STRIVING TO OVERCOME RECURRENT CHALLENGES: QUALICER 1990 - 2008

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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

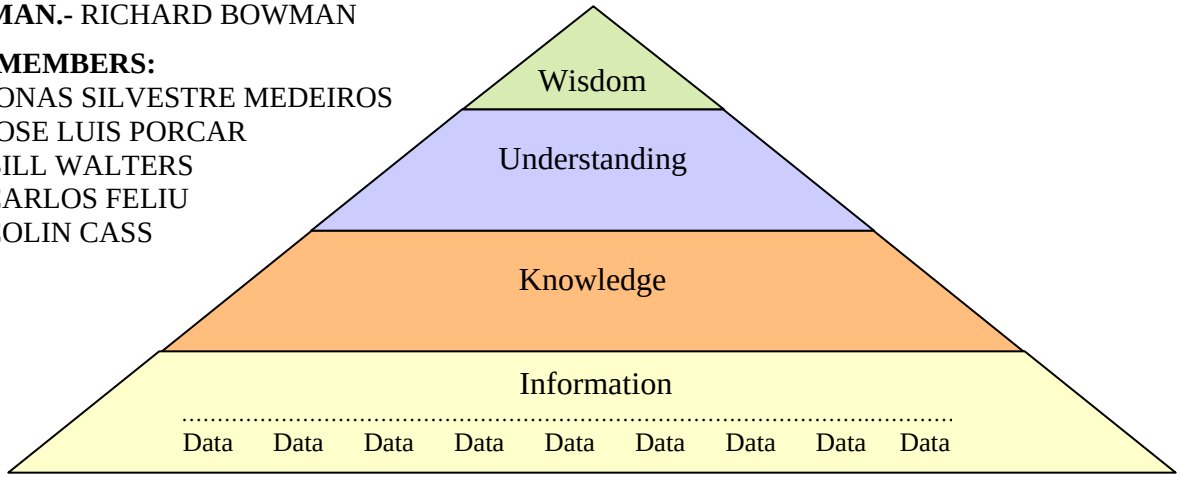
[1] W. D. Kingery, "The transition of ceramics from craft to science-based industry", 1998, Con 3 – 17.

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.- RICHARD BOWMAN

PANEL MEMBERS:

JONAS SILVESTRE MEDEIROS
JOSE LUIS PORCAR
BILL WALTERS
CARLOS FELIU
COLIN CASS



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.

[2] Fernando Peixoto, "The use of wall and floor tiles in ultra-modern Brazilian architecture", 1990, pp 57 – 60.
[3] This maxim that should be attributed to George Herbert (1593-1633), the Welsh metaphysical poet.

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

[4] R. Bowman and H.G. Leslie, "Quality Assurance of Ceramic Tiling Installations Through the Use of Expert Systems", 1990, pp 83-98; R. Bowman, "The Need for Establishing a Moisture Expansion Convention for the Analysis of Tiling System Failures", 1992, pp 459-70; R. Bowman "Development of Ceramic Tile Quality Systems - Keeping Up with Consumer Expectations", 1994, Vol 1 pp. 51-62; R. Bowman and P.J. Banks "The Crucial Need for Computer Modelling of Tiling Systems", 1996, Vol 2 pp. 617-34; R. Bowman "Assessing the Relative Contribution of Ceramic Tiles to Slip and Fall Accidents", 1998, Vol. 2, 161-73; R. Bowman, "Where to next with slip resistance standards?",' 2000, Vol. 3, GII 131-146; R. Bowman, "The future of the ceramic tile sector in the XXI century – Standards", 2002, Vol. 3, R.T. 25-41; R. Bowman, "Discrete progress in the development of an international slip resistance standard", 2004, Vol. 3 PGII 141-161.

> 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.

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[5] R. Bowman and C. Cass, 'How to Use Computer Based Systems to Increase Sales and Ensure Installation Quality', *Ceramic Tiles Today*, Nov. 1995, 38.

[6] P.J. Jones, "Powerspec, an electronic specification system for ceramic tiling", 1996, Vol. 2, 635-648.

[7] J.E. Enrique, "Technical requirements of ceramic tiles for specific uses", 1994, Vol. 1, 75-92.

[8] J.L. Porcar, "Tile installation project: A Spanish initiative for quality tiling", 1998, Vol. 1, Con 119-153.

