VII - POSSIBLE USES OF A COMPUTER-BASED EXPERT SYSTEM TO ENSURE QUALITY OF CERAMIC FLOOR TILING INSTALLATIONS

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ABSTRACT

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 preprogrammed questions with respect to the intended use of an area and its basic structural details, can provide architects and specifiers with data on appropriate floor finish materials, possible installation methods and advisory comments. Enhancement of the system can allow material requirements to be quantified, the various options to be costed, and job specifications to be issued with additional detailed instructions to tradesmen, building supervisors and others. When the expert system is linked to a product data bank containing the characteristics of tiles of certified quality, architects and interior decorators will be able to select tiles secure in the knowledge of their quality (fitness for purpose) and value (life cycle cost benefit), while making a decision based on aesthetics and initial cost. Collaboration is invited in the development of such a system.

A pilot study for the selection and installation of floor finishes is discussed with respect to the issues involved in planning for whole building quality; the management of building information; the opportunities offered by advanced computer technology; and the development of an overall model for managing building intelligence.

1. INTRODUCTION

Pressure to improve quality and value is being experienced by all sectors of the community. The building industry, which is comprised of a host of relatively small, independent organisations, is no exception. However, it has a unique problem since the processes of planning, design, documentation and construction can involve hundreds of individuals and organisations, in thousands of decisions and actions, over extended periods of time.

This problem of fragmentation is exacerbated by the fact that each member of the project team will have a slightly different perspective of the project - the issues and their relative priority - and little opportunity to apprise themselves of these differences before they become fully engrossed in determining the form and nature of the project itself.

It is important to recognise that many of the decisions and actions which will determine the performance of a product, such as a ceramic tile, will be outside the direct control of any single organisation. Under such circumstances, it is a particularly complex problem for the building industry to assure the quality of the installed product, as distinct from the manufacturer of the individual components. Reacting to individual problems as they arise is not the best means of ensuring the quality of the whole building.

While earlier papers have addressed the many aspects of the quality of ceramic tiles, this paper looks at the tile and tiling in the context of the overall quality of the tiled facility, and its role in determining 'whole building quality'. It raises some of the issues that the tiling industry must consider if it is to respond appropriately to community demand for better product quality and value, and greater individual accountability. More importantly, it enables the industry to take advantage of the opportunities offered by advanced computing systems. These can provide an effective framework of information management, and a basis for the necessary industry wide coordination

2. MANAGING CHANGE

The last decade has seen a dramatic rise in community expectations and a significant change in attitude towards professional decision-makers. Even the family doctor, whose word only a few years ago was unquestioned, is now expected to justify a particular course of action, and in some instances to defend it in the light of a second opinion. The demand for individual accountability is rapidly becoming a major factor in the way that we go about our daily lives.

The community has become more aware of the physical environment and its potential impact on the quality of life. It is becoming increasingly concerned with those decisions which determine the form of the built environment. While most people are content to voice concern, others are demanding and being granted the right to participate in project decisions, even though they may have no direct financial involvement.

The change in community expectations has coincided with a period of significant change in the science and technology of building. Projects are becoming larger and more complex. There has been a dramatic increase in the range and number of products, of both domestic and international origin, entering the market place. At the same time, tighter money supply and high interest rates are pressing for shorter project times and faster decision-making. The industry, and each individual in it, is being placed in a position of having to deal with a wider range of more complex technical and personal issues in shorter periods of time. In other words, both the risk and cost of failure is escalating rapidly, and the industry needs to develop new techniques to deal with the situation.

In the tiling industry, perhaps the greatest changes have been in the development of new adhesives, underlay materials and tiling systems. For example, adhesives offer several advantages over mortar fixing in that they are easy to prepare, can be applied to a wide range of substrates, they permit faster fixing, and they may confer required characteristics, e.g., fast setting, water resistance, chemical resistance, impact resistance, etc. However they are expensive, and can only be applied to suitably flat and properly prepared surfaces. Each adhesive must be prepared in accordance with its own specific instructions, and applied within a limited time. Given the large number and varied types of adhesives, the choice of the appropriate adhesive has thus become more difficult and more critical.

New fabrication technologies have led to a wider range of ceramic tiles, in terms of size, and aesthetic characteristics and functional performance. These tiles are being installed in areas where other materials were traditionally used. Tile fixers with twenty years of experience of mortar fixing small tiles in bathrooms do not necessarily have adequate experience for fixing larger tiles in larger areas. Such jobs require greater attention to adhesive (or mortar additive) selection, and the insertion of expansion joints. Significantly, an analysis of 112 pop-up failures indicated that movement joints were only known to have been used in sex cases, and the joints were incorrectly installed in at least three of these (1). Provision of functioning movement joints could have prevented many of the failures.

The use of these more specialised products is dependent on their compatibility with the other tiling system components. Too often good products are used in the wrong way and failures result. For example, a major change in the formulation of a fibre cement sheet resulted in greater potential for moisture movement. This required that it be fixed far more rigidly when being used as a tiling underlay. When builders continued to fix it in their traditional manner rather than in accordance with the manufacturer's instructions, this resulted in bowing of wall tiling, cracking of floor tiling, and crazing of the tiles. The cost of the failures ran into millions of dollars.

