Modern methods of construction

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Abstract

Modern methods of construction (MMC) is an umbrella term describing non-traditional building methods and materials. Innovations are often born of political necessity; a profound housing shortage, labour shortages, climate change all combine to create a high demand for construction methods that enable rapid delivery, lest waste, economic benefits and carbon reduction. For many reasons, adoption has been slow; factors such as building failures, prejudice, economic barriers, lack of performance data and customer concerns all need to be addressed. Improvements in warranty provision and a greater demand will help, but changes will also be required to building regulations to reflect matters such as fire safety and building performance. Properly designed and constructed buildings using MMC can yield significant benefits, but there are serious pitfalls, particularly if basic construction principles are ignored. This paper sets out to consider some of the benefits and risks associated with MMC and some reasons for slow adoption. Practical case studies are used to illustrate potential problem areas and to explain how modern construction does not mean that the tried-and-tested methods can be ignored. Modern methods of construction do pose challenges, but with care and persistence the rewards are there to be realised.

Keywords: MMC, condensation, prefabrication, innovation, modular, off-site

INTRODUCTION

When Brunel shipped his 1,000-bed prefabricated hospital to the Dardanelles in 1855, his innovation was the forerunner of a drive for prefabrication that has continued into the 21st century. Recent Nightingale Hospital transformations are illustrative of the remarkable achievements that can be reached, given political will and practical necessity. The ultimate goal of factory production of buildings in the same way as the production lines for other commodities such as cars, tractors and aeroplanes has long been an aspiration, but it is one to which the construction industry's response tends to ebb and flow according to periods of national emergency.

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Set up by the then Ministry of Aircraft Production, the Aircraft Industries Research Organisation on Housing (AIROH) programme constructed some 156,623 prefabricated homes, or 'prefabs', just after the Second World War to provide homes for those displaced by area bombing. These modular homes exemplified the benefits of industrialised construction, some, such as those at the Excalibur Estate in Catford, south-east London, existing up until very recently. The prefabs performed a dual purpose: not only did they provide much-needed housing, but the materials and methods of construction helped to sustain industries that faced a downturn following the end of the war.

Sadly, some post-war experiments have failed miserably, leaving a legacy of unmarketable and unmortgageable properties that has tainted the industry and prompted caution on the part of buyers, lenders and those responsible for regulatory control. The country is now facing a new emergency on several fronts: COVID, Brexit-fuelled labour shortages, climate change and a chronic shortage of affordable housing. In order for the government to achieve its stated goal of 300,000 new homes per annum, it is certain that construction needs to respond to the challenge by developing and refining so-called modern methods of construction (MMC).

While there have been, and continue to be, big innovations in construction, it is fair to say that the benefits of MMC have yet to be fully realised; there are significant barriers to widespread adoption and until these are dealt with, the supply of suitable homes is likely to be very challenging. Although UK industrial productivity has risen by some 25 per cent and the automotive industry by 45 per cent in the first quarter of the 21st century,[1] construction activity has remained static; the number of new homes has not kept up to speed with the UK's growing population.

There are deep-seated problems in the UK housing market and too few homes have been built to keep pace with demand. The 2017 Housing White Paper 'Fixing our broken housing market'[2] described some of the difficulties in the industry and, among other things, identified that the pace of development was too slow and that the very structure of the housing market makes it harder to increase supply. As part of its action plan, the government sought to address skills shortages and boost productivity and innovation by encouraging MMC.[3] While housing is a priority, it would also be wrong to ignore the potential impact of MMC on commercial schemes, as well as schools, hospitals, children's centres and community buildings.

DEFINITIONS

There is no single definition of MMC, but it is a term that has come to embrace a wide variety of non-traditional building systems. The government has established a MMC Working Group, which has attempted to classify and define MMC[4] according to seven categories, the intention being to regularise terminology in the industry and enable better understanding. The full range of classifications is outside the scope of this paper, but the following seven category definitions have been developed:

(1) Pre-manufacturing (3D primary structural systems);
(2) Pre-manufacturing (2D primary structural systems);
(3) Pre-manufacturing components (non-systemised primary structure);
(4) Additive manufacturing (structural and non-structural);
(5) Pre-manufacturing (non-structural assemblies and sub-assemblies);
(6) Traditional building product-led site labour reduction/productivity improvements;

(7) Site process-led site labour reduction/productivity/assurance improvements.

