sector, problems will continue to occur, given that few companies adopt their own measures to resolve this issue.

The author holds the view that, in order to reverse this situation, any set of actions must consider how to regain the confidence of businessmen and builders in the technology for the application of ceramic tiling systems, particularly in strategic markets, such as the metropolitan area of São Paulo, which accounts for nearly 35% of the Brazilian residential building market. Any such actions need to reinstate credibility and show that ceramic tiling can offer a safe and lasting solution, given that its other advantages are evident in Brazilian building culture.

Indeed, to go in this direction and resolve the technological and institutional gaps which exist will require some very hard and systematic work in the fields of engineering and architecture, particularly in order to learn more about the behaviour of cladding systems so that their design and construction can be improved.

As a way of contributing to the promotion of debate and collaborating critically with the evolution of facade cladding building technology, aspects the author considers relevant when it comes to improving the performance of applied ceramic cladding systems will now be discussed.

5.1. THE STATE OF CURRENT KNOWLEDGE IN PRACTICE AND THEORY

In relative terms we have evolved much more in practice than in theory, where the technology for the execution of bonded ceramic tiling systems is concerned. Here we need to point out how inadequate the term “laying tile”, so common in the ceramic industry, is to identify the series of techniques and materials, their specification criteria and parameters for use, which it covers. The term dates from a period when practical knowledge was usually sufficient to obtain cladding systems that performed well and were durable. For some time this has no longer been enough and the defects in many buildings are more than sufficient proof of this. We need to apply more engineering expertise in our use of cladding systems and engineering involves using scientific and technological knowledge combined with practical know-how.

Brazil has beaten records in its use of bonded cladding systems, which at least demonstrates the bold innovation of its technicians and its ability to learn rapidly from its mistakes. However, this has cost it dear, is very risky and is not enough to ensure a good understanding of the subject. We need to carry out detailed research to ascertain why so many buildings have problems, but also why a much greater number still exhibit compatible behaviour, even if this is only in relative terms.

If the various agents involved combined their experiences and efforts to make the most of this “laboratory open to the skies”, we would be in a position to find an explanation for so many cases of failure and success. This initial phase of professional research could provide us with better technical parameters to inform the decisions that are being made to produce this immense number of buildings, creating the conditions for monitoring and improvement we long to see in national project and execution standards for ceramic cladding – although we must not confuse cladding systems with ceramic tiling. In this context - that of technological research focused on

the performance of the products employed – the exemplary work conducted by the CSIRO in Australia and coordinated by Richard Bowman, and at LNEC, IST and the University of Oporto in Portugal, deserves special mention.

BOWMAN (1997), for example, systematically studied the phenomenon of the hygroscopic movement of tiles in cladding systems, demonstrating its importance to the stability and useful life of bonded cladding systems. The case studies he analyzed suggest that properly applied cladding tolerates an expansion while in service of up to 0.04% over a period of over 3 years, which is obviously not a long enough lifespan for our purposes. His work on the kinetics of humidity-induced tile expansion clearly indicates that we need to study the subject in depth in order to improve our ability to specify facade tiles and adhesive materials that will ensure durable cladding.

At LNEC / IST (ABREU, 2001), as a result of the work of researchers studying numerical behavioural models by means of the mixed-hybrid finite element stress method, it was reported, for example, that the use of more deformable grouting material in laying joints can reduce normal tensile stresses in the cladding system plane, but can, at the same time, cause an increase in shear stresses. The analysis of dozens of practical cases of tile detachment demonstrated breakage mechanisms originated by these stresses, warning us of a source of defects which is not normally taken into account. This increasingly common problem of tile debonding, which occurs close to movement joints, also indicates that by permitting greater freedom of movement we can reduce certain stresses in one plane but simultaneously induce their increase in another. If the specified adherences – and obviously those actually obtained in the cladding system applied – are not compatible with the stresses produced, this can lead to breakage and consequently detachment.

To cite another example, a research study carried out at the University of Oporto by FREITAS; VAZ SÁ (2005) shows the importance of predicting the durability of the adherences between adhesive mortar and ceramic tiles with different water absorption capacities. By means of an accelerated ageing test - based on the parameters in the ISO 15.856 series on *Service Life Planning* – it is possible to determine the losses which occur and, based on these losses, we can predict the lifespan of cladding systems in different situations and using different materials. Perhaps this is the most serious and important question for discussion but the answer is as yet uncertain and requires more research. Regarding this question, like SHOET; PACIUK (2004), we assert that research on the loss of adherence of tiles subjected to cyclical stresses, which can cause the fatigue of materials and bonded layer interfaces, is very relevant.

5.2. CERAMIC VENTILATED FACADES

Although still very recent, the arrival of mechanical anchoring alternatives for ceramic tiling systems in the Brazilian market naturally meant a question began to emerge: Why not adopt mechanical anchoring methods for ceramics to offer greater safety?