The demand for shortened project schedules has led to the earlier application of tiles, and new developments in building technology, such as the introduction of concrete tilt-up construction techniques have facilitated this. For instance, floor tiles have been laid as little as two weeks after paving of the concrete slab when tilt-up walls have been used on multi- storey buildings. The earlier application of tiles has increased failures due to differential movement, as greater amounts of concrete drying shrinkage have occurred after tile installation.

The individual members of the project team (designers, specifiers, builders and tradesmen) are ill equipped to deal effectively with the situation. Our contractual arrangements compound the problem by isolating groups who need to work together more closely.

While we may be aware of changes that are occurring in other industries, it is often hard to assess all of the implications for our own industry. For example, how is the tiling industry affected by changes in foundation designs, concrete mix compositions, and concrete placement techniques? Conversely does the engineer consider the effect of the concrete drying shrinkage and creep characteristics on tiling when specifying the concrete mix? Since the percentage of concrete which is subsequently tiled is relatively small, how likely is it that the concrete manufacturers will change their mixes to accommodate the requirements of the tiling industry, let along consider the needs of the tiling industry when making future changes? In fact, the usually specified concrete strength requirements are so easily met that a policy of design based primarily on control of shrinkage and cracking could be advocated with considerable justification (2). Does the builder, when approving the use of concrete curing compounds, consider the ensuing bonding problems they cause - does he even think to tell the tiler of their use?

The performance of the best quality tiles may be seriously compromised by decisions over which we seemingly have little or no control.

3. PLANNING FOR WHOLE BUILDING QUALITY

There are many who argue that the concept of 'whole building quality' is just that, a concept, that it is impractical to implement, and that quality assurance must be limited to building components. The client however is not consoled by the knowledge that the best quality tiles and adhesives have been used, if a failure occurs. He is concerned with overall facility performance and the building industry must learn to respond accordingly.

We have seem a tremendous increase in tile quality over the last few years. Conferences such as this, the 1st World Congress on Ceramic Tile Quality, and the introduction of International Standards for ceramic tiles will result in further improvements. The ISO Standards which are being developed for ceramic tiles will provide a global basis for comparing specific characteristics for individual tiles, but the sum of these characteristics must be considered when determining fitness for purpose for a particular application. The tile manufacturer can only guarantee the performance of his product if he is satisfied that all the factors associated with product selection, installation and facility operation have been carefully and correctly considered. These factors have many possible permutations. The reality of the situation is that while improvements need to be made in the processes of tile selection, installation and maintenance, the tile manufacturer is in an awkward position, as the performance of the tile depends on the suitability of the other system components, and the adequacy of the advice provided by their manufacturers. It is thus very difficult for the tile manufacturer to provide appropriate guidance and cautionary warnings. Yet, this is precisely the type of information that consumers are seeking in the product documentation. How can this information be provided? Obviously there must be industry wide coordination so that the project decision-maker can be provided with the appropriate information, and at a time and in a form that facilitates understanding and application.

3.1 What is Quality?

The widespread and popular use of a term can lead to confusion and error, for example, the term 'first quality tiles' is generally accepted to refer to tiles which pass the relevant product Standards, but the term 'second quality tiles' is used in differing ways by different people. It is therefore important to give some consideration to the meaning of the term quality. There are two common senses in which quality may be used - the best possible; and fitness for purpose. It is significant that no matter the intended meaning, 'second quality tiles' are likely to be fit for some purpose. The destined environment determines those attributes that a tile must possess - a tile with substandard abrasion resistance characteristics can be successfully used in many wall situations. Specific characteristics can be provided by purposely tailoring processing conditions, but improving one attribute may be at the expense of others. The building industry is constrained by too many building regulations, and the intents and opinions of the individuals involved, for a definition of 'the best possible' to be acceptable. The 'best' tile in the world, if improperly installed, inappropriately located, or incorrectly maintained, will be subject to failure, and the manufacturer unjustly exposed to criticism and litigation.

Quality is defined here as 'fitness for purpose'. This establishes a basis for goal-oriented decision making, and subsequently of performance evaluation. It focuses attention on a particular aspect of the project and raises the question of its purpose. Further, behind the concept of performance objectives lies the question of whose purposes? It provides a basis to consider the issue from the perspective of a number of interest groups: the developer, his legal and financial advisers, the regulatory authorities, the contractors, the facility managers, the occupying organisations, their employees and visitors, as well as the general public. More specifically, it establishes a basis for setting performance objectives, whether for the whole building, a specific room such as a kitchen, a particular area such as the floor, or the materials and individual products in such an area. Furthermore, it enables an assessment of the merits of alternate design solutions, and provides a basis for the subsequent assessment of how well the performance targets were met.