The important point to remember is that MMC is representative of a range of different products and processes; it is not necessarily all about prefabrication and off-site processes, these are just one aspect of the definition — albeit an important one. MMC is not the same as off-site construction; it is an umbrella term that encompasses off-site. The 2017 Report 'Capacity in the Homebuilding Industry' used a simplified definition:

> 'A collective term for a wide range of non-traditional building systems. These include modular construction where units are fully fitted out off-site, panelised systems (such as timber or light steel frames, site based MMC such as thin joint block work and sub-assemblies and components (such as pre-fabricated chimneys, porches etc).'[5]

The advent of 3D printed houses (additive manufacturing) has yet to become mainstream, but an Internet search will reveal many examples of forays into this form of construction; it is no longer a pipe dream. Meanwhile, robotic site-based processes such as brick and block laying are starting to become a reality. At the other end of the scale, labour-saving systems such as dry verges and glassfibre reinforced concrete (GRC) or glass reinforced plastic (GRP) architectural features such as porches and false chimney stacks have become increasingly popular in volume housing.

POTENTIAL ADVANTAGES

According to the UK Construction Industry Council (Offsite Housing Review),[6] MMC offers a number of potential advantages:

- Faster construction times;
- Better-quality construction;
- Less waste (according to the Ministry of Communities, Housing and Local Government [MCHLG] half of the total waste produced in UK comes from construction);[7]
- Lower unit cost;
- Less noise, dust and disruption;
- Improved health and safety during construction (larger proportion of workers being located in factory conditions and fewer working from height);
- Predictable performance;
- Lower operational costs.

The general rule for things that are manufactured in volume is that they improve in terms of quality and performance and become more affordable over time;[8] these improvements are driven by the usual economic factors of product price and service. But to improve, collaborative supply chains need to be created.

Most of the advantages listed above are self-explanatory. The National Audit Office report 'Using Modern Methods of Construction to Build Homes More Quickly and Effectively' suggested that it should be possible to build up to four times as many homes with the same on-site labour and that on-site construction time could be reduced by more than half.[9] The Housing Communities and Local Government committee (HCLG)[10] estimated that a 20–60 per cent reduction in construction programme time can be achieved; it went on to predict a 20–40 per cent reduction in construction costs and the potential for improved whole life cost.

The potential advantages of MMC extend beyond the above list — for example, modular building can be around 30 per cent lighter than traditional masonry construction, resulting in the possible use of shallower foundations.[11] There is, however, much work to do to convince the industry and the consumer that the well-publicised past failures in prefabrication are matters for the history books and have no relevance today. As a practical surveyor, my own experiences of MMC are not entirely supportive of this position — a topic that I will return to later.

Clearly, if construction can be undertaken partly (or completely) in factory-controlled conditions, there is more certainty of performance and less risk of damage. The process does not end in the factory, however; it continues on-site. Weather conditions during assembly can have a significant impact upon the final performance of a component.

BARRIERS TO ADOPTION

Innovation means a departure from the tried-and-tested and therefore can be perceived as presenting a greater risk. Traditional skills and construction methods have been developed over the years (with experience derived from numerous failures). As a general observation, the construction industry can be reluctant to change or modernise; it reverts to what it has always done.

The barriers or perceived barriers to the adoption of MMC have been reviewed by numerous authorities and commentators. In its 15th session, the HCLG committee reported,[12] inter alia, that:

- Homebuilders should use more digital technology in their processes in order to improve quality and not simply move construction off-site;
- The lack of long-term data on the durability of MMC homes in the UK is a considerable barrier to industry actors engaging with MMC housing schemes. Financial services providers, including insurers, mortgage lenders and valuers, need to have certainty that that MMC homes are safe and durable;
- There is a lack of robust supply chains for MMC homes;
- The government should urgently set out a clear plan for the review of the building regulations, including the whole suite of approved documents, and consider how they relate to MMC buildings. The existing regulations can be seen as confusing and difficult to apply to MMC, leading to uncertainty and creates a hurdle to development;
- The government must ensure skills programmes, apprenticeship schemes and the new T Level give learners the skills they need for both traditional techniques and MMC and encourage more young people into the sector.