First of all, we need to understand what ventilated facades are and how they work, and what safety levels different solutions can afford. There are a whole series of different mechanical anchoring alternatives and it is common sense to realize that not all of them will offer the same level of structural safety. Then we need to remember that the prices of these technologies are considerably higher than the adherence solutions which are usually included in our building estimates.

The contribution of the facade cladding system – including all layers – to the total building cost of a residential building can exceed 10%. Commercialized solutions in the form of homologated facade systems in Europe, where the technology was initially developed and is used on a market scale, cost nearly 70 to 120 euros/m^2. In other words, for them to function safely and efficiently, the use of ventilated systems would involve an increase of about 50 to 100% in direct production costs, which means the alternative is not readily viable in the current Brazilian market scenario for commercial buildings, in which the conventional building of cladding systems costs about 70 to 120 reales/m^2, in other words, almost three times less. This explains, at least partially, why most ventilated facades with ceramic tiles – porcelain tile and large-sized extruded tiles – as they are known in Europe, are more easily integrated into large institutional projects (company headquarters, schools, universities, banks, hotels, hospitals, museums, exhibition parks), where aesthetics incorporates something other than purely commercial values.

On the other hand, we need to evaluate simpler and less costly mechanical anchoring solutions – such as those that use discrete anchoring devices which are attached independently – by means of tests based on internationally accepted behavioural criteria, bearing in mind the absence of specification criteria in national regulations. Tests which evaluate how systems respond to wind pressure, air and water tightness, and the impact of soft and hard bodies, are indispensable when attempting to establish how these systems behave. Their building and maintenance grades must also be verified, evaluating aspects such as compatibility with remote aligned squares and the ease with which tiles can be replaced. What does seem to be clear is that a conventional solution should not be substituted by a mechanical one which is much more costly without demanding minimal performance requirements.

5.3. WHAT WE NEED TO KNOW IN THEORY AND IN PRACTICE

As we see it, the key problem in designing facades with ceramic cladding systems is not the characteristics of the material. Although advances need to be made with respect to our knowledge of materials, what we need most is to establish the necessary behavioural requirements in order to produce safer designs.

The parameters which exist in the standards for materials either concentrate on the characteristics of materials or adopt empirical criteria based on practical building skills. And this is not exclusively in Brazil. The corresponding technical regulations are like this practically the world over.

We should not concentrate almost all of what little research there is on the geological aspects of cladding systems and physical tests on materials. There is an urgent need to advance rapidly in our understanding of the behaviour of the materials used and their performance requirements, conceiving this as an integral part of building, unless we are prepared to put off solving essential aspects of the problem of safety and durability indefinitely.

As yet there is no physical behavioural model which explains how multiple-layered bonded cladding systems behave and what the necessary parameters for them to remain stable over time are. We need to respond to a number of basic questions to minimize the risks involved and parameterize applications which In practice have been shown to be successful, so that we can reproduce what has performed best in our projects, fully aware of what we are doing and basing our work on sound principles.

BOWMAN (1996) highlighted this question more than a decade ago but very little progress has been made.

With regard to the tensile strength capacity, for example, in which the 0.3 MPa parameter is used for values obtained on site, are we really equipped for the new situations demanded by more daring projects? The problems which have occurred in recent years show that this is not the case. A significant number of practical cases have demonstrated that even when this value is obtained some types of tiles debonded. If 0.3 MPa is not sufficient, what would the new adherence levels be for different project situations and how can these functions be adequately characterized? Our understanding is that this key point is basic to specifying, designing and constructing cladding systems and we know that, if we are not completely ignorant on this point, it is thanks the experience of a small number of specialists in this area.

In order to broaden the existing knowledge base so that bonded facade cladding systems that use ceramic tiles can be designed more safely, we pose a set of questions, the answers to which might serve as subjects for research:

1) How can different types of tiles and their intrinsic movements influence the definition of the resistances that are required? Do unglazed tiles, which have the greatest potential for hygroscopic movement, require greater adherence to withstand cyclical movements? And what about large-sized tiles and their thermal movements, which are also cyclical? What would the loss due to the bond fatigue of adhesive mortars be as a result of adding different polymers?

2) Do different ceramic tiles require the substrate render system to have different characteristics, depending on the intrinsic movements imposed?

3) If values of over 1.0 MPa are obtained for an adhesive mortar's tensile strength under laboratory conditions, will we solve the problem of tile detachment in the majority of cases?

4) How can the surface interaction between the adhesive mortar and the substrate render determine the stability of the cladding system? How can the *wettability* of adhesive mortars influence adherence to the render surface? How can the strength and the surface characteristics of the render affect the adherence we achieve in a building as a whole?

5) What deformation modulus values for adhesive mortars and grouting materials are capable of really attenuating the stresses cladding systems are subjected to? In what way can the determination of transverse deformation capacity, an indirect way of measuring what is popularly termed "flexibility", help to decide specifications for adhesive mortars and grouting material which result in cladding systems that are more tolerant of deformations?

