The impact of Permanent Volumetric Modular Construction (PVMC) on building safety

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Permanent Volumetric Modular Construction (PVMC) is an approach to construction where modules are built off-site, transported to site and assembled together to create permanent buildings. To support HSE BSR in fulfilling its duty to keep under review the safety and standards of all buildings in England, evidence on the in-occupation safety of buildings constructed using PVMC is required. It is important to understand the nature of potential building safety issues in PVMC, their likelihood of occurrence and their consequences. This report describes an initial review of evidence linked to the building safety of PVMC. Through conducting a literature review, data search and a stakeholder focus group a number of incidents are reported to have occurred in PVMC. No data has been found that can give a reliable representation of the scale of the PVMC market or the likelihood and consequences of potential building safety risks. The evidence to date does not support any conclusions about the relative safety of PVMC versus other construction methods. The results from this report are to inform the HSE BSR and the construction industry of the available evidence. This report also offers a range of potential additional work that could be undertaken, to further evidence any possible building safety risks in relation to PVMC

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The impact of Permanent Volumetric Modular Construction (PVMC) on building safety

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Research Ethics Statement

This study was reviewed by the Health and Safety Executive's Research Ethics Panel which operates under delegated authority from the University of Sheffield Medical School Research Ethics Committee (Reference REP 23-009, Date 14/08/2023).

Key Messages

HSE Building Safety Regulator (BSR) has a duty to keep under review the safety and standards of all buildings in England. This includes being regulator for building safety risks in those buildings defined as Higher Risk Buildings (7 stories or more, or 18m or more in height, that contain at least two occupied residential units).

Volumetric Modular Construction (VMC) is an approach to construction that offers potential benefits, such as speed of onsite assembly. VMC covers buildings that are permanent or temporary in nature. As part of the duty to keep safety and standards under review, HSE BSR has undertaken to evaluate the in-occupation safety of the permanent form of this approach to construction.

The aim of this research is to identify evidence of defects which were linked to the building safety of Permanent Volumetric Modular Construction (PVMC) as well as their likely frequency. As part of this research project a focused literature review, data search and a stakeholder focus group were undertaken.

Based on material found in the literature review, estimates of the size of the PVMC market were sought to determine the scale of any identified defects. Preliminary estimates of the size of the overall Volumetric Modular Construction (VMC) UK market (including both permanent and temporary VMC) are identified. However, there is no evidence found that offers estimates of the number of PVMC builds in existence. No data has been found that can be relied on statistically to give a representation of the likelihood or consequences of risks for PVMC builds.

From the literature review and stakeholder focus group, a number of incidents are reported to have occurred in PVMC. Where the causes of building safety incidents have been identified and can be evidenced, they have been mapped against the potential risks identified in the report ‘Research into Risks in Volumetric Construction’ commissioned by the Department for Levelling Up, Housing and Communities (DLUHC). The building safety issues identified in the DLUHC report are not a comprehensive list of building safety issues for PVMC. In the literature review and in the data searches it was difficult to link specific issues to VMC or PVMC builds within the sources of information analysed. Therefore, it is important to note that these issues could also relate to other (non-PVMC) builds and there is no evidence to suggest whether the frequency of the issues would be higher or the consequences of the issues more severe in relation to PVMC compared to other types of construction.

The results from an initial survey of the literature and data are to inform the HSE BSR and the construction industry of the available evidence and identify gaps in knowledge, which would be helpful to address in understanding and ensuring building safety using this type of construction. The likely stakeholders for this work could include, but are not limited to, construction industry and its clients, property insurers, investors in property and property owners.

Note: Higher-risk buildings is the term used by the Building Safety Act for buildings that are 7 stories or more, or 18m or more in height, which contain at least two occupied residential units. These are sometimes called High Rise Buildings, or High Rise Residential Buildings. This report uses the term higher-risk buildings throughout.

Executive Summary

Background

There have been a few instances reported in the media that have raised questions around the level of safety of permanent Volumetric Modular Construction. Volumetric Modular Construction (VMC) or Category 1 Modular is a type of Modern Method of Construction (MMC) where three-dimensional units are manufactured offsite and transported to and installed onsite. The Department for Levelling Up, Housing and Communities (DLUHC) commissioned a report entitled, 'Research into Risks in Volumetric Construction', that identified the possibility of VMC-related building safety issues. At the time of drafting the DLUHC-commissioned report was yet to be published.

This research was commissioned by the HSE Building Safety Regulator (BSR) to identify any evidence of the frequency or consequences of any identified building safety issues (fire safety and structural safety) for permanent VMC builds (PVMC).

Objectives

The objectives of this work were to:

- Complete an initial scoping study to identify any evidence of the nature and frequency of any defects linked to building safety for PVMC builds, either reported in published literature, identified in relevant data, or described by stakeholders.

- Formulate possible approaches to extend the work, to determine with more accuracy the likely frequency and nature of any identified defects.

The intention is that this initial scoping study will help identify possible pathways to refining an understanding of the potential hazards of fire spread and structural failure and their associated risks, which are specific to buildings constructed using PVMC or are more prevalent in PVMC.

Methods

The following methods were chosen to fulfil the project objectives within the project's three-month timescale:

A literature search and review to identify:

- any reported building safety incidents for PVMC buildings
- any links between fire spread and structural failure and PVMC buildings

A targeted data search to locate any relevant data indicating the safety of PVMC buildings. This included analysing:

- Home Office Fire and Rescue Service statistics
- Collaborative Reporting for Structural Safety UK (CROSS-UK) reports
- Recording of Incidents, Diseases and Dangerous Occurrences (RIDDOR) including any associated HSE Health and Safety Inspectors' reports
- Planning Portal data

Stakeholder engagement through a focus group to collect experiences from three organisations with experience of commissioning PVMC builds. Stakeholder engagement was agreed with the HSE BSR.

Findings

No authoritative sources were identified through the reviews conducted, that provide an estimate of the number of PVMC builds in existence. However, market research data offers preliminary estimates of the scale of the VMC market in the UK.

A wide range of building safety incidents in PVMC builds have been identified through this research. Where evidence of the causes of these was also available, these have been mapped against the potential risks identified in the report 'Research into Risks in Volumetric Construction' commissioned by DLUHC.

The examples of building safety issues evidenced in this report that have the potential to impact on fire safety are:

- Missing or incorrectly installed cavity barriers
- Defects found in fire doors and door frames
- Penetrations through compartment walls that are not correctly fire stopped
- Fire safety barriers e.g., compartmentation compromised during modifications
- Hidden voids e.g., in walls, ceilings and floors
- Lack of fire performance certificate
- Lack of clarification over structural fire design e.g., for cross-laminated timber and light-weight steel in VMC
- Building control checks are challenging, either onsite or offsite
- Lack of identification of roles and responsibilities if the modular contractor was a subcontractor (i.e., not the lead contractor)
- Limited access for checks

Similarly, building safety issues evidenced in this report that have the potential to impact on structural safety are:

- Inappropriate substitution of structural members

- Lack of clarity over design for structural robustness
- Lack of knowledge relating to structural design
- Lack of clarification over structural fire design e.g., for cross-laminated timber and light-weight steel in VMC
- Building control checks are challenging, either onsite or offsite
- Lack of identification of roles and responsibilities if the modular contractor was a subcontractor (i.e., not the lead contractor)
- Limited access for checks

The building safety issues identified in this report are not a comprehensive list of building safety issues for PVMC. In the literature review and in the data searches it was difficult to link specific issues to VMC or PVMC builds within the sources of information analysed. Therefore, it is important to note that some of these issues could also relate to other (non-PVMC) builds and there is no evidence to suggest whether the frequency of the issues would be higher or the consequences of the issues more severe in relation to PVMC compared to other types of construction.

Contents

1 Introduction

1.1 Background

Modular construction is a Modern Method of Construction (MMC) where component parts of a building are made offsite and then transported and assembled onsite. There are many cited advantages of this approach including, rapid completion on site, improved construction quality and reduction of waste. Modern Methods of Construction have been seen as a method to increase the efficiency of the construction industry.

Different types of MMC were defined by a framework developed by the Ministry of Housing, Communities & Local Government (now the Department for Levelling Up, Housing and Communities, DLUHC) cross industry working group [1]. In the context of this project the focus is Category 1 Modular or Volumetric Modular Construction (VMC) used in permanent buildings. Category 1 Modular or VMC is where three-dimensional units are manufactured offsite and can be transported to site in a range of stages of completion, such as a structural frame to a fully fitted out unit with internal and external finishes and services.

There have been a few instances reported in the media that raise questions around the level of safety of Volumetric Modular Construction for permanent construction (PVMC) and the DLUHC commissioned a piece of research which identified the possibility of building safety issues occurring [2]. The results from this report are to inform the HSE BSR and the construction industry of the available evidence. This report also offers a range of potential additional work that could be undertaken, to further evidence any possible building safety risks in PVMC.

1.2 Aims and Objectives

This project was an initial scoping, so it was uncertain what information would be found. The objectives of this work are:

- Evidence to provide an initial scoping of the nature and frequency of any defects linked to building safety reported by published literature and available data; and which other regulators, government departments and trade organisations are aware of.

- Possible approaches to extend the work to determine with more accuracy the likely frequency and nature of any identified defects.

The intention is that once this initial scoping is completed it will identify possible pathways to refining an understanding of risk for VMC.

1.3 Methodology

The following methods were chosen to fulfil the project objectives within the project's three-month timescale:

1. A literature search and review (Section 3) to identify:

   - any reported building safety incidents for PVMC buildings
   - any links between fire spread and structural failure and PVMC buildings

   Data on the size of the PVMC market, obtained through this literature search, was analysed, in order to identify any indications of the size of the PVMC market and the scale of any building safety issues that might be identified.