Tiling is generally considered defective if and when it is evident that it does not have (or no longer has) suitable aesthetic and functional characteristics (3). Investigations of tiling failures have revealed that they can be attributed to deficiencies, errors or negligence with respect to the quality of one or more of the following: the planning and design of the entire tiling system; the materials used; the installation of the ceramic tile; and the maintenance, and the way in which the floor is used.

Quality does not cost more when defined in terms of 'fitness for purpose': it is simply providing what is needed and doing so on a cost benefit basis. Indeed, getting it right the first time may be considered to offer considerable savings over having to rectify the problem. In most cases the cost of the ceramic tile itself is less than half the overall cost of retiling.

It should be recognised that **quality and value are context** specific. Every project is to a certain extent one-off. Even projects with a common brief and budget have sites with unique features and surroundings. Community expectations will differ as will the skills and level of understanding of the project team. As such considerations influence a project's objectives and priorities, so too will they alter the definition of quality and the perception of value.

Value, an assessment of benefit against cost, is a measure of the project performance. Value can be improved by either improving project performance without increasing costs, or by reducing project costs without loss of performance.

3.2 Managing for quality

Achieving quality is a matter of the project team setting clear objectives; identifying performance goals and performance mileposts; establishing appropriate value frameworks against which individual project decisions can be taken; making decisions; communicating their results of these decisions, as appropriate, to other project decision-makers; and coordination of subsequent decisions and actions.

4. MANAGEMENT OF BUILDING INFORMATION

Improving project performance is a process of improving the decision-makers' access to and application of the appropriate information and understanding. As noted, the building industry is characterised by a host of relatively small, independent organisations coming together on a project basis. These practitioners, focused on project delivery, are not always in a position to recognise a gap in their understanding, e.g., to know that there is a new and better product or system available; or that research or evaluation have found that a common practice can be detrimental under particular circumstances.

Even when such a need for external assistance is identified, the practitioner must recognise that the necessary information may not be available within the time and cost limitations determined by the project, or in a form that facilitates understanding and application. For example, manufacturers of materials used in tiling systems have made slight modifications to their recommendations as to how their product should be used, as a consequence of tiling failures: however, the alterations could only be detected by detailed examination of their new literature, which appeared to be identical to its predecessor - the changes were not highlighted, and neither were the reasons for the change. Individual practitioners are simply not in a position to monitor all fields of building intelligence to keep abreast of change and to assess the implications. If the building industry is to place itself in a position where it can effectively respond to the pressure for better product quality and value, it must develop more efficient and appropriate means of managing building intelligence.

The cost and responsibility of ensuring that the right information is available to the right people at the right time, and in a form that will facilitate understanding and application, must be shared by industry as a whole, but seeking to initiate wholesale changes in the way that industry operates is not a realistic option. The problem of information management will not be resolved quickly, but the following issues should be considered.

Industry knowledge is largely personal

Research indicates a tendency for the practitioner to rely on direct personal experience, their own or that of a peer, in lieu of the literature (4). This craft-based approach to information management poses a major obstacle to improved industry performance. For example, where the bulk of an organisation's wisdom is personal, it can be lost if an individual is unavailable for any reason: quitting, promotion, annual leave or retirement. Organisations risk the repetition of past mistakes in the process of reacquiring the necessary specialist knowledge. In today's competitive environment, an organisation cannot afford to be 'struck dumb' each time a key member of staff is 'lost'. Highly specific knowledge might ultimately be incorporated in code of practice or other documentation (appraisal/accreditation compliance requirements), but this will only occur in the case of some products or systems, and often with a significant time delay.

Another problem associated with 'personal knowledge' is that it is difficult for one person to ascertain another's understanding until they act in accordance with it. In practical terms this may mean that the designer may have almost completed the project sketch plans before the client knows whether the project brief clearly communicated the project needs; or, that the work will be constructed before the clarity of the contract documentation can be confirmed. In other words, a lack of understanding, or the need for outside help, cannot readily be ascertained until an error is made, at which point the alternatives are to redo the work - time and resources permitting - or to live with it. The problem is particularly acute when any deficiency may not be readily apparent, such as improper application of a tiling adhesive.

Without degrading the value of personal experience, the rate of technological change, and the risk and cost of failure are too great for casually gained personal experience to remain as a principal component of the industry's information and communication system.

The project team is focused on the project

It is easy to blame the project team for not applying all of the information which is available in the research and technical literature. However when seen from their perspective the problem is significantly different. The practitioner is focused on the product (the building or some element of it), on completing it on time, under budget and with the appropriate quality, rather than on the information required on how to do so. Further, unlike the researcher or product manufacturer, who is required to have in-depth knowledge of a particular area, the practitioner is required to have a broad understanding of many areas of knowledge. This means that without specific and detailed knowledge in a particular area, the practitioner is required to have a broad understanding of many areas of knowledge. This means that without specific and detailed knowledge in a particular area, the practitioner is unlikely to recognise a gap in his understanding or his need to seek additional information. The practitioner is commonly in a position of not knowing what they do not know: that research or evaluation has introduced new understanding; that new products are available; or, that the specification used on the last project has been superseded. Some books purport to contain all of the up-to-date standard specifications necessary to specify all aspects and phases of a construction project, but they are often particularly deficient with regard to tiling.