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.

[9] R. Blake, "Development of the ceramic tile industry in the Republic of South Africa", 1998, Vol. 1, Con 19-43.

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

[10] V. Riunno and P. Murelli, "How flexible are 'flexible' mortars", 1992, pp 471-489
[11] P.L. Jones, "Ceramic tile adhesives and grouts: a case for quality", 1992, pp. 445-458.

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.

[12] M. Abreu, V. Leitão, and J. Carvalho Lucas, "Modelling the behaviour of ceramic tile coverings", 2004, Vol. 2, P. GII 3-18.

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

[13] Jose Pascual Pitarch, "Effect of different ceramic tile characteristics upon its adhesion strength", 1996, Vol. 2, 521-544.
[14] C. Feliu, A. Garcia Verduch, G. Silva and J.M. Enrique, "Methodologies for diagnosing pathologies in installed tile", 1992, pp. 415-433.
[15] R.P. Goldberg, "The effects and control of moisture in ceramic tile facades", 1994, Vol. 2, 231-247.
[16] R.P. Goldberg, "The design of movement joints in adhered ceramic tile facades", 1996, Vol. 2, 607-615.
[17] R.P. Goldberg, "Architectural detailing of direct adhered ceramic tile facades", 1998, Vol. GII 201-222.
[18] W. Sitzler, "Movement joints – a frequent source of complaints", 1996, Vol. 2, 509-519.
[19] J.S. Medeiros and F.H. Sabbatini, "Designing ceramic tile building facades", 1998, Vol. 2, P. GII 83-100.

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.

[20] J.S. Medeiros, F.H. Sabbatini and S.Y. Akiama, "Flexibility of adhesive mortars: an experimental study", 1998, Vol. 2, P.GII 3-11.
[21] "Tile laying on problematic supports: New supports need new technologies", Menedez and Sitzler, 1994
[22] "Reliable tile installation on problematic substrates", 1998

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

[23] R. Bowman, “Discrete progress in the development of an international slip resistance standard”, 2004, Vol. 3 PGII 141-161.

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

[24] C. Palmonari and G. Timellini, "Application of international standards in ceramic paving and tiling – technical criteria for tile selection", 1992, pp 101-110.
[25] A. Escardino, M.J. Ibañez, A. Blasco and J.L. Amorós, "Using the roughnessmeter for the quantitative study of ceramic glaze degradation by abrasion", 1992, pp 219-243.
[26] J.A. Pascual, J. Bort and A. Boix, "Influence of the composition of fritted ceramics on the resistance to abrasion", 1992, pp 155-166.

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 Felíu 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

[27] A.P.N. de Oliveira, F.G. da Rosa and O.E. Alarcon, "Effect of the volumetric fraction and particle size on the abrasive mechanism in ceramic glazes", 1994, Vol. 2, 163-175.
[28] J. Barberá, J. Usó, J.E. Enrique, C. Felíu and G. Silva, "Durability prediction of ceramic tile subject to abrasion processes from pedestrian traffic", 1996, Vol. 2, 453-468.
[29] J.F.M. Feijão, O.E. Alarcon, J.D.B. Mello, F.G. da Rosa, R. Silveira and M. Romero, "Study of the wear mechanism in glazed tiles by scratching tests", 1996, 671-3.
[30] A. Escardino, M.J. Ibáñez, J.L. Amorós and M. Monzó, "Reversible dirt retention in glazed tile surfaces", 1996, Vol. 2, 725-6.
[31] A. Escardino, M.J. Ibáñez, R. de Lemus and S. Mestre, "Variation of roughness and gloss in glazed tile with the intensity of the wear produced with a standard abrasion tester", 1996, Vol.2, 727-9.
[32] L. Lorici and A. Bresciani, "Practical analysis of the influence of wear-resistance of ceramic materials in relation to their use destination", 1990, pp 389-404.
[33] J. Ilha, A. B. C. Arnt, A. Buoso and A. M. Bernardin, "Accuracy of the PEI method to determine the abrasive wear resistance of glazed ceramic tiles", 2008, awaiting publication.
[34] C. Palmonari, "International standards and design of tiled floors and walls. Technical criteria for the choice of the ceramic tile", 1992, pp 101-110.
[35] R. Harrison, "Development of the quality certification system in the United Kingdom", 1990, pp 29 – 33.
[36] C. Palmonari and W. Bauer, "The international standards for ceramic floor/wall tiles. Present situation and work in progress", 1990, pp 59 - 64.