6) What is the effect of movements of the concrete structure on bonded cladding systems? What numerical model can be used to evaluate the stresses that originate in movements of the substrate and movements originating in the layers themselves which are transferred to the various layers of the cladding system? In tall, slim-contoured buildings up to what magnitude can the stresses caused by deformation and the detachment of tiles owing to the effect of wind permit us to use bonded cladding systems with confidence?

6. PERSPECTIVES FOR DEVELOPMENT IN THE SECTOR

For a long time our practical knowledge has failed to address or satisfy the requirements of building projects in which cladding systems are used. This is not only true in the case of facades which, for obvious reasons, are a cause of greater concern. We also need to revise our concepts when applying cladding systems to floors and interior walls in unusual conditions, when building is conducted with or without the use of beams and with large openings which afford little rigidity. It is clear that, if we continue to apply the same dated recipe that served us for decades to execute modern projects, either we should not expect adequate results or we will have to adapt to a series of factors which will provide positive results. Specifications, the project and the execution of the cladding system can no longer be treated as a practical issue. We cannot risk company image, people's lives and investments of 1, 2 or 3 million on an important project without mastering the basics of our subject.

Although the expertise available to us today for cladding system design, as well as the parameters established by technical standards, have already evolved considerably along with our experience, there is an urgent need to transform this knowledge into a basis in engineering and technology.

Neither can we expect a simple revision of established regulations by empirical means. The expertise acquired up until now, especially practical and intuitive knowledge, needs to be the subject of technological research, which will improve the parameters on which decisions are first based and will subsequently provide a validated behavioural model. Only in this way can the risks involved in building the cladding system for a facade be effectively minimized, ensuring its integrity and avoiding any wastage of resources.

Several countries, such as Brazil, which use cladding on a large scale, have the technical and practical credentials to set international standards in the use of ceramics for the facades of buildings, if they invest in technological development.

In Brazil in particular we probably have the largest reserve of completed buildings and buildings under construction in which ceramics are used, which enables us to analyze the performance of cladding systems in practically any situation. This is a real laboratory open to the sky, ready to be exploited if it were organized to generate technological expertise and make the most of all its accumulated experience for reference purposes. This is an exceptional opportunity to promote progress in Brazilian engineering and architecture.

We need to transform up-to-date practical knowledge into technological expertise, increasing the value of quality ceramic products and adhesives in order to follow on from the results and conclusions of GOLDBERG (2002) and FERRAZ; MEDEIROS (2006). We need to convert good cladding application practices into educational and training programmes, taking the technical knowledge which ensures correct decision-making, control of execution and, finally, good performance for facades and floors to the day-to-day ambit of architectural studios and quarries.

But who will take on the responsibility for the generation and transmission of this knowledge? Who would pay for it, even if the investment were highly viable for the building industry as a whole?

The knowledge base and the effort required to make this a reality would necessarily involve numerous disciplines and, in our view, the participation of everyone with an interest in the future of the ceramic sector the world over, especially in the developing countries. National and international regulatory bodies, governments, industry and research institutes need to join forces to take advantage of this favourable moment and our accumulated experience to transform the art of ceramic cladding system application. To wait any longer would be negligent, given the enormous waste of resources which occurs year after year in order to rectify the defects in our buildings and compensate the people who use them. A small fraction of these resources would be more than enough to achieve a knowledge revolution.

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18 YEARS ARGUING WITHOUT ANY INTERLOCUTORS?

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When the Qualicer Organisation proposed a debate commemorating the tenth conference, I reached the conclusion that such a debate should serve to analyse Qualicer's trajectory, through the main subjects that have been presented at the different Congress meetings.

I fully agree with the Chairman of the debate, Richard Bowman, in the proposal of four areas of discussion, to which I shall try to respond in this personal contribution.

1. THE CONTEXT AND TRAJECTORY OF QUALICER

The start of the Qualicer trajectory in 1990 occurred in a context of great perspectives, but also of concern regarding the future of ceramic tile and its place in contemporary architecture. The context may be summarised as follows:

- Maturity of single-firing process technology in its main variables (comminution, compaction, drying, firing, and surface treatments).
- Commercial success of porcelain tile and attainment of the objective of having appropriate products for the most demanding uses.
- Prospects for change in the business management model, on the assumption that the model of price-driven competition parallel to continuous growth in demand might become exhausted in the middle term, and also as a result of changing trends in commercial policies, led by a small group of producers.

In that framework, new problems were posed and hopeful expectations created in regard to the challenges that the manufacturing sector and the entire ceramic tile marketing and sales chain needed to address in the last decade of the 20th century.

Qualicer was thus created with a view to constituting an international forum for debate, not only on manufacturing quality and the use of ceramic tile, but also on the management and marketing models that needed to be adopted in the near future. With ambition and eager expectation, the Congress organisers together laid out different lines of debate.