Goal oriented decision-making

As its most fundamental level, performance based decision-making is a process of valuing alternatives against established performance standards, i.e. defining project goals or objectives; translating these goals into performance standards; identifying alternative ways to satisfy those standards; and assessing and selecting the most appropriate alternative. This is an iterative process which at one level involves whole building quality and at another the selection of the most appropriate building materials. Very little of the available information is designed to assure 'whole building quality'. Much information on building components is designed for quality control during manufacture, while other information is more an assessment of product quality rather than suitability for a specific purpose or installation method, or compatibility with other building components. A practitioner could be expected to assess the relative performance of a range of dissimilar products prior to making a selection using the relevant Standards. In looking at the resistance to damage by a woman's stiletto heel, he would find that there is no test for ceramic tiles, but that there are indentation tests for flexible PVC (5), semi-rigid PVC (6) and cork (7). Variations in the conditioning of the sample, the shape and size of the indentation foot, the test loads and the time of their application, make a comparison of performance difficult at best.

The impending ISO Standards for ceramic tiles will provide a reasonable basis for the selection of tiles for a specific application, but the practitioner will still need to know those technical characteristics which constitute the basis for a correct choice. The practitioner is then faced with the problem of knowing how to specify an appropriate installation method. Significantly, the installation method influences the impact resistance of ceramic tiles, and many countries do not have a code of practice for ceramic tile installation.

Information Management

The recent introduction of a range of new contractual relationships for the planning, design, construction, operation and maintenance of a building can be seen as attempts to overcome perceived limitations in the communication and coordination of project information. With such changes, the need for clearly defined roles and responsibilities is critical, both contractually, and for effective management of building intelligence. The information traditionally required by the architect, engineer or contractor may have to be recast into a responsibility based system of information management.

The process of project procurement is fundamentally one in which each project decision-maker gathers information, processes it according to his respective area of expertise and responsibility and either acts on it, or passes it on, or back, for consideration by other decision makers. A great deal of work is being undertaken to improve the management of the information available to the decision-makers but, like the industry itself, it is fragmented.

Computers offer a ootential solution

The process of designing, documenting and constructing a building calls on and generates an enormous amount of data. The traditional vehicles for the coordination and communication of this information have been paper-based. While paper is still the prime vehicle, a lot of the information is being generated on computers, and this is increasingly being transmitted by electronic media. This transition affords an opportunity to improve the management of building intelligence and in doing so to improve project decision-making, and ultimately project performance.

Due to recent advances in computer technology, the capacity now exists for the problems of information management within the building industry to be comprehensively addressed at an acceptable cost. However, taking advantage of the potential on offer is not simply a matter of replacing paper with electronically based copy. Exploitation of this potential will require a careful reassessment of the processes of project procurement: what decisions are made, when, by whom, and using what input. As the process of decision making continues though the project, consideration will also need to be given as to whom each decision should be directed, and how it will subsequently be used.

Computing would appear to have two distinct, but closely related roles.

They are:

- to manage non-project specific data and to make it available to the project decision-maker in an appropriate form and at an appropriate time;
- and to manager project specific data - the graphic and text based description of the project throughout its various stages of development.

A number of computer based expert systems have been developed for use in the construction industry. These knowledge based computer programs model the knowledge and reasoning processes of a human expert in some well defined problem area (8). Each is capable of making reasoned deductions or inferences for the user from information supplied in response to questions. Conclusions usually take the form of advice supported by a structured argument based on the particular knowledge that the system has applied. The major difficulty in establishing suitable knowledge based systems will be in ensuring that they can be integrated to work together with the framework of a master system.

Although systems for planning functions, e.g., project estimation, critical path analysis for coordinating site activities, cost management, etc., have been available for some time, the construction industry has generally made limited use of them. When it comes to design functions, expert systems can produce specifications to meet defined requirements. In particular they can help the designer assess the consequences of design decisions and allow possibilities to be explored tentatively; check a design against codes of practice, building regulations and other professional or statutory restrictions; select building components to meet design objectives; prepare specifications for tender-based procurement services; disseminate design information to professionals on other aspects of a project; and present design output to site engineers.

Finally, if the industry is to learn from past successes and failures, evaluation must become a formal part of the procurement process (9,10). Computers can play a significant role in both the conduct of the evaluation and the storage of the findings. Incorporation of research and test results in such 'libraries' would make the relevant data more accessible. This would also assist in the process of amending Standards.

5. A MODEL FOR MANAGING BUILDING INTELLIGENCE

DBCE is looking at ways that might assist the project team to optimise the selection and installation of floor finishes, as part of a project to improve project performance by using computers to improve the information available to the project decision-maker. This pilot study is one of a number of individual industry sector initiatives, through which it is envisaged an efficient, effective, and appropriate industry wide building information management system can emerge.

A parallel study is looking at providing similar information about the provision of access for people with disabilities. Authorities responsible for planning hospitals, schools and other public buildings have shown great interest in these pilot projects.