2. A targeted data search (Section 4) to locate any relevant data indicating the safety of PVMC buildings. This included analysing:

   - Home Office fire statistics
   - Collaborative Reporting for Structural Safety UK (CROSS-UK) Reports
   - Recording of Incidents, Diseases and Dangerous Occurrences (RIDDOR) including Inspectors' Reports
   - Planning Portal Data

3. Stakeholder engagement (Section 5) through a focus group to collect experiences from three organisations with experience of commissioning PVMC builds. Stakeholder engagement was agreed with the Building Safety Regulator. The data collected from the focus group is given in Appendix 1-3.

Evidence from the research methods above have been mapped against the potential risks identified in the report 'Research into Risks in Volumetric Construction' commissioned by the Department for Levelling Up, Housing and Communities' [2] and given in Appendix 4.

2 Definition of Terms

In order to define the scope of the research the definition of the term Permanent 'Volumetric Modular Construction' (PVMC) is key to address, as well as broader terms that include PVMC within their definition, such as 'Modern Methods of Construction' (MMC), 'Modular' and 'Volumetric Modular Construction' (VMC). Policy, guidance, media articles and published research often refer to these broader terms and therefore they are relevant, but not specific to PVMC.

2.1 Modern Methods of Construction

Modern Methods of Construction (MMC) is a widely used term in the construction industry, but it can have different interpretations [3] and in some instances it has been assumed to indicate some degree of offsite manufacture [4], [5]. A framework of MMC technologies was defined by the Ministry of Housing, Communities & Local Government (now the Department for Levelling Up, Housing and Communities, DLUHC) cross industry working group in 2019 [1] as a broad range of offsite and onsite techniques and technologies, that have the potential to increase the efficiency of construction. This framework identifies the following seven MMC categories:

1. Pre-manufacturing (three-dimensional primary structural systems)

2. Pre-manufacturing (two-dimensional primary structural systems)

3. Pre-manufacturing components (non-systemised primary structure)

4. Additive manufacturing (structural and non-structural)

5. Pre-manufacturing (non-structural assemblies & sub-assemblies)

6. Traditional building product led site labour reduction / productivity improvements

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

Volumetric Modular Construction (VMC), and therefore Permanent Volumetric Modular Construction (PVMC), are included within this framework as Category 1.

2.2 Modular

The term 'Modular' construction is used to describe an approach to the design and production of buildings that utilises the benefits of repetition or standardisation, making 'offsite' manufacturing likely to be involved.

Repetition can occur within modular construction at different scales, for example as a building component (Category 3 [1]) e.g. steel structural section, an assembly of many construction components, such as a two-dimensional structural component (Category 2 [1]) e.g. a structural truss, a unit of a building such as a three-dimensional structural component (Category 1 [1]) e.g. a bathroom pod or a complete building such as a house. As such ‘Modular’ construction is a broad term which includes VMC, and therefore PVMC, as well as other modular construction types.

The possible benefits of the modular approach, which arise through the degree of repetition or standardisation and through the use of offsite construction or manufacture, are suggested to include:

- Lower costs due to mass-production [6], [7], [8], [9], [10], [11], [12], [13].
- More rapid construction onsite and less risk of delay from weather conditions due to offsite construction [3], [6], [7], [9], [10], [11], [12], [13], [14], [15], [16], [17].
- Faster delivery time as onsite and offsite processes can be carried out simultaneously [6], [13], [14], [15], [18].
- Higher quality of work due to more controlled conditions e.g. sealing joints to ensure airtightness can be made to a higher standard to increase energy efficiency [6], [9], [11], [13], [14], [15], [16], [18], [19].
- Improvement of acoustic insulation through the double walls created by stacking volumetric modules next to one another [6], [14], [19].
- More efficient use of materials due to more controlled conditions offsite, allowing for less material wastage and offering more possibilities for recycling, [6], [8], [11], [12], [13], [14], [15], [16], [19].
- Better tracking of products to ensure appropriate materials or products are used [13].
- Less possibilities for vandalism during construction, due to offsite construction [16].
- Reduction in need for construction workers to travel or transport goods to site, reducing CO_2 emissions, congestion, as well as road closures [6], [19].
- Reduction in onsite activity reducing noise and dust in the local area [1], [13], [16].
- Has the potential to address the skills shortage in the construction industry and contribute to local employment [13], [14], [20], [21].
- Improved health and safety for onsite construction workers, for example a reduction of working at height [6], [8], [11], [12], [13], [14], [16], [19].

- Increased customer choice [13], [14], [16].

These potential benefits have been suggested to have a positive effect in terms of the carbon impact of construction [1], [12], [15], [18]. There can, however, be additional design requirements to consider particularly for larger modular components, such as dimensional and weight restrictions for transportation to site, and specific loading or environmental scenarios they might experience during storage, transportation, and assembly onsite [22].

A lack of evidence from delivered projects, from which to determine the potential benefits, is reported in a Construction Industry Research and Information Association (CIRIA) report [23]. The report sets out the need for a consistent approach to assess and quantify the benefits of offsite manufacture and provides a possible methodology [23].

Another term for 'modular' construction that has been identified during the literature review undertaken as part of this project is Industrialised Building Systems (IBS) [24].

2.3 Volumetric Modular Construction and Permanent Volumetric Modular Construction

Volumetric Modular Construction (VMC) or Category 1 modular is defined as three-dimensional structural modules manufactured offsite. This modular approach evolved from two types of buildings. The first type were designed to be easily moved or portable, such as the Manning Portable Colonial Cottage published in 1833 [25] or Buckminster Fuller's Dymaxion House (designed in the late 1920s) [26]. The second type were intended as temporary structures such as the prefabricated postwar homes, built as part of the Housing (Temporary Accommodation) Act 1944 [27]. These two types of modular construction have, influenced the development of Permanent Volumetric Modular Construction (PVMC), which is reported to offer benefits over alternative construction methods for permanent buildings [28]. The need for temporary VMC has continued to the current day.

Therefore, within the current VMC market space there are two main applications of three-dimensional modules:

- Temporary or relocatable VMC modules are available within the industry for sale or hire. Temporary VMC modules are commonly used in applications such as temporary offices, classrooms, prisons, and toilets that are transported to site to cater for a specific temporary need, such as providing a relocation space during refurbishment of a permanent facility. These are typically low-rise applications.

- Permanent Volumetric Modular Construction (PVMC) is a term that will be used throughout this report to identify the application of VMC to create permanent buildings. PVMC can be used for buildings constructed solely from volumetric modules, or as part of a hybrid approach that includes traditional construction methods. Hybrid construction can be seen in uses where there are many similar spaces, such as a number of residential units, which could be built from the same or similar PVMC modules, and which also includes spaces with less repetition in them such as common areas, which might be constructed using traditional building techniques. A hybrid construction is also often used for high-rise construction where VMC modules require a stabilising structure such as concrete cores to resist wind loads [6]. One of the first PVMC blocks of flats, Murray Grove, was assembled onsite in Hackney, London in just 10 days in 1999, for the housing association the Peabody Trust [29].

This project is focused on PVMC. PVMC modules can be transported to site in a range of stages of completion, such as just the structural frame to a fully fitted out unit with internal and external finishes and services. Safety considerations of temporary VMC may be thought to be less critical given the temporary nature of their installation. However, it is important to note that buildings that are initially thought to be temporary can often be retained and used for long periods of time (semi-permanent).

Other terms for PVMC that have been identified during the literature review undertaken as part of this project are Prefabricated Prefinished Volumetric Construction (PPVC) [30] and Modular Integrated Construction (MiC) [31]. These two terms indicate a slightly narrower subset of PVMC in that the modules are completely fitted out offsite.

2.4 Use of Technical Terms

This report will focus on the building safety of Volumetric Modular Construction (VMC) used in permanent buildings and use the term 'Permanent Volumetric Modular Construction (PVMC)' to identify this particular application of VMC. The possible sources of literature as well as data used in this project may not relate to PVMC precisely but could indicate a relationship with broader terms such as MMC, Modular, Offsite and VMC that are likely to include PVMC. Where possible the technical terms used in the original source of information will be used. Where more than one source of information is being discussed, an appropriate technical term that encompasses all terms used in that group of information sources will be used.

3 Literature Review

A literature review of scientific publication databases including the Web of Science, has been undertaken to identify:

- Fire and structural safety incidents in Permanent Volumetric Modular Construction (PVMC).
- Research that relates to fire or structural safety of Permanent Volumetric Modular Construction (PVMC).

3.1 Literature Review Methodology

The two literature searches were conducted using a wide range of possible terms that could indicate a relevance to Permanent Volumetric Modular Construction (PVMC). The term PVMC is not included as a search term, as it has been employed in the context of this report, to identify the use of VMC in permanent buildings.

Table 1, Search Terms used for the Literature Review and Data Search.

Search Terms
Volumetric Modular Construction
Modular construction
Modular integrated construction
Modular buildings
Modular building systems
3D modular construction
Three-dimensional modular construction
Category 1
Category 1 modular
Category one modular
Modular
Modern methods of construction
MMC
Offsite construction

The search term ‘Volumetric Modular Construction’ was not widely used in the literature. However, the term ‘Modular’ was included in the search terms to locate as many relevant publications as possible, even though it produced results from publications on a much wider set of construction types. This approach identified an overall issue with the terminology used in publications, where there was a tendency to use more general terms such as ‘modular’ or ‘offsite’ without clarifying if they were indicating VMC or a wider group of methods of construction.

In addition to the use of the search terms in Table 5 the following approaches were used for the two literature searches:

- Fire and structural safety incidents in Permanent Volumetric Modular Construction (PVMC).

The search terms, Accident*, incident*, injur*, fatal*, death*, dangerous occurrence*, occupational risk*, or safety were searched for with a proximity operator to the terms constuct* or build*. To reduce the number of results which were not relevant to the construction industry a NOT operator for the terms ‘‘nuclear’ and ‘reactor’ was also introduced.

- Research that relates to fire or structural safety of Permanent Volumetric Modular Construction (PVMC).

The searches for fire safety and structural safety were conducted independently. Search terms fire*, combust* or ignit* were used for fire safety and the additional terms structu* and integrity, performance, reliabil*, stability or behaviour were used for structural safety.