The technological component relating to manufacturing predominated in the first meetings, for obvious reasons. On the one hand, Qualicer arose in a land of manufacturers and it was supported by a Technology Institute that had already devoted a decade to work in research and development programmes on process technology and the resulting product. However, the first conference already opened up the subject-matter to industrial design and the use of ceramic tile in Architecture and Interior Design. In an almost sequential form, Qualicer has continued opening up subjects for debate in different areas:

- The adoption of industrial design as an independent function in the ceramic company and driver of product innovation management, these being much further-reaching facets than tile decoration.
- Attention to the complex world of Architecture and its leading professionals, with an intense striving to seduce, in which the Qualicer Organisation has not scrimped in drawing architects of international renown to the meetings, starting at that long-ago second meeting of 1992.
- The debate on the consequences of non-quality extended to the entire tile commercialisation and installation process, and sought to lay the groundwork for a commercial policy that might be able to contribute to quality assurance, particularly in the installation stage.
- In direct relation to the foregoing point, the profound debate and contributions to the Congress on the technology of tile installation by adhesion and the professional qualification of the tile fixers. This has been a recurrent feature in Qualicer's trajectory since 1996, which has led to:

— The incorporation of the industrial sectors devoted to tile installation materials and equipment; i.e., for the first time, there was indirect contact between the tile manufacturing sector and the building sector.

— Contributions in regard to professional qualification and training to access the trade, as well as to ongoing training and specialisation, with brilliant, clarifying presentations like those delivered by Colin Cass, from Australia.

- In the last phase of that trajectory, starting with the first contributions to technical marketing by Group II of the Congress (current Group B), the need has arisen to incorporate into the Qualicer subject-matter the debate on business management as a whole, focusing especially on the strategic aspects of international competition, marketing variables in a global market and, of course, the debate on the management model.

A simple review of the tables of contents in the Congress Proceedings confirms my view that Qualicer has anticipated, in many ways, the actual evolution of company industrial and commercial activity. Such foresight was a Qualicer objective and must be a source of pride for the organisers, since it has been more than accomplished. Quite another matter is the feeling of solitude that some of us that have worked for the Congress have lived through, in the sense that many of the problems posed and solutions proposed twelve years ago have not even been minimally addressed by the world tile manufacturing sector.

Have there been failures in communication? Has the Qualicer framework been the appropriate context for encouraging dialogue between the manufacturing sectors and everything that follows in the chain formed by ceramic tile commercialisation and use.

Some of us who have worked for Qualicer have repeatedly asked ourselves those and other questions. Personally, I have come to the conclusion that the fault has lain neither in Qualicer nor in the quality, appropriateness, or timeliness of the proposals and arguments advanced, but rather in two, hardly questionable realities:

- Not only has the business model grounded in production and price-driven competition not exhausted itself in the first years of the 21st century, but it persists in all its variables at the current time. In that model, non-technological intangibles and every approach unrelated to process technology are valued in a very minor way by the manufacturing sectors.
- The main manufacturing sectors have failed to adopt the concept of industry as it is understood in English-speaking countries, materialising specifically in the case of ceramic tile along the three axes of commercialisation: the manufacturer, the entire marketing and sales chain, and the building sector as target user.

These premises allow us to understood the scarce advances in product characterisation with respect to use and in the regulations that underpin this, the scarce implementation of industrial design, technical marketing, technology and professional qualification in tile installation, the replacement of the concept tile with that of covering system and the very scarce investment in the development of construction solutions adapted to current industrialised building construction, in which ceramic tile is the epidermis of a more complex, multifunctional construction element, or an effective response to a need or problem of the habitat.

2. ON THE CHARACTERISTICS OF THE CERAMIC TILE WITH RESPECT TO USE

If we assume that the current offer covers practically every demand in regard to modular rigid coverings and that new advances are to be expected in porcelain tile and in laminates or sheets, it is a contradiction that:

- Ceramic tile technological characterisation lies far behind the needs and demands of sustainable, quality Architecture, and fails to constitute an effective aid for the specifications writer:
  - — Standard EN 14411 was a compromise adaptation of extinct standard EN 87 of 1985, though it was referenced as an adaptation of international draft standard ISO 13006, of 1998, in order to conform to the requirement of the CE mark according to EU Construction Products Directive 89/106/EEC.
  - — The test methods associated with this standard have been outstripped in certain technical aspects and they fail to satisfy the requirements of tile suitability for use and adaptation to the building process. The dimensional tolerances according to EN 14411, the tests set out in EN ISO 10545-7, EN ISO 10545-12, and the failure of draft standard ISO/DIS 10545-17 illustrate these deficiencies.
- The extension of product characterisation in regard to other parameters inherent to particular applications (for example, the case of facades) and, in particular, in regard to the parameters that define the life cycle of the materials, in response to the growing social demand for sustainable Architecture.

If we dare to imagine a ceramic firing based on solar energy or the use of hydrogen as fuel, an increasing technology transfer from advanced ceramics towards 'traditional' ceramics and new product developments that link up with quality and sustainability of the habitat as well as with the technological requirements of current Architecture, is that deficient characterisation not to be perceived as a brake on application needs, now and in the future?