DBCE has developed a number of expert systems including **Windloader**, a successful commercial product which has attracted considerable international interest. **Windloader** is a valuable design tool wherever wind loading factors are a consideration in the design of structures, in that it helps its users to accurately interpret the Australian Wind Loading Code (11). It takes the user through the labyrinth of variables and significantly reduces the possibility of error and overestimation. It may become the model for the computerization of the European Code.

Another knowledge based system is being developed to make the Building Code of Australia easier to use. Designers and builders should find that they no longer have to resubmit plans to local authorities because they have made errors or misinterpreted the Code. They can also use the system to quickly explore a wider range of design options, e.g. using it to test changes in dimensions, exit locations and fire protection. Regulatory authorities will be able to use it to process building applications more speedily and accurately, and incorporate State and local government variations quickly.

Each of these systems tackles a new problem whose solution will produce significant benefits. Standard terminology is being incorporated in these systems so that they will be able to communicate with computer aided design (CAD) and other software packages. While they have well defined boundaries, it is intended that they will eventually be linked together within the context of a larger framework.

DBCE is collaborating with the National Committee for Rationalised Building, Government authorities and a number of industry groups ranging from builders to suppliers to software developers and the newly formed Australian Intelligent Building Forum. This collaboration will facilitate communication between the knowledge based systems which are being developed in the various organisations.

As a longer term objective, DBCE is developing a complex building intelligence model for the planning of a whole building. This industry model is based upon an identification of the data which is needed in the various stages of planning and construction of an individual building and its being readily accessible from a network of 'libraries' in a process of longitudinal management of project data.

6. THE FLOOR FINISHES KNOWLEDGE BASED SYSTEM

Most people tend to take floor finishes for granted. It is not until we slip, have to clean it, or replace it, that we recognise the significant part a floor finish plays in our buildings (12). It is visually dominant, can affect our health and safety as building occupants, and represents a significant proportion of investment in capital and recurring costs.

A diverse set of issues must be considered and optimised in selecting a floor finish. While trade literature provides data on individual products, little data is available to support comparisons of different types of products, since the existing Standards for the different coverings determine widely different characteristics using a range of test methods and evaluation criteria. Even the expertise in the area of floors and floor finishes is fragmented with many specialists concentrating on only one type of material or finish. The project decision-maker must often use his subjective judgement and guess at the relative performance of alternative products. The body of knowledge in this field, like many others in the building industry, needs to be abridged and systematized, to assist the project decision-maker optimise whole building quality.

Floors are complex building systems formed by various layers, which are usually classified on the basis of their function, even though the same layer may have more than one function. Thus the use of different and specific materials does not always correspond to a given functional layer. Too many designers have tended to overevaluate the role of the final tile layer, as if the performance and durability of the system depend exclusively on it. In practice, it is the whole system that must resist the stress (mechanical, chemical, thermal, etc.) associated with the structure and the tiling environment. The behaviour and performance of the system depend on how the system was planned and designed, i.e., on the materials used, their relative dimensions, etc. as well as the quality of the construction.

Codes of practice for the fixing of ceramic floor tiles recognise that it is the entire multi-layer system which must withstand the different types of applied stress, rather than the ceramic tile, and accordingly provide models for the composition of a system according to the specific requirements of the destined environment. These models respect two fundamental design criteria, namely that the materials used must have the necessary chemical-physical-mechanical characteristics to withstand the stresses they will be subjected to; and the materials must be assembled in such a way as to prevent any interference which would compromise the behaviour of the composite system.

The proposed system, which is intended to support performance based decision-making, has two distinct but related stages. The first seeks to assist the practitioner identify the most appropriate product(s) for a particular application. The second is to assure, once a particular product has been selected, that its potential 'quality' is real by offering information on its installation and maintenance. In the case of ceramic tiles, this will be in accordance with the relevant installation Standards.

The following notional approach to the development of the system represents a consensus that has been arrived at in discussions with various interested parties. The current work is a pilot study to further devolve the nature and necessary features of a system. It is expected that the system may comprise a number of sub-systems, that in time it will be compatible with a wide range of other knowledge based systems being developed for the construction industry.

6.1 Product identification

The system will not select products: this is the responsibility of those who have knowledge of the issues and priorities of the particular project - the project team. The system will be designed to simply identify those products whose performance profiles match the performance characteristics asked for by the operator.

Conceptually the computer based selection system is being designed to operate as follows:

a). Upon entering the system the practitioner will be asked to classify the surface which is to receive the floor finish, in terms of the purpose of the building, the nature of the room, and the intended subfloor. Under some circumstances, other information may be called for, such as climatic factors.

b). The practitioner will then be presented with a list of performance attributes which one might wish to use in selecting a product. This list would not necessarily be as long as that given in Table 1, since some characteristics are only relevant in a limited number of specific circumstances, e.g., thermal shock resistance, frost resistance, electrical performance. The system will use the information already provided to suggest those performance attributes it considers desirable for the indicated floor environment. The operator will be asked to nominate other performance attributes, and to signify whether such performance level is essential or desirable. Where appropriate, minimum performance levels will need to be identified. The operator may choose to seek higher or lower performance levels than those suggested by the system. This may trigger an appropriate cautionary warning, but the operator will be free to make the final decision.