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.

[37] G. Timellini and G. Carani, “Cleanability and hygiene of ceramic tile surfaces”, 1996, Vol. 1, pp 43-59.
[38] M. D. Caridade, A. P. M. Menegazzo, E. Quinteiro, N. G. Silva, L. L. Dias, T. A. Deyuri, R. C. B. Neto, K. Ribeiro, and J. O. A. Paschoal, “Comparative analysis of ISO and ASTM Standard test methods and results”, 2006, Pos. 285-7.

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

[39] W.L. Walters, "Determination of impact resistance by measurement of coefficient of restitution", 1996, Vol. 1, 231-238.
[40] J.E. Enrique, "Integrated pollution prevention and control in the ceramic tile industry. Best available techniques (BAT)", 1998, Vol.1, Con 89-117.
[41] R. Probst, "International, European and National Standards for the protection of the environment and their impact on the European ceramic industry", 1998, Vol. 1, P. GI 241-9.

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,

[42] http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/l_094/l_09420020411en00130027.pdf
[43] http://ec.europa.eu/environment/ecolabel/pdf/ceramic_tiles/hardfloorcvgsuserman_190202.pdf

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,

[44] Life Cycle Engineering, 'Study for the HFC criteria revision and SFC criteria development', 28 November 2007, http://ec.europa.eu/environment/ecolabel/pdf/ceramic_tiles/wp_preliminary_report_nov2007.pdf.
[45] J.L. Porcar, "Professional qualification in the ceramic tile sales and installation process", 2000, Vol. 3, RT 33.

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?

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46 "Quality assurance in flooring installations. Example of the public sector companies' head office building in Medellin, Colombia", 1998, Vol. 2, P. GII 229-243.

47 R.P. Goldberg, "Ceramic Tile Sector in the XXI Century - Architecture", 2002, Vol 3, RT 7-14.

48 R.P. Goldberg, "Ceramic tile at the forefront of architecture", 2002, 2002, Vol. 1, Con 85-105.

49 R. Bowman, "The future of the ceramic tile sector in the XXI century – Standards", 2002, Vol. 3, R.T. 25-41.

50 R. Bowman, 'Reconsidering the ISO ceramic tile standards' *Tile Today Asia*, July 2005, 28; 'Should the presence of glaze determine the method of test?' *Tile Today Asia*, October 2005, 36; and 'Redefining first quality ceramic tiles' *Tile Today Asia*, February 2006, 26.

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

[51] G. Mondini, "The ceramic tile sector in XXI century", 2002, Vol. 3, RT 43-7.
[52] F. Stephani, "Ceramic wall and floor tiles in the new century", 2002, Vol. 3, RT 49-51.
[53] F. Michavila, "What will be the competitive position of ceramic tile with regard to other floor and wall coverings in the XXI century", 2002, Vol. 3, RT 53-9.
[54] A.O. Boschi, "Ceramic wall and floor tiles in the new century", 2002, Vol. 3, RT 67-76.
[55] S. Martí, "The future of the ceramic tile sector in XXI century", 2002, Vol. 3, RT 61-66.
[56] C. Díaz, "Ceramic Tiling Pathologies", 2004, Vol. 1, PD 3-10.

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 2006 "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

[57] B. Bettiga, Chair, "The challenges to the growth of the United States ceramic tile market", 2006, Vol. 1, PD 19-25.
[58] J. Avellaneda, Chair, "Ceramics and Architecture", 2006, Vol. 1, PD 13-17.
[59] J.L. Porcar, Chair, "Adhesion and deformability of cementitious adhesives and grouts for the installation of ceramic tiles and other modular rigid slabs", 2006, Vol. 1, PD 3-11.
[60] J.K. Felixberger "Stresses in the composite system: tile – fixing mortar – base", 2006, Vol. 2, PBB 191-203.

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?

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.

[61] J. Avellaneda, Chair, "Ceramics and Architecture", 2006, Vol. 1, PD 13-17.

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 mortgage 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

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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.

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

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

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.

[62] E. Astrachan, Updates to an American Method for Measuring Coefficient of Friction, Tile Dealer, November 2007: http://www.tiledealer.org/archives/2007/novdec/installerupdate.shtml