Updating ceramic tile characterisation should have been top priority for at least a decade, as a competitive instrument not just against other rigid materials, but also against non-rigid and/or non-modular ones. In addition, it should tend towards harmonised characteristics and test methods for product families with the same intended use, at least for those that provide a response to a specific functionality and share an installation technology.

3. TECHNICAL MARKETING INSTRUMENTS FOR THE MARKETING AND SALES CHAIN AND THE PROFESSIONAL GROUPS IN THE BUILDING SECTOR

If technical marketing is taken to be the part of marketing that concerns itself with promoting products based on their technological features, the manufacturing sectors should undertake initiatives in that area:

- First, they should respond to the demands of the designer, providing solutions and not products (even though these may be set in appropriate environments).

- Secondly, instruments and specific training for the sales chain, focusing, on the one hand, on the adoption of tile selection criteria as a function of a tile's intended service application and, on the other, on supplying reliable technical arguments in the comparison between materials.
- Thirdly, improving the instruments for communication and promotion in this area, especially in electronic catalogues and Web sites in Internet.

4. VERY BROAD FIELD OF ACTION IN THE TECHNOLOGY OF TILE INSTALLATION BY ADHESION

Since thin-bed or medium-bed adhesive tile installation occupies an important place in the installation of modular rigid coverings, particularly in non-conventional applications, the line of development in the deformability of adhesives and cementitious grouts is of great interest, as well as the adaptation and assurance of the durability of directly adhered modular rigid coverings on current substrates, including prefabricated drywall systems.

Additionally of importance is also the further extension of the standards and perfection of the test methods for adhesives and grouts. The correct characterisation of these materials is as important as, if not more so than that for tiles. The debate over standards 12002 EN and EN 13888 and the particular problems of some test methods are examples that justify the need to act in this field.

Supplying specifications writers with technical reference documents is another line of action that should be undertaken, at least partly, by the manufacturers, in close collaboration with the professional stakeholders in the building sector. It is quite striking that it is precisely countries that are notable importers of ceramic tiles that have developed the greatest number of initiatives in preparing and disseminating technical documents (such as the German Instruction Sheets, the *Cahiers* of the French CSTB, or Australian standard AS 3958).

After the failed attempt to achieve a European standard on tile installation, which in the end remained an informative document with a generic content (CEN/TR 13548), it would be even more utopian to propose that modular rigid coverings should go beyond the category of finishes and become functional construction elements, pertaining to the section of construction equipment. That would lead to working for a specific Eurocode, as a unitary technical reference in the European Union. Together with normative development, technical documentation is the basis for an auspicious quality assurance of ceramic coverings.

Another widely-treated chapter in Qualicer has been the development of tiling systems with the best available materials and techniques, adapted moreover to industrialised building construction, progressively inclining towards the adoption of prefabricated systems. Most advances have stemmed from other sectors and, sometimes, ceramic tile has been a victim of its maladjustment to those advances.

From the 1994 to the 2000 Qualicer meetings, albeit with isolated later contributions, the problem of the professional qualification of tile fixers has been present both in the papers presented and in the debates that were organised. It is quite surprising that in 2008 all those approaches remain absolutely topical, and even more surprising still that

in the countries with the greatest consumption in ceramic tiles there has hardly been any progress in this field. The following thus remain valid issues:

- Professional accreditation, including instruments recognising prior learning, such as that presented by Colin Cass at the first Qualicer meetings.
- Adaptation to the social environment of the training models providing access to the trade, in a context perhaps of crisis in long-term traditional training and its makeover into an intensive training that facilitates immediate occupational insertion of the trainee.
- The needs of ongoing training and specialisation, now in terms of very dynamic models compatible with the professional activity of the target users, under the ineluctable premise that such training should be measurable in terms of economic profitability for the target users.

The inauguration in 2006 of the new thematic group dedicated to management and commercialisation, and especially the brilliant performance by Patti Fasan and Bart Bettiga in the Debate Forum, have brought training of the sales staff, and the service that companies marketing and selling tiles should provide in tile installation to the forefront of the debate, that marketing and sales link being essential to spreading a culture of quality in ceramic tilings. In a particular geographic area, we observe that the company that sells building materials is so often the only available interlocutor for building professionals, and even for the consumer. This has thus been a further issue broached at Qualicer, and it is in fact the most recent one, for which very specific actions are required by the manufacturing sectors.

5. NEW INSTALLATION TECHNOLOGIES AND NEW FUNCTIONAL REQUIREMENTS FOR CERAMIC COVERINGS

It is evident that ceramic tile will continue its evolving trajectory towards better technical characteristics and further adaptation to ever more specialised requirements of the habitat in general, and of the home in particular. There have been numerous advances in product innovation, some of which have already been presented at Qualicer, such as the 'Earth Ceramics' by Emile H. Ishida, and others adapted from other manufacturing processes. It is not difficult at this moment to imagine materials made from natural raw materials and ceramic manufacturing processes that respond to specific construction requirements, some of which are already on the market.