TABLE 1

Physical Performance attributes of floor finish materials

- Visual performance	- glare - consistency of colour and appearance - freedom from defects, cracks, etc.
- Acoustic performance	- sound absorption - sound transmission
- Thermal performance	- thermal insulation - thermal storage - thermal shock resistance
- Mechanical performance	- slip resistance wet dry with contaminants other than water - abrasion resistance - impact resistance dynamic static - resistance to: water frost acids alkalis solvents oil and grease staining
- Fire performance	- ignitability index - spread of flame index - heat evolved index - smoke developed index - resistance to scorching
- Dimensional stability	
- Electrical performance	- conductivity - resistivity

c). The system will then search its data files for those products whose performance profiles match the selection criteria. It will identify its 'strike rate' so that the operator can tighten or relax the selection criteria to achieve a manageable product list - this might be based on a number of criteria including the product being available locally. It may be necessary to use colour codings so that the operator can differentiate between those attributes he has selected and those suggested by the system. The practitioner may also be given the option of eliminating any floor finishing materials he does not wish to consider.

d). The operator will be able to access data on each identified product in two ways. The first would be to specify the product type in accordance with the relevant product Standards, e.g. a glazed Group A1 or B1 tile with Class AA chemical resistance, according to BS6431. The second would be to access data on individual products. Where a large number of similar products are found to be appropriate, the operator might seek a reduction in numbers by requiring that the system ask further questions. For example, in looking at ceramic tiles, it could ask for the minimum and maximum acceptable product size, whether there was a preference for a particular type of surface finish, colour range, plain or patterned tiles, etc.

In terms of output, it is proposed that manufacturers will be given the equivalent of an A4 page on which to present each product and its features. The data on individual products might include:

- manufacturer and suppliers (to indicate local availability)
- product description
- the availability of complementary accessories such as cove and skirting tiles
- attribute performances (determined in accordance with the relevant Standards)
- technical specification (how to specify the product according to the Standards)
- contacts for additional information and product literature
- an indication of cost in broad terms - when the data was last updated

6.2 Product Installation and Maintenance

The second stage of the system will offer technical information on the appropriate installation and maintenance of an identified product.

The practitioner, having narrowed the field by considering the range of potential products, might wish to further narrow the field by considering the installation and maintenance requirements. Or, having selected a particular floor finish, or individual product, the practitioner may seek specific technical information for inclusion in contract documentation, or guidance on installation, commissioning and maintenance. The system will ultimately be able to suggest construction details and specification notes appropriate to the particular combination of floor finish and sub-floor; and offer guidance where appropriate, on the critical features of installation and maintenance. Tiles are a low maintenance product, but documentation detailing appropriate cleaning methods and materials should be provided: inappropriate cleaning practices can render a slip-resistant tile slippery.

If the operator has a predetermined notion of which type of flooring finish he intends to use, the product installation stage of the system might be consulted before the product selection stage. For example Table 2 summarises the phases involved in planning and designing a tiling installation, starting from a certain amount of data and a complete picture of the performance requisites which must be fulfilled. Phases 1 and 2 in Table 2.2 are effectively interchangeable. Since several of the parameters are interrelated, the specification of a tiling system is not as simple as it might at first appear. For example, phase 2 requires that fixatives be specified: this will necessitate a separate data bank on adhesives. Their performance profiles should include characteristics such as the modulus of elasticity and any limitations on the adherend.

Once the floor finish and the installation method have been provisionally selected, a preliminary costing could be made. This could then be used as a basis for comparison with other materials and installation systems.

When comparing between products, the practitioner will undoubtedly want some comparison of the initial installation costs, the anticipated longevity of the surface, the maintenance costs, etc. The degree of generality in this area will require detailed consideration, and this is being left for a later study.

TABLE 2.1 A flow chart of the process of designing a ceramic floor tiling installation:

INPUT DATA - Analysis of the Project Data.

1. TYPE OF ENVIRONMENT AND EXPECTED LEVELS OF STRESS AND PERFORMANCE

- internal/external
- private/public
- civil/industrial
- new/renovation
- mechanical loads
- impact resistance
- abrasion resistance
- water exposure
- thermal exposure
- slip resistance
- cleanability, etc.

2. TYPE OF LOAD BEARING STRUCTURE AND ITS CHARACTERISTICS

- suitability of the surface to directly receive bedding layer cleanliness; planarity; need for priming, strengthening, grading, etc.
- inherent dimensional stability of the substrate material(s) thermal expansion characteristics; reversible and irreversible moisture movements
- movements due to the structural design settlement, creep, applied loads, deflection, vibration, etc.
- provision for movements location and type of construction joints and other movement joints

3. GEOMETRY OF THE SURFACE TO BE COVERED

- shape of the area to be tiled and location of fixed construction elements and fittings - limitations on bedding system thickness

4. CONSTRUCTION SCHEDULE CONSTRAINTS

- age of the substrate at the time of tile fixing
- maximum time period between the commencement of fixing and trafficking of the area

TABLE 2.2 A flow chart of the process of designing a ceramic floor tiling installation:

OUTPUT DATA - planning and design

PHASE 1: CHOICE OF BEDDING SYSTEM

- identification of bedding systems compatible with the type of load-bearing structure, its characteristics, the service environment and the expected perfonmance levels.