Both searches were conducted over the period 1990-2023. The results were assessed for relevance based on a review of the title, abstract and any links to in occupation structural or fire safety risks, with any shortlisted papers then being read in detail. The results of this analysis are reported in Section 3.3.

A further search was undertaken with the same search terms, given in Table 5, but using Google to identify any media reports of building safety issues in PVMC. As for scientific publications the type of construction was not always clearly identified. This suggests that there could be further building safety PVMC incidents reported in the media, but that are not identified as such in the news articles. The results of this search are given in Section 3.4.

The results of the two literature searches were also used to give an overview of the PVMC sector (Section 3.2). This included identifying any data relevant to the size of the PVMC market, in order to gauge the potential scale of any building safety issues that might be identified.

3.2 The Permanent Volumetric Modular Construction Market

This section uses the literature searches, described in the previous section, to provide an overview of the development of, as well as current and future projections for, the Permanent Volumetric Modular Construction (PVMC) market. This included an analysis of data that could indicate the size of the PVMC market in order to estimate the scale of any potential building safety issues. In the searches carried out very little data was identified that offers a picture of the size of the PVMC market. However, there is more available information around Modern Methods of Construction (MMC), Modular construction in general and VMC. It cannot be implied that data on the size of the MMC, Modular and VMC market is indicative of the PVMC market. Such data only indicates the scale of a wider range of construction approaches including PVMC.

3.2.1 Context

There has been a drive to encourage the uptake of MMC processes since the Egan report was published in 1998 [28]. This report highlighted the positive benefits of standardisation and offsite production. The following timeline outlines key policies and reports of relevance that occurred prior to the completion of this project in October 2023.

2001 – The Housing Corporation (the non-departmental public body that funded new affordable housing and regulated housing associations in England which was abolished in 2008) promotes MMC through a £80 million Affordable Housing Programme [32].

2002 – The Housing Forum, (housing association, developers, house builders, contractors, and NHBC) published a report 'Homing in on Excellence' promoting MMC, in particular offsite manufacture [33]. A further report was published by the Housing Forum in 2004, which suggested that through the use of new technologies the quality of construction could be improved [18].

2002 – 'Accelerating change', a report written by the Strategic Forum for Construction, chaired by Sir John Egan, repeats the need for standardisation and more offsite production [34].

2004 – The 'Barker Review of Housing Supply', set out several policy recommendations and underlined the need for a higher level of house building [35].

2004 – The Government's Sustainable Communities Plan required a quarter of new publicly funded social housing to use MMC [36].

2005 – The National Audit Office publishes 'Using Modern Methods of Construction to Build Homes More Quickly and Efficiently' [37].

2006 – 41% of Housing Associations' activities are reported to use MMC [38].

2008 – MMC targets from the Affordable Housing Programme are removed during the financial recession [38].

2016 – ‘The Farmer Review of the UK Construction Labour Model: Modernise or Die’ promoted offsite and modular construction [20].

2017 – In response to the Farmer Review, The Department for Communities and Local Government published ‘Fixing Our Broken Housing Market’ which also promoted modular construction and MMC [39].

2018 – Homes England is established and its strategic plan for 2018/19 – 2022/23 is published, which supported the use of MMC [40].

2019 – The Department for Housing, Communities and Local Government Committee promotes MMC, modular and offsite construction [41].

2021 – Homes England relaunched the Affordable Homes Programme which offers a long-term ‘Strategic Partnerships’ development grant for the completion of 1,500 homes or more, a quarter of which must be built using MMC [42].

2022 – Government guidance, ‘The Construction Playbook’ set out an expectation for departments and Arm’s Length Bodies to have a target for the proportion of new builds to use MMC [43].

A more detailed description of policy and guidance is given in ‘The UK Government’s Modern Methods of Construction (MMC) Policies and Strategies’ [32].

3.2.2 Trade Associations

Three key trade associations represent the Volumetric Construction Modular market.

- Modular & Portable Building Association in the UK [44] – This association covers all types of VMC including temporary and permanent buildings and has members such as recruiters for the modular industry, manufacturers of the components and products used in VMC as well as modular manufacturers themselves.

- Make UK Modular [45] – This association appears to be for companies delivering Permanent Volumetric Modular Construction for housing in the UK.

- Modular Building Institute [46]– This institute states that it is an international association for the modular or offsite construction industry.

The membership of these organisations gives a good indication of companies involved in the VMC market.

Make UK Modular believe that most of their members are producing low-rise housing, below 11 metres tall [47]. However high-rise schemes are also starting to be built, such as the construction of a 48 storey (156m tall) block of student accommodation in Canary Wharf, manufactured by Vision Modular Systems [48].

3.2.3 Output and Value of the Market

Several reports about the development of the modular industry were identified through the literature searches detailed in Section 3.1, that might offer an insight into the number of current PVMC buildings in the UK and the possible future numbers. The challenges in interpreting these data are:

- How the data is collected. Some market reports will set out the origins of their data, which is often based on surveys of members. Extrapolation techniques are then used to infer the sector's performance. Data from other sources appear as estimates with no obvious supporting methodology to indicate how they have been determined.

- Different boundaries around the market sector the data is taken from. For example, data can be from specific use sectors e.g., housing, it can include temporary VMC buildings as well as permanent VMC (PVMC) buildings and most data encompasses all Modern Methods of Construction (MMC) which is a wider market than just VMC.

- The time-period over which the data is recorded can vary i.e., not all values are quoted over a calendar year.

- The units of data used can vary, for example cost in £ millions or number of buildings.

- Where data is given as a percentage of the current construction industry output there can sometimes be no reference to indicate what data is being used as the construction industry output.

- Where the data is given as a financial value, more detailed work would be needed to understand what the value represents e.g., the market value of the resulting properties or the profit made on the properties.

- In some cases, future predictions can suggest a large step change from current manufacturing levels.

The result is that it has not been possible to isolate the data that would enable the quantification of the PVMC market, or to make a rigorous comparison across available data.

Given these constraints the data in Table 1 reported for the UK MMC housing sector between 2015 and 2020 [49], [50], [51], gives a preliminary estimate that the proportion of houses built using MMC could range from 6% to 10%. Predictions that relate to MMC housing alone indicate an increase to as much as 20% of the housing market by 2030-2031 [49], [50].

Table 2, Data on the size of the UK MMC housing market from Industry reports using the number of units.

Timeline	RICS (2020) [49] Units: % of homes built with MMC	Savills Research (2020) [50] Units: % of homes built with MMC	House of Commons (2019) [51] Units: % of homes built with MMC
2015	-	-	10%
2019	-	-	-
2020 (COVID-19 Pandemic)	8%	6-10%	-
Future Predictions	Could rise to 20% over the next 10 years (2030)	Could rise closer to 20% over the next 10 years (2030)	-

A preliminary estimate of the possible scale of the UK modular or offsite market has been derived based on data from two sources [52], [53], that cover the period between 2013 and 2019. The first source [52] offers data for the turnover of the 'modular and portable' market and the second [53] offers the value of the 'offsite' market. These data sources and the value of the total work undertaken in the construction industry each year, as reported by the Office of National Statistics [54] has been used to estimate the range of percentages, 2.0% to 2.5%, that the whole modular market could represent of the value of the total work undertaken in the construction industry each year as shown in Table 2.

Table 3, Data on the size of the UK Modular or Offsite Market from Industry Reports using the value of the work.

Timeline	G, Sherriff (2019) [52] – Modular and Portable Units: £m	C. Vokes and J. Brennan (2013) [53] - Offsite Units: £m	Construction statistics annual tables - Total of all new work, Office of National Statistics) [54] Units: £m
2013		£1,500m (2.0%*)	£74,129m
2019	£2,956m (2.5%*)		£119,211m

* Published values given as a % of the 'Total of all new work', Office of National Statistics [54].

Using a similar approach, data published up to 2020, that indicates the value of both the UK temporary and permanent Volumetric Modular Construction (VMC) market [55], has been used to estimate the range of percentages, 0.8% to 1%, that this sector could represent of the value of the total work undertaken in the construction industry each year [54], as shown in Table 3.

The historic rate of growth of this sector is not well covered in the data found. Data, which includes temporary and permanent Volumetric Modular Construction (VMC), indicates a gradual growth, which was impeded by the COVID-19 pandemic [55]. Future predictions for the temporary and permanent Volumetric Modular Construction (VMC) market indicate steady growth [55].

Table 4, Data on the size of the UK VMC Market from Industry Reports using the value of the work.

Timeline	AMA Research [55] Units: £m	Construction statistics annual tables - Total of all new work, Office of National Statistics) [54] Units: £m
2015	£904m (1%*)	£91,269m
2016	£931m (0.9%*)	£98,991m
2017	£907m (0.8%*)	£109,056m
2018	£987m (0.9%*)	£112,287m
2019	£1004m (0.8%*)	£119,211m
2020 (COVID-19 Pandemic)	£850m (forecast) (0.9%*)	£100,199m
2021 (COVID-19 Pandemic)	£880m (forecast) (0.8%*)	£115,579m
Future Predictions	'Steady Growth'	

* Published values given as a % of the 'Total of all new work', Office of National Statistics [54].

The only data available on the number of UK VMC builds, shown in Table 4, relates to the production of VMC houses. The first source of data gives an estimate of over 1,650 houses being built in 2017 [47], and an estimate of over 3,300 houses being built in 2022 [47]. Both of these estimates are for 'factory-built modular' homes. However, based on the report [47] it is clear they are referring to VMC houses. In addition, an estimate of 4,000 - 5,000 houses being built in 2020 [56] relates to, what are termed, 'Modular' and 'MMC' houses in the published article. However, the article refers to examples that are clearly VMC builds.

If 5,000 houses are taken as a maximum production level between 2018 to 2022, that would suggest a maximum of 25,000 VMC houses were built during this time period. Here because it is the housing sector, it is possible these numbers relate to PVMC rather than temporary VMC.

Table 5, Data on the size of the UK VMC Housing Market from Industry reports using the number of housing units.

