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FMEA applied to cladding systems – reducing the risk of failure

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Failure Mode and Effects Analysis (FMEA) is a systematic and analytical quality planning tool for identifying and addressing what potentially could go wrong with a product or process. The project 'Failure Mode and Effects Analysis (FMEA) in the cladding industry' describes the FMEA technique, investigates failures of cladding on a system, component and process level, and maps the cladding supply chain and cladding-related decision making. The level of knowledge of failures and the fragmented industry structure prevents rigorous use of FMEA exemplified by other industries. However, a simplified form of FMEA can be performed based on the research findings to prioritize and inform decision-making and facilitate site inspection/supervision.

L'analyse des modes de défaillance et de leurs conséquences (AMDC) est un outil systématique de planification de la qualité qui sert à détecter tout ce qui pourrait nuire à un produit ou un processus et à y remédier. Le projet 'Analyse des modes de défaillance et de leurs conséquences chez les fabricants de bardage' a pour objectif de décrire la technique AMDC, d'étudier les défaillances de bardages au niveau système, composant et processus, et d'établir une correspondance entre la chaîne d'approvisionnement en bardages et le processus décisionnel en matière de bardage. Le niveau de connaissances en ce qui concerne les défaillances et la structure fragmentée de cette industrie empêchent l'utilisation rigoureuse de l'AMDC comme en attesient d'autres industries. Une forme simplifice de l'AMDC peut toutefois être utilisée sur la base des résultats de recherches, qui permet d'indiquer au processus décisionnel les priorités et de faciliter les interventions d'inspection et de surveillance sur les chantiers.

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Failure mode and effects analysis (FMEA)

Failure Mode and Effects Analysis is a systematic and analytical quality planning tool that was developed in the aerospace and defence industries to identify and prevent potential problems. The analysis comprises three stages:

(1) Identify potential and previously unknown failure modes and all corresponding failure mode causes and effects;

(2) Rank causes of failure according to likelihood (probability of occurrence and of nondetection) and impact (severity of the effects of the resulting failure mode);

(3) Provide for problem follow-up and identify corrective action to be taken.

Cladding

Cladding accounts for up to 25% of the cost of a building, has a major impact on its integrity and service life and provides and preserves its appearance. The term cladding embraces a broad range of building envelope constructions including traditional fully-sealed and modern pressureequalized cladding panels, curtain walling and structural glazing systems.

FMEA of cladding

Successful application of FMEA depends on the availability of information regarding the manner in which failures occur and are caused, together with the frequency, severity and detectability of such occurrences.

Risk identification

Stage one of FMEA identifies all potential failures and their causes and provides a check list to ensure no aspect of performance nor cause of failure is overlooked. Table 1 identifies the manner in which cladding can fail on a system level. Each type of failure may be caused by design or construction errors at a system or component level.

A concept essential to FMEA is the breakdown of the system into 'elements', in order to identify failures which have consequences affecting the functioning of the system. The results of the above exercise applied to three cladding components are summarized in Table 2 where potential causes of one failure mode are identified.

Table 1. Potential effects of failures in priority order

1 Water penetration	10 Budget overrun
2 Air permeability	11 Acoustic performance
3 Lack of fit	12 Security
4 Durability	13 Thermal performance
5 Condensation	14 Hygiene (resistance to vermin/rot)
6 Time overrun	15 Fire performance
7 Aesthetic	16 Environmental
8 Structural performance	
9 Maintainability	

The FMEA thus identifies the relationship between component failures and failures, degradation of performance or integrity, of the system (Table 2). For example, failure of a wet-sealed joint by loss of adhesion with the adjoining substrate usually undermines substantially the performance of the joined components – the cladding system – in terms of weathertightness, thermal insulation etc.

Risk analysis

FMEA is a form of risk analysis and stage 2 requires 'real' data to determine the level of risk of the product/process being analysed. In the automotive industry, this takes the form of ranking the identified failure modes and causes according to probability of occurrence, severity of effects and probability of nondetection to form a risk priority number (RPN).