PHASE 2: CHOICE OF MATERIALS

- ceramic tile: possesing the necessary physical attributes; influence of shape and sice.
- fixative: possibly defined by choice of bedding system or limits on bed thickness; may be depended on tile type; need to know precise adhesive characteristics.
- material for the joints: consistent with the anticipated environment; possibly influenced by joint width and flexibility requirements, where the joint width may be influenced by the type and size of the tile and anticipated differential movements.

PHASE 3: DETAILING OF EXPANSION JOINTS

- type
- dimensions
- location

these details are influenced by the type of load-bearing structure, its age, dimensions, etc.; the geometry of the surface to be tiled; the moisture expansion potential of the tiles; the size of the tile and the grout joints; and the location of any construction joints, movements joints, etc.

PHASE 4: VERIFICATION OF ACCEPTABILITY OF MODEL

- expert assessment of the compatibility of the choices made and the ability of the specified system to perform adequately in the designated environment.

PHASE 5: PREPARATION OF DRAWINGS, SPECIFICATIONS, etc.

PHASE 6: PREPARATIONS OF INSTRUCTIONS

- specific instructions to purchasers, builders, tradesmen, supervisors on critical aspects wich must be observed.
- instructions for the operation, cleaning and maintenance of the facility.

The system will be able to state the requirements and limitations of the selected tiling systems, and the pictorial representation of the system includes all of the necessary functional layers, e.g., separating membranes, underlays, levelling beds, etc. It should also be able to refer the user to other sections of the Standard for additional detailed information on aspects of the preparation of the substrate, installation of the tile, interaction of the various components, etc. In addition to text, operators will be able to obtain data in various graphical forms, such as a cross-section of the flooring system.

6.3 Operation and Maintenance of the System

Central to the selection system is a program of comparative testing. The particular test criteria will reflect the desired performance attributes identified by the user groups. Where existing tests such as Standards are appropriate they will be used, otherwise attribute specific tests may be devised. For example, DBCE is undertaking studies to develop an Australian Standard for the moisture expansion of glazed ceramic tiles (13). Testing would be undertaken by recognised laboratories, unless the product is covered by a recognised quality assurance program. Individual manufacturers, or their local suppliers, will be expected to supply the relevant product data and to meet a small charge to pay for the maintenance of the system.

The identification and testing of performance attributes should be relatively straightforward. There will however be a number of attribute areas which cannot be easily quantified. Some of these, for example colour, texture and pattern, will best be left to the judgement of the project team. In other areas, where the cost/benefit of qualification or quantification is questionable, the system will draw the issue to the attention of the operator, outlining the problem and discussing points to be taken into consideration in assessing product performance. For example, in a hospital operating suite, there is a need for smooth continuous flooring in order to avoid jarring patients and delicate equipment. Clearly ceramic tiles would be inappropriate. Another consideration would be the ease of finding dropped items, such as micro-needles, which would depend on the combination of colour, texture and pattern.

In such circumstances, the issue is clearly subjective and should be left to those who are aware of the project details. In others, the cost of establishing and conducting tests may be outweighed by the relatively narrow benefits offered. Decisions as to how each issue should be handled will be best addressed as they arise.

6.4 Benefits of the system

The proposed system has been made possible by the widespread introduction and acceptance of the computer in all sections of the industry. As noted, the computer offers the ability to manage large volumes of data, to filter it according to the issues and priorities of the particular project, and to do so on a stage basis.

The cost/benefit of the proposed system is difficult to assess because of the current stage of development, and because of the potential savings available through it being part of a larger more comprehensive system.

The system offers the basis for developing a proactive, application based, information system which can eventually supplement the computer tools being used by the practitioner, i.e., CADD.

Broadly the projected benefits of the system would be

- **for the consumer/designer**, it provides the practitioner with access to information and products that he may be unaware of;
- it makes 'expert' advice and unbiased information immediately available to the practitioner;
- it indicates where suitable products can be found locally;
- it provides the opportunity to involve the client in project decisions without delaying the project itself;
- it filters out unsuitable products and allows selection decisions to be based on aesthetics and cost; and
- it reduces the risk of failure;
- **and for the supplier**, it should ensure that suitable products are selected for the anticipated conditions, and that their performance is less likely to be compromised by unsuitable installation practices, thereby reducing the incidence and cost of failures;
- it will offer improved support to the designer, who should feel more confident in using new products;
- and by monitoring the practitioners' selection input criteria, it will be possible to assist the manufacturer to identify market needs and where to focus their research and development.