Timeline	Make UK Modular (2022) [47] Units: Number of housing units	J. Gardiner (2020) [56] Units: Number of housing units
2017	Over 1,650 a year (in the last five years - more than doubling its output)*	
2020 (COVID-19 Pandemic)		4,000-5,000 housing units*
2022	Over 3,300 a year (3,300 a year or 1 in 60 houses)*	
Future Predictions	10,000 a year by 2025 (10,000 homes a year - or about 5% of the current level of house building*)	10,000 to 15,000 – the industry's production capacity*

* Published values

3.2.4 Market Vulnerabilities

Despite the predicted benefits of PVMC the uptake of this new approach has faced challenges. In May 2019 the Housing, Communities and Local Government Select Committee held an inquiry to review the current market and identify any barriers to its expansion [57], [13].

Some of the barriers identified in published reports and research are:

- A lack of understanding around MMC [58].
- Difficulties in making repairs [13].
- High levels of capital investment required [7], [11], [13], [14].
- High cost of construction [59].
- Challenges in securing a constant demand [11], [13].
- Shortage of skilled workers or limited factory capacity [7], [13], [14], [18], [20], [21], [60].
- Lack of confidence in the quality of this type of construction including certification [7], [9], [13], [18].
- Lack of specific design guidance and design standards causing challenges in complying with existing building regulations [11], [13], [19], [59], [61].

- Challenges experienced in insuring and mortgaging [13], [62].
- Challenges experienced in procurement and contracts [63], [64], [65].
- Poor data sharing and communication between stakeholders, clients, manufacturers, logistics companies, and building contractors [7], [24], [59], [66], [67], [68], [69].

Reviews of the modular market's vulnerabilities have been published in the following references, [30], [31], [70], [71], [72], [73], and possible areas of research to understand or address these vulnerabilities have also been identified [11], [74], [75].

Illustrating these barriers, several companies producing PVMC buildings, particularly homes, have either ceased trading or withdrawn from the sector over the past couple of years e.g. Urban Splash [76] in 2022 and Ilke homes [77] and Legal and General Modular [78] in 2023.

3.2.5 Standards

A preliminary review of the available design guidance and regulation for PVMC builds has been undertaken. A thorough analysis of design standards has been undertaken for offsite construction by the British Standards Institute [79].

There is currently no formal design guidance available in the UK for VMC. There is however the following material:

- Guidance to Local Authorities in Scotland on assessing MMC buildings [80] on their compliance with the Building (Scotland) Act 2003 [81].

- A fire safety standard for modular buildings has been developed by the Defence Infrastructure Organisation [82]

- In 2006 a Loss Prevention Standard (LPS) for 'Innovative systems, elements and components for residential buildings' was published by BRE Certification Ltd. This LPS was to offer assurance to the insurance and mortgage sectors for new construction methods, where standards and guidance were not yet developed, and thereby encourage the construction sector and those in the housing market to invest in MMC [62]. This standard was withdrawn in 2007 [83]. There is however a current Loss Prevention Standard approach set out by the Building Research Establishment for fire testing innovative methods of construction [84].

In January 2023 the Department for Levelling Up Housing and Communities commissioned the British Standards Institution to create a design standard PAS 8700 for MMC [85].

3.2.6 Global Market

Section 3.2.3 focused on analysing the UK PVMC market, however there is research which reports 'prefabricated' housing forming 88% of the single-dwelling timber detached housing market in Sweden and 15% of the housing market in Japan. This data is cited as being reported in 2017 and 2013 respectively [86]. It is not clear how the term 'prefabricated' relates to VMC in these statistics. This data suggests it may be beneficial to look in further detail at markets in other countries and research conducted about them [87], to see how they assure building safety and to see if there are any available data sets which can indicate the resulting level of building safety.

3.3 Incidents and Safety Issues

The first literature search detailed in Section 3.1 was carried out to identify incidents linked to PVMC construction in the UK. It identified 28 papers as potentially relevant to PVMC and out of those, five papers offered evidence of building safety incidents.

A working group paper for the International Association of Engineering Insurers in 2021 [8] notes that because current technologies in modular construction are relatively new there had not been a significant number of claims to report. This suggests that since PVMC has been introduced relatively recently, there might be a lag time before building safety issues come to light. The paper sets out three case studies, two of which do not appear to be related to PVMC, but which are broader examples of modular construction. The third case study related to two separate fire incidents (one is mentioned in detail). This case study is summarised here:

- Moorfield Hotel and the Fair Isle Bird Observatory (March 2019) on the Shetland Islands, UK, It is reported in relation to the Moorfield Hotel that 'a lack of compartmentation, an absence of the fire-proof inner walls and wide usage of a combustible material were likely to be key factors in the uncontrollable spreading of the fire' [8].

In addition, a significant survey of construction clients in the UK was conducted in 2003, regarding what is defined as 'pre-assembly' construction. Whilst responses indicated that the benefits of pre-assembly were reduced time, increased quality compared to onsite construction, as well as cost, the most common disadvantage cited was that the modules were poorly constructed [9]. A similar survey was conducted in 2020 by researchers in Australia and China, although it does not appear to cover the UK market and responses are more likely to be opinion rather than based on experiences [88].

Research published in 2009 surveys maintenance records for 'offsite' bathroom modules over a period of three years [89]. The maintenance records cover 216 precast concrete offsite modules, 84 Glass Reinforced Polyester offsite modules and 96 bathrooms which were constructed onsite. The report finds that the offsite modules performed better in terms of maintenance requirements than the onsite constructed modules, however the issues encountered did not have a direct link to building safety issues [89].

The final paper investigated a total of 17 housing projects built by two Swedish timber module manufacturers. Defects in selected projects were identified by analysing audits undertaken in the factory, on completion and for a warranty [87]. Whilst the modules are identified as 'prefabricated' and 'industrialised housing' it is likely these are PVMC houses. The defects are recorded to indicate where they occurred in the building, what was defective, what type of defect was identified and its root cause, when the defect occurred, what was done to correct it and where the defect arose. It is not clear through the categorisation of results the relationship of the identified defects to the risk of fire spread or structural failure, as opposed to other practical issues as well as aesthetics. The results are compared against six traditionally built buildings. As with the previous study the results are reported as showing that the defects are fewer in the prefabricated modules than in traditional construction but are caveated with the need for a larger investigation to ensure statistical robustness [87].

The second literature search, set out in Section 3.1 which links PVMC with structural safety or fire safety issues identified 47 papers as potentially relevant to PVMC but did not contain evidence of building safety incidents. However, both these and the results from the first literature search were used to offer surveys of structural safety and fire safety in PVMC, which are given in Section 3.3.1 and Section 3.3.2 respectively. The remaining papers were reviewed to identify any other safety issues relating to PVMC and are reported in Section 3.3.3.

3.3.1 Published research relating to structural safety.

The papers identified as part of both searches into incidents of structural failure and structural safety, highlight the current development in understanding of PVMC as a structural system. The papers also indicate the innovation that is occurring to develop structural systems that respond to the specific requirements of offsite construction.

The behaviour of stacked volumetric modules as a structural system is different to traditional construction. In traditional construction there are typically continuous columns that support the floor structure and take the gravity (vertical) loads to the ground. The floor structure works as a diaphragm transferring horizontal loads, such as wind loading. For volumetric modules, the overall structure is made up of separate modules creating a discontinuous structure where the connections between modules are key in transferring both vertical and horizontal loads.

There are different types of modules which are based around different possible structural load paths, which are:

- Load bearing modules: This is where loads are taken through the sides of the module.
- Corner structured modules / open sided modules: This is where the loads are taken through primary structure in each corner of the module [6].

An overview of structural behaviour and research from 2018 is given in ‘Structural response of modular buildings – An overview’ [90].

Volumetric construction has typically been used for medium to low rise buildings, but high-rise buildings are being built [91] such as ‘Ten Degrees’ in Croydon, London, a 135 m tall residential high-rise built in 2021 [92]. For high-rise structures there is an increasing requirement to understand their overall structural behaviour under horizontal loading such as wind loads and seismic loadings [93], [94], [95], [96], [97] as well as to ensure the overall robustness or response to the collapse of part of the overall structure [98], [99], [100], [101], [102], [103], [104]. Much of the research in this area focuses on using numerical methods, with papers highlighting the limited experimental data to validate models [98], [99] which is attributed to the cost and lack of appropriate facilities [99]. New numerical methods to analyse these structures are being developed [105].

A list of experimental standards for modular buildings and prefabricated components is given in Table 8 in 'Structural response of modular buildings – An overview' [90] from 2018. The table also gives a few references to papers where experimental data is available. It is commented on and evidenced in Table 8 in the paper that the experimental standards 'for modular buildings are limited' [90], with references to the American Applied Technology Council's experimental standards given for cyclic seismic tests on module frames [106] and the American Society for Testing and Material's standards for the impact of air borne debris on the module envelope [107], [108].

In addition to papers on robustness, a further paper was identified researching the structural collapse mechanisms due to different fire scenarios through Finite Element Modelling (FEM) of a six-story steel framed 'modular' building [109]. This is relevant to the overall structural performance of PVMC buildings during a fire.

The connections between modules have a significant influence on the response of volumetric modular high-rise structures to wind loads, seismic loadings, and their robustness [110]. The components of these connections are fabricated as part of the volumetric modules offsite, under factory conditions. However, the connections between modules are made onsite and as such they are also important for adjusting for any manufacturing tolerances. These connection tolerances are important in controlling any misalignment of load paths and therefore determining the forces and bending moments experienced in the modules' structure, as well as the deflection of the overall structure [6].

There is considerable research that has been identified in this area with both numerical models and experimental tests being used to develop an understanding of different types of connections and their impact on the behaviour of the surrounding structure [110] [111], [112], [113]. Novel approaches to making these connections are also being developed to improve the efficiency of construction and safety on site [114], [115], [116], [117], [118], [119], [120], [121]. A review of experimental test methods for connections between modules from 2022 was also identified in the literature searches [122].