Occurrence ranking

In the automotive industry the occurrence ranking may be computed from service history data documenting internal process failures (i.e. from the quality assurance department) and external use failures (e.g. from warranty claims) of either the product being analysed or a similar product.

Table 2. Potential causes of one failure mode of three cladding components

Component	Sealant	Glass	Finishes
One failure mode	adhesion loss	breakage	loss of durability
Effects (Table 1)	1, 2, 7, 13	8, 12, 13	4, 7
Causes	joint configuration joint preparation wrong sealant wrong or no primer poor installation (e.g. poor tooling) poor joint design poor mixing (two-part) material fault	impact edge damage glass design (thermal) material fault (e.g. NiS) glass design (wind) building movement	workmanship (cut edges/handling) coating application base metal/galvanizing architectural detailing poor maintenance weathering (colour/gloss/chalking) coating selection

In this study, qualitative failure data have been compiled from the experience of industry which enables the cladding system failure modes to be listed in order of occurrence (Table 1). A quantified study of cladding systems under test substantiates, in part, these findings: the first-time-pass rates for static water penetration, air permeability and structural serviceability tests of 26, 86 and 92% respectively, show water penetration as unequivocally the most common cladding failure mode under test (McDonald, Kerr and Layzell, 1997).

The causes of failure of the three cladding components listed in Table 2 are listed according to the experience of component manufacturers and specialist companies. This is supplemented, in part, by the study of cladding test failures in which 43 different causes of water penetration were identified in the 65 facade samples that leaked. Table 3 lists 21 of the most frequently occurring faults.

Severity ranking

The severity of the effects of failure can be assessed either subjectively or objectively. In the automotive industry failures are assessed in terms of their effects on system (i.e. vehicle) performance and hence customer satisfaction, which is clearly subjective (Table 4). As shown in Table 4, the same analysis is also amenable to cladding, although in the construction industry the customer may be viewed as the person who pays for the building or those who occupy it. With collation of appropriate data, cladding failures can be ranked objectively, in terms of cost of repair, cost of loss of building use, cost of injury and so on.

Non-detection ranking

The third ranking is a measure of the probability of control procedures not detecting the cause of failure or failure mode before reaching the

Table 3. Common causes of water penetration/remedial work of cladding systems under test

Cause of failure (remedy)	Incidence	Cause of failure (remedy)	Incidence
Frame connections (sealed)	14 samples	Panel butt-joints (sealed)	7
Gaskets (corners sealed)	14		
		Screws (sealed)	6
Window perimeter (sealing)	12	Membrane gap (sealant application)	6
Window (mitre joints sealed)	12	Pressure/glazing beads (sealed)	6
Gaskets (re-selection)	11	Windows (mechanism)	5
		Membrane gap (extra/new membrane)	5
Sample to test rig (sealed)	10		
		Holes (added)	4
Glazing rebate/profile (sealed)	8	Holes (unblocked)	4
Panel/pressing to frame (sealed)	8	Holes (sealed)	4
		Windows (re-manufacture)	4
Screws (tightened)	7	Mullion expansion joints (sealed)	4
Gaskets (re-seated)	7		

Table 4. Ranking the severity of effects of failure

Rank	Effect(s) of failure	Automobile	Cladding
9/10	potential safety problems	loss of steering	structural (breakage, deflection)
7/8	high degree of dissatisfaction	inoperable vehicle	water penetration
4/5/6	some customer dissatisfaction	high pedal efforts	draughts, condensation, noise
2/3	slight customer annoyance	poor appearance	aesthetics (staining, colour, finish)
1	no noticeable effect		

customer. Based on the quality control checks in place, the automotive industry ranks the probability of an individual defect reaching the customer on a scale of '1' (remote likelihood, e.g. 0–5% probability) to '10' (very high likelihood, e.g. 86–100% probability).

Non-detection is very difficult to rank for construction because of the variable level of quality control of a labour intensive process. Practice shows that there is likely to be a high risk of defects going unrecognized during the construction phase and manifesting themselves as failures after building handover because of ineffective supervision. This problem is compounded by the fact that some causes of water penetration (the biggest area of concern, with on-site installation a major cause) are less easily detected than others.