The report adds:

> 'MMC homebuilders require capital upfront to pay for factories and assembly lines. This presents the biggest barrier to SME homebuilders that do not have reserves to draw on to invest in MMC. Private investors are cautious about investing in innovative methods of construction, so the Government should ensure it is enabling homebuilders to access the finance they need for MMC.'

However one argues the case for traditional construction, it is the case that quality standards in traditional construction are in some cases lamentably poor. Perhaps because I am actively involved in disputes between homeowners and developers my view is somewhat jaundiced, but I do find that in some cases MMC incorporated into traditional building leads to a reduction in quality (and I accept that this is a sweeping generalisation) resulting partly from building becoming a process of assembly rather than the use of traditional craft-based skills. Something needs to be done to improve quality in construction and if this can be achieved by product development and improvements in investment, training and materials, then this is to be commended.

WARRANTIES

In an attempt to respond to some of the more negative barriers to the adoption of MMC, better warranty and assurance processes and products are needed. The insurance industry has been particularly cautious to engage, citing a lack of long-term performance data, according to the Association of British Insurers:

> 'At present, compared to the wealth of historical data and evidence on which to assess the risk posed by a traditionally built property, there is a lack of data and evidence on the ability of MMC buildings to withstand the effects of named perils in real-world scenarios, therefore limiting the assessments which insurers can make on such properties.'[13]

In evidence to the MCHLG committee, it added:

> 'MMC products often incorporate lightweight combustible materials such as wood, polystyrene and recycled materials, which have the potential to increase the risk of fire spread, leading to major damage to property and significant insurance claims costs for reinstatement. Hidden cavities and voids caused by bad practice during the installation phase can also enable the spread of flame, smoke and toxic gases causing harm to any inhabitants within the building.'[14]

One potential option for the developer of an MMC home is to seek accreditation under the Build Offsite Property Assurance Scheme (BOPAS) in order to demonstrate the quality and durability of the property. This system is risk-based and is intended to show that homes will last at least 60 years. BOPAS is not a warranty scheme, however, and does not provide the means to fund the cost of remedial works should these be necessary. The National House Building Council's (NHBC) Accepts scheme is a similar means of demonstrating that innovative products or systems have already been reviewed.

House purchasers will expect to obtain an insurance-based warranty, of which several products may be available; the adoption of an 'MMC scheme' or what the NHBC term a 'Warranty Assessment Protocol' will help to remove some of the obstacles to a wider adoption of MMC.

BUILDING REGULATIONS

Compliance with building regulations is a further issue that requires examination. Dame Judith Hackett's report following the Grenfell Enquiry summarises the position:

> 'The Approved Documents are not produced in a user-friendly format. The current format of covering each requirement (fire safety, thermal insulation, noise abatement, etc.) in separate sections leads to multiple, separate specifications for overlapping or common elements of a building, with no easy means for these to be integrated into a single, compliant specification.'[15]

The Hackett report is echoed in comments made by the Fire Brigade following delays in the completion of a twin 38 and 44-storey residential development in East Croydon. When the project was launched it was hailed as the tallest modular building in the world and while construction times were remarkable, the project ran into difficulties and faced significant delays prior to practical completion. According to reports in *Inside Croydon* and *Property Week*,[16] a Fire Brigade spokesman is quoted as stating:

> 'We are concerned that buildings are being built using more unusual methods without a complete understanding of their performance in fire, so we would encourage developers proposing new

construction approaches to engage fire and rescue services at an early stage in the design process.

As we increasingly see boundaries pushed in terms of developments built using modern methods of construction, we have found that there is a need across the industry for more research on how this impacts building and fire safety.'

During a recent pre-acquisition survey, my company was tasked with the examination of a new housing scheme constructed from converted Chinese shipping containers. As with the development in Croydon cited above, the developer was able to achieve significant savings in construction time, with completed containers being stacked and connected together rapidly and efficiently. In concept terms the system had much to commend it, but expectations on the quality of the finished product were not achieved. Among some of the reported issues we noted were the following:

- Lack of cavity barriers around windows and between containers. The containers were erected on site and then clad with a simple rainscreen. No barriers were provided around window openings and the voids between the individual containers were not fire stopped, meaning that a fire spreading behind the rainscreen would also have access to the voids between containers. The developer argued that this did not matter since the floors were essentially not combustible. In our view that argument needed to be challenged;
- Questionable fire protection to structural steel elements;
- Difficulties proving fire resistance to external wall build-up considering metal container construction and obtaining third-party certification/BR135 test data;
- Alignment issues with containers around floor levels and to external faces, creating issues with site assembled cladding;
- Fire stopping around services and ventilation ducts to containers and corridors;
- Missing bolts to steelwork connections;
- Missing paint coatings to site-based fabrication and welding;
- Fire doors to the bedrooms were manufactured in China but without verifiable test data and certification on doors and ironmongery;
- Inappropriate use of foams for fire stopping/coordination issues between trades, resulting in poor execution of fire stopping;
- Difficulties in obtaining type approvals such as Water Regulations Advisory Scheme (WRAS) for plumbing and mechanical and electrical (M&E) fittings in bathrooms pods that were manufactured off-site.

It would be entirely wrong to be critical of one development and conclude therefore that all similar modular developments are likely to have the same defects. Our experiences, however, serve at least to illustrate the need for enquiry and an examination of the practical implications of buildings. For example, the use of prefabricated toilet and shower pods is commonplace, but how does the end-user maintain those pods and, in particular, gain access to hidden connections such as shower traps, pipe connections, etc., and even if that is possible, can replacement parts be obtained? The performance of materials and components must be assessed at the outset; a lack of ability to replace or amend significant parts could result in an overall reduction in the service life of the building — something that is entirely contrary to the requirements for durability, carbon reduction and so on. Similarly, some systems such as cross-laminated timber (CLT) or structurally insulated panels (SIPs) may not lend themselves to physical adaptation at a later date and so may restrict the service life of buildings.

BUILDING PHYSICS

Just because certain types of construction are modern or innovative, the designer cannot be excused for taking liberties with building physics, ie adopting methods of construction that do not obey the basic rules of building such as providing protection against water ingress, reducing condensation risk and allowing proper ventilation. These principles have been hard won over the years but are proven and very much ignored at the designer's peril. Indeed, the more buildings are highly engineered, the harder they will bite back if not constructed properly. The following case studies illustrate the point.

Case study 1

The first case study involved the use of prefabricated 'super cassettes' which formed the roof decks of a new school development. These super cassettes were factory built with insulation contained within the roof construction. They were shipped to site, erected and then covered with a site-applied membrane. All well and good, you may say — but there were a number of factors which led within a few years to their failure and the need to replace them at considerable cost and inconvenience. To achieve cost savings, it appears that the original warm roof design was amended to a cold roof (error 1). There is a possibility (although unproven) that the cassettes became wet during installation and before the membrane was installed (error 2). The vapour control layer was of polythene and of dubious integrity (error 3) and the roof membrane was changed from a reasonably vapour-permeable material to a membrane of much higher vapour resistance (error 4). The roof cassettes were too large to permit effective ventilation (error 5). As any diver or pilot will tell you, disasters are often the product of a series of individually small errors acting in combination. In this case, the lack of efficient vapour barrier, absence of ventilation and possible water entrapment resulted in severe condensation and subsequent decay and partial collapse of the structure.

Case study 2

A similar scenario to case study 1, but involving a substantial private dwelling. In this case the factory-made roof cassettes were fitted with a highly performing metallised vapour control layer (VCL) but insulation was contained within the roof zone. Condensation analysis software predicted that the flat roof would perform adequately, but this assessment was probably optimistic. A leak from a rooflight permitted water ingress into the roof, whereupon a certain amount leaked out and some became entrapped. Over a period of months, the entrapped moisture distributed itself around the roof via a repeated process of evaporation and subsequent condensation. In turn, the moisture content of the plywood deck and joists shot up to well over the 20 per cent threshold needed to support fungal decay. Within months, the roof deck had become unstable, and the deck failed (see Figure 1). Had the designer followed the common practices defined in BS 5250 they would have avoided the construction of a cold unventilated roof like the plague. The message is simple: a cold unventilated roof is not sound construction and do not be misled into thinking that calculations can tell you otherwise.