Loading experienced once the building has been assembled is not the only loading that the structures of volumetric modules need to be designed to resist. Loading experienced during transportation and installation must be considered too [123]. The requirement to transport volumetric modules makes their overall weight an important design parameter which promotes the need for structural efficiency. Structural efficiency needs to be balanced with the need for structural safety. Structural monitoring of volumetric modules has been proposed to monitor the stresses including those experienced in transit and those due to misalignment of load paths once the modules are assembled on site [124].

Given the relatively new application of VMC to permanent buildings there are many new innovations being researched, looking at novel materials, novel construction types or composite construction for volumetric modules. There are a few papers researching the understanding of two particular construction materials used in the structure of volumetric modules. The first is light-gauge or cold-formed steel sections, which due to their low weight to strength ratio are typically used to create frames for the walls and floors of volumetric modules [125], [126]. Further research has looked to optimise these cross-sections for particular loading cases [127]. The second is timber, in part because of its low density but also because it can offer a reduction in the environmental impact of the structure, [87], [128], [129]. One paper proposes the potential combination of cold-formed steel and timber [130]. The use of concrete and steel together as a composite material are also explored [131], [132], [133], [134], [135]. Novel construction types are also considered such as corrugated steel plate walls reinforced with steel strips [136].

There are no specific building safety concerns highlighted in these papers. These papers demonstrate that the understanding of structural behaviour is developing alongside innovations in materials, structural components, and connections, which all influence structural behaviour.

3.3.2 Published research relating to fire safety.

Nine papers were found that linked fire safety and modular construction from the literature searches undertaken. Four of these papers focus on understanding the fire performance of light-gauge or cold formed steel modular walls and floors [137], [138], [139], [140]. One of these four papers has sought to improve the fire performance as well as taking into account the efficiency of manufacture [140]. Two additional papers look at the impact of introducing larger steel sections into a light-gauge steel frame [141] and different approaches to providing the fire performance for steel Square-Hollow-Sections that are also efficient in terms of fabrication [142].

The final three papers focus on the fire performance of relatively novel lightweight materials for application in modular construction. One focuses on three dimensional-printed concrete using foamed concrete [143], another on a type of fibre reinforced polymer composite [144] and a final one on a range of fibre reinforced composites [145].

These papers highlight how much innovation is occurring to develop efficient production for modular construction, the importance of research around new materials and construction approaches which would influence fire performance.

3.3.3 Other published research relating to safety.

Through both literature searches safety issues, not related to fire spread and structure collapse, were identified. Research has been conducted to understand the potential for airtight, well insulated, volumetric modules that have a low thermal mass to overheat in warmer weather [146]. In addition, the airtight volumetric modules have been studied to understand the level of build-up of Volatile Organic Compounds that can occur [147].

Several papers have been identified that focus on safety issues relating to the manufacturer and installation of volumetric modules, which would come under the Construction (Design and Management) Regulations 2015 [148]. Reviews of fatalities and injuries data from the United States related to modular or prefabricated construction have been conducted [149], [150], [151], [152]. The safety issues that relate to the offsite manufacture of modules are highlighted and approaches to address them are explored [153], [154], [155], [156], [157], [158]. One of the key safety issues researched in the identified papers are the safety issues in crane operations used for module installation [159], [160], [161].

These potential safety issues are not related to fire spread and structural failure and therefore are not relevant to the focus of this report.

3.4 Media Reported Safety Issues

A number of instances of fires and construction issues in PVMC buildings in the UK had been reported in the media prior to the completion of this project in October 2023. The literature searches, set out in Section 3.1 identified information on the following PVMC building safety incidents, which have been reported in the media:

- Yarl's Wood Removal Centre (February 2002):
  - This building was low-rise and used timber PVMC. It was reported that fire spread rapidly through the roof void causing destruction of part of the building [162], [163].
- Fair Isle Bird Observatory, Shetland (March 2019):
  - This building was low-rise and used timber PVMC. It was reported that the fire started in the roof, spread rapidly, and caused the destruction of the building [164]. This incident is also referenced in Sections 3.3 and 4.2 [8].
- Moorfield Hotel, Shetland (July 2020):
  - This building was low-rise and constructed from Structural Insulated Panels (SIPs) which included polyurethane insulation.
  - It was reported in the media that it was not possible to determine the ignition source of the fire which caused the destruction of the building, but it was thought to be electrical. It was reported that the spread of fire may have been aided by wall or roof cavities [165], [166]. This incident is also referenced in Sections 3.3 and 4.2 [8].
- Paragon, flats and student accommodation, Brentford, London (October 2020):
  - This building was made up of six blocks of up to 17 storeys and constructed using steel frame modules. It was reported that structural and fire safety issues caused evacuation of all residents. The modular system was provided by Caledonian Modular [167], [168], [169].

- Prison block, Monmouthshire (November 2021):
    - This was a low-rise prison that failed its fire safety inspection, resulting in its demolition [170].
- Bonnington Walk, Bristol (July 2023):
    - This was a timber frame modular housing scheme by Legal & General modular. There were issues identified with the foundations causing the homes to be dismantled and rebuilt, delaying occupation. There were also concerns about mould in another scheme [171], [172].
- Launceston Primary School and Newquay Primary School, Cornwall (April 2023):
    - These were two partially built low-rise school buildings by Caledonian Modular. Due to concerns about construction, they were demolished [173], [174], [175].
- Haygrove School, Bridgewater, Somerset and Sir Frederick Gibberd College, Harlow (August 2023):
    - These are low rise school buildings by Caledonian Modular that were closed due to concerns about construction [176].

Further incidents, which are not clearly identifiable as PVMC builds are listed below:

- 42 schools in the Republic of Ireland (October – November 2018)
    - These school buildings were built by Western Building Systems between 2003 and 2018 and were subsequently closed for inspection. The 'vast majority' of the buildings were identified as modular [177]. It is not clear if any, or some of the buildings were PVMC builds. Fire and structural safety issues were reported to cause a range of outcomes including closure and remediation [177], [178].
- Bristol Premier Inn, Cribbs Causeway (2019)
    - This hotel was destroyed by rapid spread of fire [179].

These incidents provide evidence of building safety issues having occurred in PVMC buildings. However, there is a possibility that these reported incidents may be due to issues not related to or not influenced by the fact they were PVMC builds. For example, the issues relating to the foundations at Bonnington Walk may or may not have been because this was a PVMC build. A further example of the importance of this distinction is the fire performance of timber modular as in the three cases: the Yarl's Wood Removal Centre, The Fair Isle Bird Observatory, and the Moorfield Hotel. It is worth noting that traditional (non-VMC) timber structures as well as timber PVMC have had fire incidents which have caused considerable damage [180]. The fire safety of timber structures is an issue of concern for the construction industry [181], [182].

It has not been possible, within the limitations of the project to obtain evidence to identify the root cause and what caused the incidents' escalation. Therefore, no conclusive evidence has linked the use of PVMC and the causes and consequences of any of the cited incidents. In addition, the number of reported incidents cited here could not be used to assume a frequency of building safety issues within PVMC buildings because:

- The number of incidents cannot be said to indicate the number of building safety issues in existing VMC buildings.
- Some safety issues were only noticed during other checks, which then triggered further inspections.
- It is possible that other incidents are reported in the media but are not clearly identified as PVMC buildings.
- It is also possible that incidents related to PVMC are reported more frequently than for incidents in traditional (non-PVMC) construction because it is a relatively novel approach to construction.

3.5 Literature Review Summary

MMC, 'modular' and 'offsite' construction have been promoted as having a number of benefits, but the development of the sector has experienced challenges in its expansion. No reliable data on the scale of the PVMC market has been identified through the literature review, however, some sources that provide an indication of the scale and output of the VMC market have been found.

This literature review offers evidence of building safety issues occurring in PVMC buildings. Based on the information available (outlined in Section 3.3), the identified building safety incidents in PVMC and further possible PVMC incidents cannot necessarily be attributed to the PVMC method used to construct buildings. Further work would need to be undertaken to see if causes of the incidents and their escalation could be uncovered in fire incident reports and structural surveys. These reports may not be able to give a complete picture of the evolution of the incident, particularly given the level of destruction of some of the fires reported. Therefore, it may be appropriate to consider using lab testing as a means to control the situation under examination, to compare the fire spread and its consequences in PVMC and non-PVMC builds.

The cited building safety incidents [162], [163], [164], [165], [166] do highlight a potential for timber modular structures to have an increased risk compared to general PVMC, due to concerns over the fire performance of timber frames.

Two studies from the literature review offer a comparison of the frequency of occurrence of defects in PVMC and non-PVMC. The first related to bathroom pods [89] and the second to timber prefabricated housing modules [87]. However, these surveys of defects do not indicate a direct link to changes in fire or structural safety.

4 Data Search

A data search was conducted to see if any relevant data could be located that might provide evidence about the proportion of PVMC buildings in the UK and building safety in PVMC. Alongside this it was recognised that data on building safety in PVMC alone would not allow an assessment of whether any identified building safety risks in PVMC were more frequent or could cause more significant outcomes than other types of construction, for example for traditional builds. Based on the research conducted there appears to be no available data that offers a benchmark for frequency or severity of incidents linked to the type of construction.

Four possible data sources were searched:

- Home Office fire statistics
- Collaborative Reporting for Structural Safety UK (CROSS-UK) Reports
- Recording of Incidents, Diseases and Dangerous Occurrences (RIDDOR) including any associated HSE Health and Safety Inspectors' Reports
- Planning Portal Data

The data searches were conducted using the same search terms as given for the literature review in Table 5, where the data platform enabled such a search to be undertaken.

However, the terms that included the phrase 'category 1' or its variations were excluded from some of the searches as this phrase has a different meaning depending on the context. For example, it can mean a category 1 hazard in relation to reportable incidents. In a similar way the term 'modular' was also used with care depending on the context, since it could return an unmanageably large number of entries that were unrelated to the focus of the research.