Therefore, a reduction in the non-detection ranking will depend on the nature of the failure cause: some will require a higher level of knowledgeable site supervision (e.g. to check that the joint configuration and seal materials are correct), others, inspection (e.g. the removal of sealant to check its depth and the presence of primer, bond breaker tape etc.) and some, on-site testing (e.g. hose pipe test to detect incomplete sealing etc.). Having said this, reducing the risk of failure by increasing detection does not address the root cause of failure, unless it forms part of an education/learning process. With this in mind, perhaps a more certain, effective strategy would be to target the findings of FMEA at installers, as well as construction practitioners (see below).

Risk responses

A thoroughly thought out and well developed FMEA will be of limited value unless the final stage of FMEA – implementation of positive and effective actions – is undertaken to address areas of concern. The simplicity of cladding compared with, say, an automobile, means evaluation of which failure causes to address can be simplified so that it is based largely on likelihood, but also recognizes impact of occurrence. The failure data can be translated into several forms of concerted action:

(1) Reducing/eliminating the likelihood of failure by design (e.g. use of continuous frame gaskets to eliminate a cause of water leakage). This course of action can also take the form of a framework for decision-making, that is, a list of questions (relating to the potential failure modes and failure causes – Table 2) to be asked of suppliers when selecting components.

(2) Reducing/eliminating the likelihood of failure by detection with the aid of a checklist of prioritized causes of failures to avoid. This course of action shows that, for instance, it is crucial for the Clerk of Works to alert the architect if a sealant joint width is found to be incorrect. Design actions can also be made that increase the effectiveness of the current quality controls; practically, this could take the form of choosing a cladding system with very few parts.

(3) Reducing the impact of failure. This can only be accomplished by design actions, for example, by introducing system redundancy (by the addition of a secondary seal) or by designing a fail-safe failure mode (by the use of laminated/wired glass or the incorporation of drainage provision). Repair of the failed component will still be required.

(4) Defining the basis for training and product development in the cladding industry.

(5) Aiding fault diagnosis when failure occurs.

Implementation

The principles of FMEA have wide application with many possible extensions. As a result, each industry, or even individual company, tends to develop its own system and style peculiar to its own circumstances. In the case of cladding (an instance of high risk and severe consequences of failure) a simplified form of FMEA has been shown to be feasible (Layzell and Ledbetter, 1998). However, some questions concerning implementation of FMEA within the construction process remain, namely:

(1) Motivation
In the automotive industry for example, FMEA is performed by the vehicle assembler/manufacturer and the major parts suppliers. Use of FMEA in the parts supply community is often a mandatory

requirement which serves to both motivate use of the technique and assign responsibility. The building client can drive the use of FMEA by demanding evidence that FMEA and the reseach findings have been considered and addressed in an appropriate manner.

(2) Participation and responsibility
In the automotive industry, responsibility for the preparation of FMEA is assigned to an individual having a good working knowledge of the process or design being analysed. Input from relevant departments ensures that the document is complete, and agreement is reached on the proposed corrective actions.

The systematic approach of FMEA formalizes the mental discipline that a designer normally adopts in any design process to prioritize and inform the design method and ensure every conceivable potential failure has been considered and addressed. The architect, contractor and cladding contractor may have experiences to add to the evidence of failures from the research to help build quality into the process by targeting corrective actions at the design stage. They are also in a position to effect and monitor follow-up actions on site.

(3) Feedback
The current FMEA of cladding is based on feedback of test failures and of failures/problems experienced on site. Rigorous use of FMEA depends on the industry becoming a learning organization which, by establishing a stronger link between design and construction, undertakes feedback of defects and their causes from site personnel and clients/tenants and translates this into knowledge for future exploitation. In this way, the industry drops what it did badly and replicates what it did well and FMEA becomes a living document that reflects the latest information and actions.