This case study is illustrative of the problems of modelling condensation effectively. The common Glaser method (see BS5250) is often used as a design tool, but as a means of demonstrating actual performance it is limited. More sophisticated programs such as WUFI[17] enable more accurate hygrothermal modelling, save that the quality of the model is only as good as the information that is put in. Sometimes it can be very difficult to find the correct materials properties; these are often presented in different ways by different manufacturers. In this case

Figure 1: Example of extensive failure of roof deck to a private house — the effect of water entrapment in a cold roof

it was possible to calculate the amount of water that had entered the roof, either as vapour or by direct entry, by comparing the current moisture content with that which existed (or was likely to have existed) at the outset. Using WUFI and knowing the area of roof involved, it was possible to establish the amount of moisture that had accumulated (see Figure 2). In theory this would not have all been due to water vapour, but it becomes very difficult to model the myriad small holes or discontinuities in the VCL which must have been present to permit water to enter the building and alert the occupier to the problem in the first place.

Case study 3

This study involves the construction of prefabricated houses shipped over from a European supplier. These highly engineered and insulated houses all have European Technical Approvals and again condensation analysis shows (or rather suggests) that the 'hybrid warm roofs' would perform satisfactorily. In this case the roof cassettes were insulated with around 400mm of mineral wool between the joists and around 300mm of polyurethane foam insulation on top of the oriented strand board (OSB) decking. The cassettes were installed in place and the foam insulation and single ply roofing were added afterwards. The system relied upon an effective VCL at ceiling level. In theory, therefore, all was good; in practice, all was far from good. OSB can have a fairly high level of vapour resistance and thus the movement of vapour through the structure could be restricted. Defects in the weathering of the parapet upstands resulted in

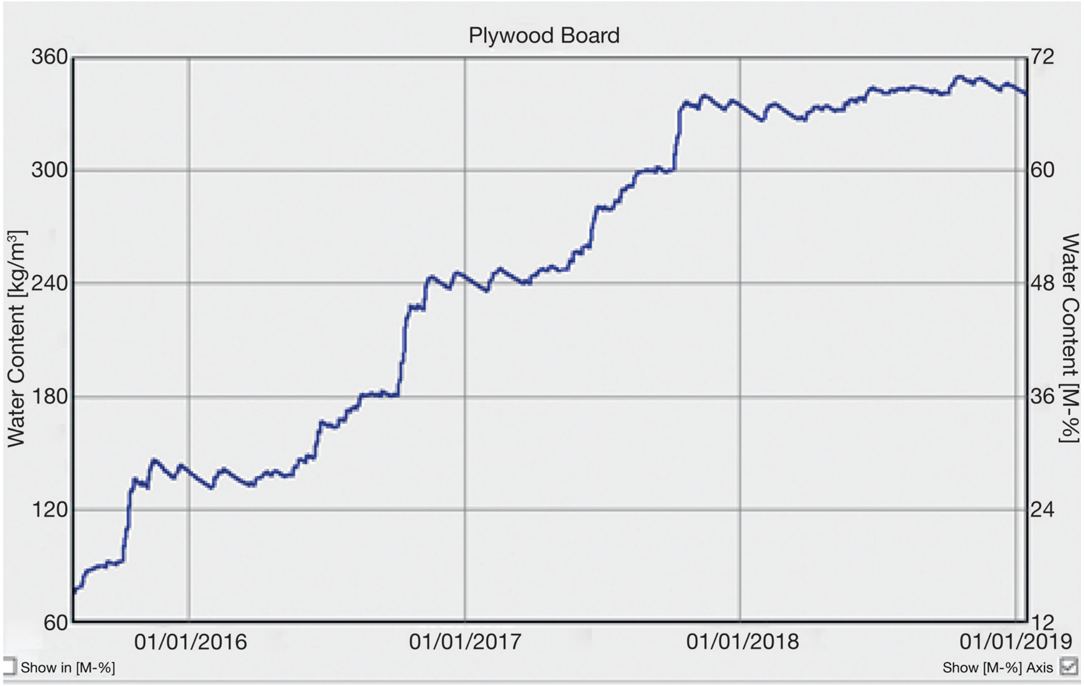

Figure 2: Chart generated using WUFI software to illustrate the effect of 0.05 per cent of total rainfall into a cold roof structure

minor water ingress internally; these issues were attended to, and the initial problem was abated.

Further opening up revealed, however, that there was a serious problem of water retention within the construction. The OSB was saturated and had lost integrity, the only feasible repair option being to lift off the substantial timber roof terrace above and reconstruct the roofs down to joist level — and all this in a property less than a year old.