4.1 Home Office Fire Statistics

Home Office Fire and Rescue incident statistics [183] are collated from incidents attended by the Fire and Rescue Authorities in England and reported on an annual basis. This data reports the number of fires, the number of injuries and/or fatalities and the causes of the fires. The function of the building is recorded by the attending fire officer within the data set, but no data is collected that relates to the building materials or construction type of the buildings. This means that no data from the source reviewed can be related to VMC builds to indicate the likelihood and consequences of fire spread, but it has the potential to offer a background level of fire statistics for the construction industry as a whole [58].

4.2 Collaborative Reporting for Safer Structures UK Data

Collaborative Reporting for Safer Structures UK (CROSS-UK) is an organisation that enables professionals that are working in the built environment to confidentially report fire and structural safety issues [184].

Two key types of reports are published on the CROSS-UK website, confidential ‘safety’ or incident reports and ‘theme pages’, which are reviews or feature articles that discuss specific technical concerns.

4.2.1 Methodology for Collaborative Reporting for Safer Structures UK Data

Reports published on the CROSS-UK website were analysed using the keyword search function. The search function enables searches to be undertaken on words that may appear in the report title, the body of the report, or both. The website also offers the ability to filter results using a range of categories, however the filter function was not used during the search because of the small number of unique results that were returned using the keyword search.

Additional searches were undertaken on specific categories such as 'material type', 'safety area' and ‘CLT’ (Cross-Laminated Timber) without a keyword search term being inputted, to ensure that any relevant reports were not missed.

Once all structured search terms were completed a final unstructured search was conducted, where the titles of the 817 CROSS-UK database records were read to identify any that may be relevant. However, no new reports were discovered using this approach.

4.2.2 Results for Collaborative Reporting for Safer Structures UK Data

Nine unique CROSS-UK reports were identified through the keyword search.

Four of these reports relate to concerns around the use of a type of engineered timber or Cross-Laminated Timber (CLT), with two of them relating to fire safety concerns [185], [186] and two relating to rot caused by water ingress [187], [188]. These concerns may be seen as separate to any specific issues related to PVMC since they are also points of concern for non-PVMC construction. For example, onsite construction uses two-dimensional CLT modular panels [189]. However, there is the potential that building safety issues in VMC construction could increase the frequency or consequences of building safety risks for timber PVMC compared to non-PVMC timber construction.

One report was about an inappropriate installation of two-dimensional modular trusses and therefore irrelevant to PVMC [190]. Two reports relate to the use of cold-rolled or light gauge steel sections. The first of these two reports related to a disagreement about the fire design of light gauge steel sections in a structural wall that might be subjected to a fire on both sides [191]. This relates to the specific design guidance for light gauge steel sections, a type of structural section that is used in both PVMC and non-PVMC construction. The second of these reports related to types of sections being inappropriately substituted, offering a structural capacity which was less than that required in the structural design

[192]. There was concern within the report that other ‘modular’ manufacturers could make similar substitutions.

One report relates to PVMC or ‘permanent stacked modular buildings’ and the importance of the correct installation of cavity fire stopping, of a suitable design life, due to the difficulty of maintaining them and inspecting them [193]. It references two of the fire safety incidents in Section 3.4 but does not give direct evidence that the installation of cavity barriers was the cause of the fires.

The final report relates to a difference of opinion around the robustness of a low-rise modular building with a lack of fixings between the modular units and the foundations, resulting in the author suggesting the need for additional design guidance for clarification [194].

The number of relevant articles that reference PVMC cannot be used to give an indication of the likely occurrence of safety issues occurring in PVMC compared to other construction types because:

- CROSS-UK is not a mandatory reporting process.
- CROSS-UK has only recently included the option to report fire safety issues.
- A report cannot be assumed to represent one building safety incident.
- Some of the reports are written by CROSS-UK as reviews or feature articles of specific technical concerns and are not incident reports.

4.3 Recording of Incidents, Diseases and Dangerous Occurrences Data

Under the reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 [195] the Recording of Incidents, Diseases and Dangerous Occurrences (RIDDOR) [196] is a mandatory requirement for any work-related death or in some specific cases work related injury, such as loss or reduction of sight or loss of seven consecutive days of work.

It is also a requirement of the Diseases and Dangerous Occurrences Regulations 2013 (Schedule 2) [195] to report a range of categories of Dangerous Occurrences that have the potential to cause death or serious injury. The most relevant categories for this project are:

- ‘Structural collapse

23. unintended collapse or partial collapse of -

(a) any structure, which involved a fall of more than 5 tonnes of material: or

(b) any floor or wall of any place of work

Arising from, or in connection with ongoing construction work (including demolition, refurbishment, and maintenance), whether above or below ground

24. The unintentional collapse or partial collapse of any falsework.

- Explosion or fire

25. Any unintentional explosion or fire in any plant or premises which results in the stoppage of that plant, or the suspension of normal work in those premises, for more than 24 hours.' [195]'

These reporting systems are unlikely to include any PVMC building safety issues related to the in-occupation phase of such buildings due to the nature of the reporting requirements.

4.3.1 Methodology for Recording of Incidents, Diseases and Dangerous Occurrences Data

COIN is the internal system used by the HSE to record the details of work-related fatal and non-fatal incident investigations. It only records those cases where an incident that is reportable under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 [195] leads to an HSE investigation. The COIN system was interrogated by the Analysis and Data Team at HSE using search terms covering 'modular construction', 'modular building', 'modern methods of construction', 'MMC', and 'category one' as well as variations on the spelling of those terms, producing a data extract covering the period from 2001 to 2021. The search produced a total of 601 records, each of which was manually reviewed for relevance. The results included duplicate cases and duplicate customer reference numbers because COIN can sometimes contain multiple entries for one case.

4.3.2 Results for Recording of Incidents, Diseases and Dangerous Occurrences Data

The analysis of the data extract for COIN did not result in any cases that were relevant to the in-occupation safety for PVMC buildings. This result reflects the fact that RIDDOR, and therefore the cases recorded in the COIN system, relate to incidents where someone has died or been injured because of a work-related accident.

It has also not been possible to identify any reportable incidents that relate to the construction or refurbishment of a PVMC building which could have safety implications once the building is in occupation. Further research into the relationship of safety during construction (either onsite or offsite) and the quality of workmanship may be useful in understanding the causes of defects.

The analysis did not result in cases that were deemed relevant to the in-occupation safety for PVMC buildings.

4.4 Dangerous Occurrences Data

4.4.1 Methodology for Dangerous Occurrences Data

Also relating to the reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 [195], dangerous occurrences that relate to specific types of incidents that have a high potential to cause death or serious injury are required to be reported [197]. HSE publishes summary statistics on dangerous occurrences that have been reported to it [198], and in 2021/22 there were 2,881 reports. There are a range of reportable categories within Schedule 2 of RIDDOR, but one category was chosen to see if any relevant data could be identified. The chosen category was:

> '23. unintended collapse or partial collapse of -
>
> (a) any structure, which involved a fall of more than 5 tonnes of material: or
>
> (b) any floor or wall of any place of work
>
> Arising from, or in connection with ongoing construction work (including demolition, refurbishment, and maintenance), whether above or below ground' [195]

There were 120 reports for this category, and the case details were obtained from the Analysis and Data Team at HSE. The data was checked to determine if the case description contained the project search terms, and subsequently the case details were reviewed for each of the 120 cases.

4.4.2 Results for Dangerous Occurrences Data

The 120 records did not contain any of the search terms for the project. The review of each of the individual cases determined that 117 of the cases were not related to PVMC. In the remaining three cases it was not possible to determine whether the case related to a PVMC building, or not, because they did not contain enough case information to make an informed judgement.

4.5 Planning Portal Data

The Planning Portal supports the UK online planning application and building control service [199]. It receives information on various types of applications, creating a source of information on potential construction projects. The portal does not hold details on whether projects progress through or beyond the planning application process and therefore cannot been seen as representative of what has actually been built.

4.5.1 Methodology for Planning Portal Data

The Planning Portal provided two data sheets covering planning applications that were submitted during July 2023. One data sample contained information on the basic details of the planning proposal in a free text field that had been populated by the applicant. The sample contained 1522 records. The second data sample contained the same planning application information but with the addition of a ‘materials’ field, which again had been populated by the applicant. This sample contained 1513 records.

Analysis was carried out on these samples of data from the Planning Portal to see if any relevant information could be extracted about PVMC buildings.

Analysis was undertaken on both data samples using a keyword search based on the terms listed in Table 5.

4.5.2 Results for Planning Portal Data

A review of the first data extract identified six records that contained one or more of the search terms. Five of the records related to modular building projects, and the sixth record was excluded because it was not relevant. The search on the second data extract, which contained the materials field, identified the same six records as the first data extract. It also contained one additional record where the term ‘modular’ was referenced in the materials field but not in the application description. This means that there were six potentially relevant records that contained some reference to the search terms in Table 5.

A review of the six records showed that three related to planning applications for new or additional school or nursery units. The remaining three records related to the use of modular units for sports changing facilities, a boardroom/office, and a single storey building extension.

‘Modular’ was the only search term found in the applications. Therefore, it was not possible to determine the type of modular construction being proposed in the planning applications. The data analysis determined that 0.4% of planning applications in the sample contained reference to the ‘modular’ search term, in either the application description and/or the materials field. This result is lower than the estimated range of VMC builds given in Section 3.2.3 indicating that it is likely that the sample is not representative of the VMC market or projections of future build volumes.

4.6 Data Search Summary

Four data sources were reviewed as part of the data review. It was not possible to identify PVMC specific data on fires or incidents from the Home Office Fire and Rescue Service Statistics, nor was it possible to identify representative data on planning applications from the Planning Portal data. The data from Recording of Incidents, Diseases and Dangerous Occurrences [195] did not identify any information relevant to PVMC construction or occupation, partly due to the nature of the information that HSE requires when RIDDOR reports are submitted.

Analysis of the CROSS-UK database identified evidence highlighting three potential building safety issues, covering:

- Inappropriate substitution of inferior structural products in modular factories.