The next step

FMEA, as a potential cost saver and tool for reducing cladding failures, faces the following industry/cultural barriers to implementation:

* FMEA demands resources 'up front' (but will save money in the long run). Its use therefore faces commercial pressure and requires the industry to accept change (e.g. a price increase, increased inspection/supervision) which will entail a change in culture and a long-term learning process so that every operation is undertaken satisfactorily for those who follow. FMEA was developed in the automotive industry over time – the construction industry should take a similarly long-term view of how to improve.
* The main benefits of FMEA to the client are measured in terms of life-cycle costs. Unfortunately, the practice of life-cycle costing is not yet widespread within the construction industry. Moreover, additional capital costs to save overall costs are hard to justify to the client because the benefits of many decisions cannot be quantified. Further indepth research on the actual causes of cladding failure and the cost of rectifying them is required before FMEA can be thoroughly practised and improvements fully realized.
* FMEA in itself is no panacea for the problem of cladding failures (but shows how the risk of failure can be reduced); cladding failures are symptoms of one or more of the following technical or process deficiencies:

Incorrect selection/specification

The four cladding components most likely to fail (sealants, gaskets, glass and metal finishes) too often receive inadequate consideration from initial selection through to incorporation within the building. For example, despite their fundamental role, sealants are low cost and seen to be a low priority, an afterthought or even the target for cost savings. Specifications for cladding components can be incorrect or contain vague requirements that transfer decision-making, potentially to a disreputable or unqualified contractor, greatly increasing the risk of failure.

FMEA provides a design methodology for selecting components and focuses attention on high-risk components and performance criteria, regardless of their size or cost. Eradication of the nonsensical practice of targeting cost savings for low cost, high risk cladding components is an obvious and much needed initial benefit of FMEA.

Poor communication

Poor communication can be symptomatic of commercial pressures or a lack of knowledge and lead to misunderstandings or omissions that contractually force quality to be reduced. Correct, complete and timely communication is crucial to successful procurement.

Cost cutting

The culture of cutting capital costs is damaging to the cladding industry and is not in the client's long-term interests because it increases the risk of failure with repair costs disproportionate to any initial saving.

A change of culture, for example by the recognition of life-cycle costs, would mean the best value-engineered solution is selected as opposed to the cheapest solution. The fragmented structure of the construction industry and the inability to evaluate cost against worth, hinders communication of this message back to the client. Potentially, FMEA would play a greater part in the decision-making process to help argue the case for cladding systems, materials, components, processes, quality control measures and so on that yield lower overall costs.

Subversion of specifications

A correct and explicit specification may be undermined by the practice of deliberate noncompliance later in the construction process in order to reduce costs. This can be reduced by a cultural change, whereby everybody strives to improve everything they do, and by effective site supervision.

Fabrication errors

Fabrication errors – typically incorrect sealing/drainage provision – occur on both standard and bespoke cladding systems. The facilities for training system fabricators already exist but are largely under-utilized.

System suppliers and inquisitive specifiers can motivate fabricators to train. System suppliers should also explain their products better and check that they are being used as intended.

Installation errors

On-site practice was said to present the greatest potential for failure because of the lack of knowledge of installers. In defence of installers, they may be under pressure to complete the job or be required to build complex details, perhaps without proper assistance, installation manuals or appropriate drawings/instructions.

Trained installers who are familiar with the system to be installed and who preferably installed a test mock-up (if project testing was undertaken) will reduce the risk of installation errors. This must be coupled with proper communication to site, knowledgeable supervision and reasonable time-scales.

Poor supervision

The low level and superficial nature of supervision has been widely criticized. All parties should take an interest in the cladding installation process because the standard of site workmanship can be improved by rigorous, knowledgeable inspection and supervision, which the currently developed FMEA for cladding facilitates.

Poor motivation

Cladding installers can be left to their own devices and paid in a manner that rewards quantity and not quality of work. Site working conditions should be conducive to a high standard of workmanship and promote a regime of making sure every process is carried out satisfactorily for both internal and external customers. This can be achieved by high levels of supervision, reasonable contract time-scales, co-operation between trades, a higher regard for competent installers, modified methods of payment and so on.

Contractual pressures

Unreasonable cost and time pressures compromise quality, regardless of training. Increased lead times would allow increased planning so that problems are recognized and solved at the design stage rather than during construction where there is a greater risk of quality being compromised or subordinated by commercial pressures.

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