I believe that such a line is currently materialising through prototypes and tiles with particular properties (bactericidal, self-cleaning, luminescent, humidity-regulating, chemically adsorbing volatile compounds…), albeit presently just as a commercial anecdote, though they may achieve a notable market share in the future. However, another line features coverings systems with very specific objectives: namely, avoiding adhered tile installation, providing an envelope or walling with specific functionalities (insulation, waterproofing, etc.), or which are attractive because of the installation cost/logistics without the need for skilled workers.

Despite the commercial success attained by some companies in the case of cross-ventilated envelopes with open joints, no clear positioning has yet occurred

in that line in the manufacturing sectors. Here too, it would appear that we are moving on a level of experimentation in alternatives to traditional tiling, though without believing too much in these. To date, technological transfer has come from other branches: auxiliary structures and fastening systems from natural stone in the case of ventilated facades, and from the parquet and raised flooring branch in the case of dry-installed ceramic flooring.

Prefabrication continues to be done by just a few installation companies in very specific geographic areas. Surprisingly, here as well, more advances have occurred in materials for envelopes and drywalls than in the coverings sector.

What does appear to be clear (and this is especially topical at the present time in Spain with the coming into force of the Technical Building Code) is the association of finishes with the comfort of the dwelling. From now on, a flooring or wall tiling will necessarily need to be associated with materials that are present in the envelope backing and also in the walling, which on so many occasions serve as fixing surfaces for ceramic tile. In regard to soundproofing against impact and airborne sound, thermal insulation, waterproofing, vapour transpirability, and even underfloor heating, unless the manufacturing sectors provide appropriate responses, other materials will form the epidermis of the construction solutions that address these functional requirements.

STANDARDS AND THEIR RELEVANCE TO THE QUALITY OF THE TILED INSTALLATION

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1. INTRODUCTION

Qualicer has been in existence for 20 years and I have been involved with standards committees for all of that time.

For me and many Europeans, standards involvement is at three levels, national, European and World.

As can be imagined, I have experienced the conflicts and difficulties which beset standards development at all these levels.

2. STANDARDS – WHAT DO THEY DO?

In the ceramic tile sector, the standards largely reflect the performance of the individual components of a tiled installation – the tiles themselves, adhesives and grouts. Nevertheless, it is the combination of these components which ultimately gives the customer what he or she wants – a tiled installation. I have been making the point at Qualicer and around the world since the early 1990's that no matter how good the individual materials are, the design, specification and installation techniques are just as important to this ultimate goal - the tiled installation. Key issues for this to be achieved are the design, choice of correct materials, appropriate background and ability of the tile fixer. Failure in any of these areas and the quality of the component materials is of little significance. Moreover, failure in these areas can have consequences for the whole ceramic tile industry when there are so many alternatives on the market ready to step in when a customer is dissatisfied. It is in everyone's interests for the installation to be undertaken using the same high levels of quality that goes into the manufacture of the tiles and adhesives themselves. To this end, the UK has a very comprehensive British Standard for Design and Installation.

As to the tile standards themselves, the last 20 years has seen the establishment of ISO world standard test methods in the series ISO 10545. These were largely similar to the previous EN standards. They were complemented by the requirements document ISO 13006. This, in modified form to include the CE marking annex, became EN 14411 in CEN. This is now out in newly modified form as EN 14411:2006.

3. KEEPING STANDARD UP-TO-DATE

Technical developments require that these standards are reviewed and modified regularly. At present, the proliferation of large format tiles has forced a proposed revision of the Dimensions and Deviations requirements. Hitherto, these have defined the acceptable tolerances in percentage terms. As I predicted in a Qualicer presentation in the 1990s, this was sure to lead to problems as larger and larger tiles became more common. This revision proposes that a maximum value be incorporated with these percentage tolerances so that, after the defined value, the percentage tolerance on the largest tiles would be a much smaller percentage of the overall tile size. This is being considered at the present time and it is clear that there are two basic opinions. Firstly, the manufacturers want this to give as much tolerance as possible whereas the installers and customers want the tolerances as tight as possible. This is particularly important in the case of the distortion, curvature and warpage values as these define the overall flatness of the whole installation.

Further consideration and possible revision of the standards may also be necessary now that the simple glazed/unglazed description of the tile surface is no longer so clear-cut. All manner of surface finishes are now produced which seem to make the traditional definition obsolete. The tests for surface wear are a case in point. There seems to be no good reason why the surface (PEI) test method, EN ISO 10545 part 7, cannot be performed on all tiles. It seems to me to be equally relevant on unglazed, polished or any surface, in all cases using the same inspection criteria. Again, from the customer's point of view, scratching wear is the same whatever the technical nature of the ceramic surface. A similar argument can be advanced for the deep abrasion test, hitherto only officially used for unglazed tiles. Many products defined as unglazed, and therefore subject to this test, do have surface or partial surface layers which are penetrated by the deep abrasion test. Hence why not do the test on all tiles?