So why did the roof fail if the technical approval suggested that the roof would perform? I remain deeply sceptical of this form of construction; an unventilated cold roof is inherently vulnerable, particularly if water can become entrapped within it. Examination of the site records suggests that on day three of the erection process (before the roof was weathertight) there was a significant rainfall event; it seems highly likely that water entered the roof at that point and so initiated the decay process — it does not take very long. Again, the message is simple: stick to the rules and avoid an unventilated cold roof (even if the designer tries to argue that it is a hybrid warm roof).

Case study 4

This case involved a series of timber-framed modular buildings used for pre-school/nursery activities. These lodge-style buildings were constructed off simple concrete foundations and brick sleeper walls. Air bricks were located within the external plinth wall but many were obstructed by terraces or play areas, with the result that they became ineffective. The oversite was covered with gravel and construction debris and no waterproofing measures were incorporated. The net result was profound condensation within the floor voids, leading to timber decay and the collapse of some parts of the floors (see Figure 3).

Figure 3: What happens when you do not ventilate a floor void properly

The provision of suitable ventilation and damp proofing has been part of mainstream building for many years; why ignore it when installing a prefabricated building? The early failure of these floors could have been averted by the simple provision of good cross-ventilation and a suitable membrane over the oversite.

Case study 5

This case involves the construction of a modular academy school. The classroom modules were factory assembled, shipped to site and then made weatherproof. Unfortunately, a severe rainstorm occurred during construction, resulting in water entry into the construction. Fortunately, the supplier was a responsible contractor and organised appropriate remedial works, but these involved the removal of ceilings and floors, insulation and finishes all carefully installed in the factory and now replaced by site-based operations. The key message here is that temporary weathering methodology needs to be considered carefully at design stage; it is as much part of the system as the building itself.

The above examples are illustrative of the significance of water ingress into buildings and the need to obey traditional, proven methodology in protecting structures from moisture. Modern methods of construction do not permit a designer or installer to ignore the basic physics of building.

2D MATERIALS

Another modern method of construction that has become firmly established in both low-rise and high-rise construction is SIPS panels, which are efficient structural panels made from two layers of oriented strand board with a rigid foam core. These panels are often used as part of an external wall construction behind a lightweight rainscreen system. Putting concerns over combustibility to one side, SIPS panels can suffer if they are exposed to moisture — either water passing through the outer rainscreen or via water vapour from inside the building passing through improperly sealed joints. In one example, profound loss of integrity of the OSB was discovered as a result of poor interface details between windows and rainscreen cladding. Another example involved a failure to provide a suitable vapour seal between the panels, with the result that water vapour passed through the construction to condense on the rear face of the metal cladding panels forming the external finish. The lack of a ventilated cavity behind the cladding and the probable incidence of condensation on the rear face of the metal rainscreen resulted in very high levels of moisture, causing the OSB to fail. Given that the metal rainscreen panels were screw-fixed to the OSB, the situation could have been catastrophic.

CLT is another potentially useful material and is becoming more popular. The material is sustainable, reasonably lightweight (allowing savings in foundation costs), fast to construct and has good thermal performance. Construction requires accuracy, however, and as in earlier examples, the incomplete structure must be protected against the weather. The installation of services requires careful consideration and, like many MMC, there is a need for more up-front design at the outset; once designed, the system is not as flexible to late changes as traditional construction. Until recently, the material was thought to perform well in fire, but a recent CROSS report[18] has highlighted a potential concern over fire performance, with a correspondent identifying that whereas conventional timber forms a char layer that serves to protect against fire, CLT tends to delaminate, with successive layers becoming exposed to the fire; it is suggested that this restricts the ability of the timber to self-extinguish.

The CROSS report questions whether the building regulations guidance has kept up with the development of systems such as CLT and suggests that this could potentially lead to the construction of buildings that may not satisfy the functional requirements of the regulations or the expectations of the owners and their insurers. Some of these buildings might allow fire development that could endanger the occupants, neighbours and firefighters.

FINALLY

The above examples are illustrative of some of the problems and challenges that affect the widespread adoption of MMC. I have illustrated things that can go wrong as opposed to things that can go right, and in so doing it is certainly not my intention to caution against the use of MMC and the innovation that precedes it. But MMC do pose challenges to surveyors and other building professionals; a lack of knowledge of performance trends or simply a lack of knowledge of how systems perform can raise suspicions and fuel prejudice. The key thing to remember is that while methods may be unfamiliar, the agencies that act upon them are all well known; apply the knowledge that you do have to help work out the things that you do not know.

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