In addition to saving the practitioner time and money in the selection of the most suitable product(s), the system will aid the client in identifying and communicating their requirements, particularly in public sector projects. It will afford the manufacturer the opportunity to supply the decision-maker with specific technical data on the use of that product in the circumstances described. For example, a finish may require a specific installation technique for a particular combination of subfloor conditions and usage requirements. In addition to offering product specification notes, the system could draw attention to particular installation requirements, e.g., the moisture content of the subfloor, the need for a particular setting bed, or a treatment required after installation.

7. IMPLICATIONS FOR THE TILING INDUSTRY

Where does the tiling industry stand? It has an obvious self- interest in the education of the architects, specifiers, contractors, builders, supervisors, tile fixers, and users. Those involved in the planning and design of buildings, should ideally think of the tiling in terms of a complex multilayer building system, where the role of the tile and the other layers must be understood in terms of the material characteristics and the nature of their interaction, in the context of the conditions they will be subjected to. However past experience suggests that it is unlikely that significant progress will be made: it is unrealistic to expect that so many people will become experts, besides being impractical for practitioners to become experts in all materials.

The traditional means of communicating good practice has been the use of the few published codes of practice. In Australia, we have traditionally used the British Standards for ceramic tile fixing (14,15) as de facto Standards, but while they are well written, they do not cater for the needs of a tiler fixing larger impervious floor tiles to a cellulose cement sheet underlay in a tropical environment during seasons of extreme humidity. Release of Australian Standards over the next few years, and the ensuing educational public awareness campaigns may result in an improvement in the quality of ceramic tiling, but they will not effectively address the inherent problems of poor management of information. The problems of communicating sound tiling practice are complex and will take time and effort to resolve, even with the adoption of a computer based system.

The manufacturers of tiling adhesives and specially tiling substrates must play a role in the educational process, and particularly with respect to the installation and use of their products. If the tiling industry is to respond appropriately to community demand for better product quality and value, and greater individual accountability, a less reactionary and a more coordinated stance will be required. The tiling industry itself must become better informed of how tiling systems will be affected by changes in other sections of the building industry. One of the ways of doing this is to become more aware of international developments.

While this computer based floor finishes system is being developed in Australia, there is great scope for international participation. Tile fixing practices are based on the same fundamentals, and differences basically result from small differences in the characteristics of the materials used, the ways in which the materials are assembled, and in the prevailing environmental conditions. Such differences have deterred any serious consideration of an international code of practice for fixing of ceramic tiles, but a knowledge based computer system can readily accommodate them, as its output can be 'tailored' by subtle manipulation of the system rules. In fact DBCE developed a prototype ceramic tile installation expert system based on the Tile Council of America's Handbook (16). This system was then modified to accommodate Australian materials, conditions and practices. While it was capable of providing a number of alternative solutions, the expert system 'shell' that was used to develop the software was too slow to satisfy the users' needs, and that prototype system will not be developed further.

DBCE would welcome collaboration with interested organisations on any aspect of ceramic tiling systems and the development of appropriate knowledge-based computer systems to improve the quality of tiling installations. A wealth of data exists on the characteristics of ceramic tile and ceramic tiling adhesives. International coordination of these data, and particularly the evaluation of results of experimental tiling studies, should lead to the better installation of tiles, improved performance of tiled facilities, and consequently increased use of ceramic tiles.

SUMMARY

Clients expect buildings to be designed using the latest advances in technology, to tight budgets, to be constructed as quickly as possible, and to last indefinitely without formal maintenance programs. the building industry is unable to realise these expectations without compromising whole building quality due to problems of information management.

Elements of the building industry have recognised the advantages of knowledge-based expert systems for information management, and software is being developed privately and commercially. Unless development of this software is coordinated, it is unlikely to reach its full potential. DBCE is developing a conceptual model for the coordination and communication of such knowledge-based systems for the overall management of building intelligence. this model caters for project decision making and project management, and relates to all sectors of the building industry. The technology exists for such an integrated system to be developed and sponsored work is proceeding in some areas, including a pilot study for the selection and installation of floor finishes.

The development of a model for the ceramic tiling industry would offer significant commercial advantages. Ceramic tiles are an international trading commodity, and it behoves all those interested in the quality of tile to consider participating in the establishment of such a system.

The realisation o the ISO Standards for ceramic tiles when combined with mandatory quality assurance programs, will result in the immediate and mutual international recognition of tile quality. It is expected that the system will contain information on the performance characteristics, durability, safety, environmental considerations, installation instructions, maintenance requirements, etc, together with the appropiate certification details, and that the data acquisition system will overcome any language difficulties. Inclusion of the relevant characteristics of quality assured products (tiles, adhesives, grouts, sealers, sealants, cleaners, membranes, underlays, etc.) on the relevant databases will assist in their marketing, while the improved specification of tiling systems and the provision of detailed installation instructions will reduce the incidence of failures and improve the performance of the completed tiling.

CSIRO DBCE is pleased to seek international collaboration as this will eliminate any duplication of effort and save manufacturers and users a considerable amount of time and money.

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