Staining is a further example of a test which has a requirement for glazed products but not for unglazed. The customer certainly does not care about this when his or her newly laid and expensive floor tiles cannot be cleaned satisfactorily. From the customer's point of view, it is just as important for all tiles to undergo the staining test with the same criteria of pass/fail.

It has been suggested that new definitions for 'glazed' and 'unglazed' be developed but it is now my feeling that these definitions are not required as all the tests should be performed an all tiles whatever their surface finish. Moreover, there should be similar requirements for all tiles.

4. THE MANUFACTURER/END USER BALANCE

Such a suggestion highlights the same basic conflict which always exists in standards. This is the balance between what the manufacturers want and what the customers want. In the tile standards committees, there is a predominance of technical and manufacturing personnel and total absence of customers' representatives. Resistance to the inclusion of such people is clear when it is suggested that these people will slow down standards development because of their lack of specialist knowledge. While this may be so, the views and requirements of the customer cannot be ignored. The discussions already referred to in the issue of dimensional tolerances show how different opinions can exist within the industry.

One test which has been extremely contentious throughout the 20 years of Qualicer is the slip resistance test. This is, of course, very much a consumer driven test as there are clear safety issues. Some countries, and UK is amongst these, have a very powerful and active Health and Safety Executive with well-funded research laboratories. As a result, much work in this field is taken right away from manufacturers, and methods and requirements are very much dictated from the Health and Safety lobby. The issue is, for instance, one of the 'Essential Requirements' imposed by the EU in their Construction Products Directive and the CE mark. It is, therefore, mandatory for ceramic tiles to comply with these essential requirements as with all construction materials. Test methods used have to be in the form of 'Harmonised Standard Test Methods'. This is focussing the ceramic tile standards committee as there is no such agreed standard test in Europe. The situation is further complicated by the fact that different flooring materials all seem to have a CEN Technical Committee and they all seem to have taken an independent approach to how they assess slip resistance. Some have agreed a test for their product. Some only measure slip resistance in the dry

whereas it is well documented that over 95% of slipping accidents occur in the wet! An umbrella Technical Committee, TC 339, now exists in CEN to try and develop a definitive assessment method for slip resistance of floors of any construction.

5. TILE ADHESIVES STANDARD

A European adhesives standard including test methods and requirements has been established during the life of Qualicer. In UK, these documents superseded a well-established British Standard. It has to be said that the new EN system is not without its problems and critics. It has had its teething troubles and has already been subject to some modifications. UK, of course, had to abandon its national standard as required by the CEN rules. This requires that where any agreed and published EN standard has been established, it must be introduced into all CEN member states without modification and the relevant national standard withdrawn. This is despite the fact that UK felt that the BS standard worked perfectly well with sound reproducible tests and clear-cut requirements.

6. CEN AND ISO – A KEY DIFFERENCE IN APPROACH

If this situation had occurred in ISO, the problems seen with the EN standard could have been ignored by any country having an existing satisfactory standard. This is because a member state in ISO is not obliged, in the ISO rules, to adopt any new ISO standard. This leads to a wide range of actual standards; each country either ignoring the ISO standard altogether or applying national modifications. This is exactly the opposite of what umbrella standards committees should be working towards. It is clearly in everyone's interests that the same standards are established in all countries. This gives the manufacturers a level playing field whichever country is chosen to sell into. In CEN, no such problems exist as all members have to adopt any standard which has been agreed and remove a national standard.

7. STANDARDS DEVELOPMENT

A further issue which the international standards organisations have to contend with is that of speed of reaction and development of new documents for discussion. Many individual countries propose new standards or modifications (cf the dimensional tolerance debate) but these are not progressed with any sort of urgency. Al Gore, recent Nobel Peace Prize winner, quoted an old African saying; 'if you want to travel fast, go alone; if you want to travel far, go together'. He was referring to the climate change issues but the same could be said for standards development. Countries developing their own standards can do so relatively quickly but the effectiveness is questionable if no other country works to the same standard. In particular, some countries have seen fit to produce specific standards for porcelain tiles. This has come about because there is no definition of 'porcelain' as a tile type in ISO. This has been addressed in CEN as there is a footnote to paragraph 3.1 in EN 14411:2006 defining 'fully vitrified (or porcelain)' tiles as having a water absorption lower than 0.5%. This has not prevented some manufacturers claiming their tiles as porcelain without achieving the fully vitrified condition as defined in the CEN standard. This situation certainly needs some urgent attention in ISO to prevent inferior tiles being mis-sold as porcelain.

8. CONCLUSIONS

In conclusion, my involvement with standards work over twenty years or so has seen many advances while leaving much still to be achieved. The world standards on ceramic tiles are now well established and work is advanced on a similar system for tile adhesives. Work is also well advanced on standards for waterproof membranes to go behind tiling in wet areas. Unlike the CEN situation, where all these standards (with CE mark annexes) have automatically been adopted by the member states, there is no guarantee that the same will happen when the same standards are finalised and agreed in ISO. For instance, USA still uses the ANSI/ASTM system for tiles despite the existence of ISO 13006/10545 for so many years.