- A requirement for clarification around fire design guidance for cold formed / light gauge steel sections.
- A requirement for clarification on the design guidance around structural robustness.

Incidents cited in these CROSS-UK reports have been mapped against the potential risks identified in the report ‘Research into Risks in Volumetric Construction’ commissioned by the Department for Levelling Up, Housing and Communities [2] (see Appendix 4).

However, no relevant data has been found that could be used to identify the frequency of the building safety issues, nor the severity of any consequences. It might however be possible to carry out a study on site safety, conducted in connection with the Construction (Design and Management) Regulations (2015) [148], to see if there is a link between site safety and production of a quality build for PVMC.

5 Stakeholder Engagement

A focus group was arranged with stakeholders in order to collect information from as wide a set of sources as possible within the project timeframe. The purpose of the stakeholder engagement was to enable those with knowledge and expertise in the sector to contribute information to the review. Stakeholder engagement was determined by the HSE BSR and based on the stakeholder's availability in the given timeframe. Participation was agreed based on anonymity of the participants. During the project several stakeholders identified sources of information to support the understanding of PVMC, which has informed the literature review in Section 3. There was, however, limited opportunity to follow up with participants after the focus group sessions due to the time constraints of the project.

5.1 Focus Group Methodology

Ethics approval was obtained from HSE Research Ethics Panel to conduct the focus group (Reference REP 23-009, Date 14/08/2023). Consent to participate required that the individuals and organisations in the focus group, and the respective buildings that they own or manage would not be identified in this report to ensure anonymity. Furthermore, participants were required to respect the confidentiality of other participants as set out in the focus group information sheet. Consent was obtained from participants through completion of a consent form, prior to the focus group.

The focus group was held as a virtual meeting and chaired by a representative from HSE and was attended by three stakeholders. Notes of discussions during the focus group were taken by a scribe.

Participants were asked to share their views on both the positives and negatives relating to PVMC building safety, to ensure the focus group was not making assumptions around the stakeholders' perception of the safety of PVMC builds. Participants anonymously posted the positives and negatives on an online interactive board to ensure all participants could contribute and were not concerned about being identified.

Some of the negative safety issues were selected and used to conduct hazard identification scenarios. These scenarios were intentionally disconnected from specific incidents or builds so that participants were able to contribute their general experience without needing to discuss specific and possibly sensitive information. It was possible to conduct three hazard identification scenarios within the time available, with two hazard identification scenarios considering fire spread and one considering structural failure. For each scenario the hazard, cause, preventative safeguards, consequences, mitigation safeguards, actions and any other comments were recorded by the scribe in a manner that enabled participants to see the records being made and ensure their accuracy.

In addition, participants were asked to anonymously provide specific information about their experiences via an online form.

5.2 Focus Group Results

The outputs of the focus group are given in Appendix 1, Appendix 2, and Appendix 3. It is worth noting that there was a variation in the functional types of PVMC with which the stakeholder focus group members were involved, with some stakeholders having experience of what were planned to be temporary VMC builds, but which have been used for a significant amount of time and therefore could be considered as semi-permanent VMC. This has potentially led to variations in responses, given the differences in functional requirements. It would be useful to identify these differences and link them to the experience of stakeholders, however this would risk identifying participating stakeholders, so this has not been pursued in this research.

Appendix 1 lists the positives and negatives identified for both fire and structural safety in PVMC buildings. The exercise identified twelve negative fire safety issues and one positive issue for PVMC builds. It also identified six negative structural safety issues and one positive issue for PVMC builds.

Appendix 2 provides the scribed record of three hazard identification scenarios:

- Fire spread due to difficulties to inspect during installation and manufacture.
- Fire spread due to difficulties in ensuring that future modifications do not impact on fire safety.
- Structural failure due to lack of clear responsibility or accountability in manufacturing.

The list of safety issues (Appendix 1) and the hazard identification scenarios (Appendix 2) offered some initial evidence on the occurrence of the identified issues, but without specific incidents being identified during the focus group to evidence their occurrence, the issues raised are unverified.

Appendix 3 gives the questions asked and responses to the online forms. Two responses were received to the online form, one of which was only partially completed.

The two responses had differing opinions relating to the frequency and consequences of building safety issues with PVMC compared to other types of construction. One respondent felt that both the frequency and consequences of fire safety issues in PVMC builds were less than non-PVMC (traditional) builds and the other felt that the frequency was marginally more for PVMC builds and that there are also worse consequences in PVMC builds.

Neither response provided any specific data relating to the potential building safety risks of PVMC that could be used within the time constraints of the project, but one respondent was contacted outside the focus group regarding specific incidents mentioned in the responses.

From the online form, and correspondence to follow-up the information in the forms, the following building safety incidents in PVMC were identified by stakeholders during the focus group:

1. Possible closure of a building due to the lack of fire performance certificate for the building.

2. A timber framed PVMC building was found with significant compartmentation issues:

    - Fire doors and frames were in poor state of repair.
    - There were hidden voids e.g., walls, ceilings, and floors.
    - There were non-fire stopped penetrations through compartment walls.

3. Project delays occurred for a building where the contractor could not prove fire performance of their modules. This caused an 18-month delay in completion and the need for an operating manual to be issued for the building.

4. Two fires which were initially external to the buildings progressed into the buildings' cavities. These fires were deemed to be caused by misuse by the occupants and it could not be proved that there was a failure in the building construction. The building was only out of use for a short period of time. The cost of repair for one of the fires was around £300,000.

5. A survey conducted on cavity barriers in over 250 PVMC buildings found missing cavity barriers or barriers that were not installed correctly. This cost more than £200,000 on surveys, increased mitigation costs such as more frequent checks of the fire alarm systems and assessments by maintenance. A similar survey was also carried out on traditional (non-PVMC) builds.

6. Defects and breaches were found by a fire safety survey that included fire door installations and compartment penetration. The consequences in terms of cost were still being realised.

7. Demolition of four PVMC buildings built in 2000 due to compartmentation breeches such as:

    - Excessive gaps at the top of fire doors.
    - No packing between door frame and walls.
    - Service penetrations that were not fire-stopped.

    Once these issues were identified these buildings required additional mitigation during use, such as fire alarms and were ultimately demolished.

As with Section 3.3 the number of incidents given above cannot be said to indicate the number of building safety issues in existing PVMC buildings. However, the causes of many of the incidents identified as part of the focus group are evidenced through detailed reports obtained from the stakeholders.

The building safety incident listed as number five above, where a survey was conducted on over 250 PVMC buildings as well as traditional buildings, does offer data on the frequency of building defects, which is given in Table 6 and 7.

Table 6, Studies on cavity barriers in PVMC and Traditional builds (Study 1 (2005/6)-2 PVMC Manufacturers).

	No. of Building Surveys	No. of Cavity Barriers Inspected	No. of Cavity Barriers Missing or with Gaps	% Cavity Barriers Missing or with Gaps
PVMC Builds	261	24,529	8,190	33%
Traditional Builds	12	188	77	41%

Table 7, Studies on cavity barriers in PVMC and Traditional builds (Study 2 (~2014)-1 PVMC Manufacturer).

	No. of Building Surveys	No. of Cavity Barriers Inspected	No. of Cavity Barriers Missing or with Gaps	% Cavity Barriers Missing or with Gaps
PVMC Builds	14	1,503	282	19%

This survey comprised of two studies. The first study was carried out in 2005/6 onwards, which included traditionally constructed buildings and PVMC buildings which were manufactured by two modular companies. The second study started around 2014 and focused just on PVMC buildings produced by one of the manufacturers from the first study.

The first study found that in 260 PVMC buildings (one was surveyed twice), 33% of the 24,529 fire cavity barriers inspected were either missing or not installed correctly. For 12 traditional builds 41% of the 188 fire cavity barriers inspected were either missing or not installed correctly.

The second study found that in 14 PVMC buildings, 19% of the 1,503 fire cavity barriers inspected were either missing or not installed correctly.

The different sample size of each set of data is important in determining whether the lower numbers of missing or defective cavity barriers in PVMC is likely to be statistically reliable when compared to traditional builds. This is also the case in determining whether the improvement in the quality of PVMC builds between the two surveys is likely to be statistically reliable.

It is not possible to indicate the statistical error because the data available does not relate specific cavity barrier assessments to specific buildings. This means that all the missing or defective cavity barriers could be found in just a few of the buildings surveyed and none in the rest, or the missing or defective cavity barriers could be more evenly distributed amongst the buildings. Having the data to determine which of these possible scenarios is the case is key in determining which, if any, of the buildings have all cavity barriers installed correctly and the reliability of the data.

In addition, systematic errors must be noted, such as the potential for a particular modular manufacturer's level of workmanship to influence the defect rate. This is particularly important in this data, given the low number of manufacturers involved in these surveys. This has the potential to make the results non-representative of PVMC buildings made by other manufacturers. Systematic errors are important to consider because of the possibility that defects might be decreasing over time, since the manufacturer whose work was assessed in both studies may have learnt and improved because of the results of the first study. In addition, this data is from just one sector of the UK construction market and defect rates in PVMC builds may vary between sectors depending on the specific approach taken to their design and construction.

Incidents cited in these focus group activities have been mapped against the potential risks identified in the report 'Research into Risks in Volumetric Construction' commissioned by the Department for Levelling Up, Housing and Communities' [2] and are given in Appendix 4.

5.3 Stakeholder Engagement Summary

Building safety issues and specific safety incidents in PVMC and semi-permanent VMC builds have been identified through a focus group, which engaged a limited number of stakeholders. The outputs of the focus group are given in Appendix 1, Appendix 2, and Appendix 3. Through the workshop data has been located on the quality of the installation of cavity barriers for both PVMC builds and traditional builds, however the results are not considered to be a statistically reliable representation of all PVMC builds.

6 Findings

There is no evidence found that offers estimates of the number of permanent VMC (PVMC) builds in existence. However, market research offers preliminary estimates of the scale of the VMC market in the UK.