Technical and other developments have required the various standards committees to look at the documents and make revisions. These generally take place very slowly and some countries fill the void by rapidly publishing their own national standard. The demands of the end-user are often at odds with those of the manufacturers.

Discussion has never stopped on the subject of slip resistance but progress is being made on this issue which always generates strong opinions. I hope to see some agreement in the not-too-distant future.

Most people are now taking much more interest in the subject of tile installation and realising that product quality can only be appreciated if the installation is of the same high quality. The role of the background is being seen as increasingly important. The growth of heated and insulating backgrounds not to mention backgrounds which lack the rigidity of concrete and are subject to distortion and vibration have only added to the challenge of achieving a quality tiled installation. Embracing the whole system will lead to increased awareness of the importance of these aspects. This in turn will lead to tiled installations of higher quality and durability.

SUPPLYING SUFFICIENT COMPETENT TILERS TO ENABLE THE GROWTH OF THE INDUSTRY.

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I was asked to contribute to this panel debate on the recurrent challenges facing the ceramic tile industry with particular regard to analysing the problem of "Supplying sufficient competent tilers to enable the growth of the industry". I will start by exploring two fundamental issues assumed in the problem. Firstly, the concept of "growth" as being essential for profitability, and secondly, is there a shortage of competent tilers and will this negatively impact upon the tile industry? It seems sensible to see if there is a problem before we rush to solutions.

1. EXPLORING THE IDEA OF GROWTH

At some point in the next 20 years, industries and governments (economies) must work out how to successfully manage a reduction in non renewable resource use and a reduction in greenhouse emissions while still maintaining profitability and social cohesion. If this is not achieved, the viability of human kind (and planet earth as we know it) will be seriously threatened. That the Qualicer panel can resolve the looming nexus between profitability and growth is doubted, but it can alert the industry and instigate the discussion of the problem. The idea of selling less or using less without sacrificing profit will have to be the goal, and having the product competently installed will become an essential aspect of that goal.

2. IS THERE A SHORTAGE OF COMPETENT TILERS AND WILL THIS NEGATIVELY IMPACT UPON THE TILE INDUSTRY?

The laissez-faire approach of do nothing because "in a market economy, if tiles are sold, someone will always show up to install them" has prevailed and been found to be largely true. Little has been done to formally train tilers over the past decades yet the industry is largely profitable and has generally grown. Why will this not simply continue? There appears to be little a manufacturer of tiles in Spain, Italy or China can do if there are insufficient tilers in the country where their products are eventually sold. However, if the consumers of tiles are not satisfied with the completed installation, or if the product does not perform to its potential, or is not cost competitive as a finish, then alternative products will take our market share. This is already happening. The key to maintaining or increasing the market for ceramic tiles is "education". This means education of the consumers as well as the designers and installers. The tiles themselves hardly ever fail, problems are almost always linked to the selection, design or installation of the tiles, and this can only be addressed by training. The key to addressing installation and design problems lies with the competence of the installer or designer, and their level of competency is affected by their training, their experience and their intellect. The easiest of these to provide is training. Who should be instigating that training? The immediate answer is "the industry that stands to benefit" from that training. This leads us to defining who the industry is, and what is its make-up? In most cases, apart from international standards organisations, it is national or state bodies such as tile associations or councils that look after the welfare of the tile industry, and they have largely failed to meet anything approaching their training needs.

If the above concepts are accepted, then training is urgently needed for consumers, designers and installers as well as those involved with the associated industries such as adhesives and linings, and tile sales.

Just concentrating on tile installers for the moment, I know of no first world nation that is not suffering a shortage of skilled tilers, all first world nations are experiencing large increases in immigrants entering the tiling trade. Immigrants are also filling positions at what are know as "entry to the workforce level" occupations such as taxi drivers, labourers, cleaners, etc, indicating tiling is becoming an entry level occupation rather than a skilled profession or trade. In other words, **the first world has failed to train enough tilers for its own needs**. It now relies heavily on migrant labour to meet its requirements for completing the key transitional process of turning a tile into a finish, and consumers are not interested in tiles, only the finish that installed tile represents.

The level of competence at installing tiles of many entry level workers is low and consumer disappointment at the finished installation is predicted to increase.

Many of the problems faced by the shortage of competent tile fixers are set out on the attached "mind map". I have also laid out some options for addressing the current and expanding skills shortage, I hope the Qualicer panel debate can provide more options and even set out a list of actions that can be taken to enact those options.

One of my preferred options is for an increase in the "Supply and Fix" mode of operations where the tile seller is also responsible for the installation of the tiles sold. This brings the provision of skilled labour to install the tiles to the finish required by the customer, back into the sale of the tiles. However, it does not see the manufacturer involved in directly supporting the training of tilers to install their products.

I look forward to receiving feedback on how training for the industry can best be structured and funded.

Training: trying to give people something they need when they don't want it is not efficient