Building safety incidents have been identified through this research and where the causes can be evidenced i.e. in the media reported incidents (Section 3.4), the CROSS-UK reports (Section 4.2) and in most of the stakeholder reported incidents (Section 5.2) they have been mapped against the potential risks identified in the report 'Research into Risks in Volumetric Construction' commissioned by the Department for Levelling Up, Housing and Communities' [2] in Appendix 4.

- Missing or incorrectly installed cavity barriers.
- Defects found in fire doors and door frames.
- Penetrations through compartment walls that are not correctly fire stopped.
- Fire safety barriers e.g., compartmentation compromised during modifications.
- Hidden voids e.g., in walls, ceilings and floors.
- Lack of fire performance certificate.
- Lack of clarification over structural fire design e.g., for cross-laminated timber and light-weight steel in VMC.
- Building control checks are challenging, either onsite or offsite.
- Lack of identification of roles and responsibilities if the modular contractor was a subcontractor (i.e., not the lead contractor).
- Limited access for checks

Similarly, building safety issues evidenced in this report that have the potential to impact on structural safety are:

- Inappropriate substitution of structural members.
- Lack of clarity over design for structural robustness.
- Lack of knowledge relating to structural design.
- Lack of clarification over structural fire design e.g., for cross-laminated timber and light-weight steel in VMC.
- Building control checks are challenging, either onsite or offsite.
- Lack of identification of roles and responsibilities if the modular contractor was a subcontractor (i.e., Not the lead contractor).
- Limited access for checks.

The building safety issues identified in this report are not a comprehensive list of building safety issues for PVMC. In the literature review and in the data searches it was difficult to link specific issues to VMC or PVMC builds within the sources of information analysed.

Therefore, it is important to note that these issues could also relate to other (non-PVMC) builds and there is no evidence to suggest whether the frequency of the issues would be higher or the consequences of the issues more severe in relation to PVMC compared to other types of construction.

There are potential risks cited in 'Research into Risks in Volumetric Construction' for which no evidence has been found in this project. In these cases, it cannot be assumed that because in this project no evidence has been found, that the safety issue has not occurred or that the risk of it occurring is less than for those issues where evidence of an incident has been found.

No data has been found that can be relied on statistically to give a representation of likelihood or consequences of risks in the PVMC market. However, it is possible, based on stakeholder engagement that further data could be obtained and analysed.

7 Potential Pathways Forward

Pathways forward may be different to address building safety issues in buildings that currently are under procurement, design and construction, compared to existing buildings in general or those which have identified an urgent building safety concern. Pathways forward could include a selection from the following non-exhaustive areas:

1) New PVMC builds (currently under procurement, design, or construction). To reduce building safety risks being built into new builds, it would be helpful to:

- Conduct research to identify levels of safety in all stages of the PVMC procurement, design, and construction and across a range of different PVMC types. This research might have implications for existing buildings and may inform any urgent concerns about PVMC.
- Undertake fire and structural testing of modules in a way that represents the typical contexts of these modules e.g., stacked or part of a hybrid structure. This would help identify the consequences of any building safety issues in comparison to traditional (non-PVMC) builds. Testing should include timber PVMC to determine the nature of potential risks of VMC overlapping with the potential building safety risks of timber structures. Such tests might have implications for existing buildings and may inform any urgent concerns about PVMC.
- Research into the links between the health and safety of construction workers, which is regulated by the Construction (Design and Management) Regulations (2015), and the in-occupation building safety of PVMC. This could potentially identify risks experienced by workers both offsite and onsite that could affect the quality of a PVMC build and its resulting building safety.
- Undertake a more detailed study into international PVMC markets. Linking the quality assurance processes in the design, manufacture, transport, and onsite construction for PVMC, including design guidance and legislation, to data on building safety, such as fire statistics.
- Undertake a study identifying good practice in all stages of the PVMC procurement, design and construction across UK manufacturers, onsite contractors, and clients.

The above pathways could help support increased awareness within the construction industry of potential safety issues, inform HSE BSR’s regulatory role for VMC Higher Risk Buildings and inform development of codes and guidance for manufacturers, onsite contractors, and clients.

2) Existing PVMC builds:

For existing PVMC builds in general, it could be worth considering:

- Further engagement with stakeholders already involved in this project, as well as additional stakeholders to widen expertise, as it has the potential to uncover:

    - The root cause and subsequent escalation behaviour of building safety incidents in PVMC buildings, to determine whether they are caused by, or whether the risk is increased by the PVMC process.
    - More detailed data relating to the frequency and consequences of building safety issues in existing PVMC buildings. This is particularly the case where existing stakeholders have already indicated they are conducting building safety inspections on buildings including PVMC builds and collecting data on identified issues.
    - Knowledge gaps for potential risks where there is no current evidence.

- Whilst some sort of building safety inspections could be a step, the impact should be considered. This could include the impact on inhabitants and any additional risks created in the building through intrusive inspections. Compulsory inspections by any regulatory body would require the legal powers to carry them out.
- In undertaking inspections, it would be important to consider a large number of factors, including: aspects of the building or building process to be surveyed, whether the survey was conducted on both PVMC and non-PVMC builds, the range of manufacturers and sectors surveyed, the need to prioritise in higher risk situations including those with larger or vulnerable populations and the sample size required to allow meaningful conclusions and its consequent reliability.

3) PVMC builds with urgent building safety concerns:

Where building safety issues have been identified which raise urgent concerns around a group of, or specific, occupied VMC builds:

- It would be important to undertake the appropriate survey relating to the concerns and prioritise buildings that have a higher building safety risk including those with larger or vulnerable populations.

For all three areas the continuous recording of building safety incidents across the UK, related to construction types would, after an initial period to build up a statistically reliable data set, help with the identification of abnormally high building safety risks within sectors and support the risk-based prioritisation of any current or future building safety issues.

Stakeholder engagement from a wide range of expertise could help with prioritisation of the possible pathways for areas 1) and 2) and also help inform whether the activities suggested above should be undertaken by government or industry.

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Appendix 1. Focus Group Outputs: Positives and Negatives of Building Safety in PVMC buildings

Tables 8 and 9 list the positives and negatives identified in the PVMC stakeholder focus group for both fire safety and structural safety respectively.

Table 8, Positive and Negatives of Fire Safety in VMC Buildings

<table>
<tr><th>Positives of Fire Safety in PVMC Buildings</th><th>Negatives of Fire Safety in PVMC Buildings</th></tr>
<tr><td>Common construction elements, so controls and mitigation could potentially be standardised.</td><td>
Build could satisfy building control, but occupational activities e.g., mounting a TV could compromise safety.
Difficult to ensure future modifications do not impact on fire safety measures.
Difficult to inspect, both at the offsite manufacturer and also during installation onsite.
Building Control process does not align with offsite construction.
The current Building Control approval process is not fit for purpose and relies on good practice, drawings, and information only.
Manufacturers are not always able to demonstrate technical compliance on their component parts.
Manufacturers still have a transient labour force in some instances which can lead to poor workmanship.
Forms of construction not inherently resilient to fire.
Unseen voids depending on module configuration.
Cavity barriers missing or next to insulation.
Quality control and selection of materials could allow flammable elements to be introduced.
How MMC buildings are expected to respond to fire safety is not well understood or delivered.
</td></tr>
</table>

Table 9, Positives and Negatives of Structural Safety in PVMC Buildings

Positives of Structural Safety in PVMC Buildings	Negatives of Structural Safety in PVMC Buildings
Common construction elements could potentially have consistent installation and good practice guidance produced.	• Not 'as specified' structural elements could be used or badly installed. • Difficult to inspect. • Quality control of construction elements is outside the control of the overall building's structural design. • Structural elements rely on the manufacturer. There is a lack of inspection of manufacturers (but it is getting better). • Construction looks 'fairly simple' however there is a lack of information about construction. • Lack of knowledge of how the structure works. Who checks this? It might be different for high rise construction.

Appendix 2. Focus Group Outputs: Hazard ID

Table 10 provides the scribed record of three hazard identification scenarios considered in the stakeholder focus group:

- Fire spread due to difficulties to inspect during installation and manufacture.
- Fire spread due to difficulties in ensuring that future modifications do not impact on fire safety.
- Structural Failure due to lack of clear responsibility or accountability in manufacturing.

Table 10, Hazard ID

No.	Hazard	Cause	Preventative Safeguards	Consequences	Mitigation Safeguards	Actions
1	Fire Spread	Difficult to inspect both at the manufacturer, but also during installation	• Certification. • An effective building control system that provides genuine assurance from a third party. • End user information. • Meeting the functional requirements as originally designed. • Design-in an easier route to inspecting components? • Asset tagging and digital information on fire critical	• Fatalities and injury. • Loss of property. • Lack of business continuity. • Reputational damage. • Potentially more rapid fire spread and potentially different spread of fire than traditional construction. • Common mode failures are more likely.	• Sprinklers (not required for every building type). • Fire suppression. • Early warning systems. • Access routes for emergency services and ability to fight any fire internally as opposed to defensive firefighting. • Site-specific	• The expectation that the building would be lost for a significant fire. - Subsequent investigation and cause and effect investigation to question whether the building and procedures performed as expected. • Systematic review

No.	Hazard	Cause	Preventative Safeguards	Consequences	Mitigation Safeguards	Actions
			components to enable systematic inspection throughout the building lifecycle (could incur additional costs). • The threat of genuine enforcement action - embedding ownership of risk (difficult because of complex supply chain and design responsibilities). • Clear roles and responsibilities and a responsibilities matrix in addition to Construction Design and Management Regulations 2015. • Building Regulation, Regulation 38 requirement to provide fire safety information to the 'Responsible Person' at completion of a build.		information for emergency services? • Dynamic site survey. • Possible inhibitor gas injection system between buildings?	of similar construction types within stock - dependant on type of failure. • Proactive rather than reactive future inspections.

No.	Hazard	Cause	Preventative Safeguards	Consequences	Mitigation Safeguards	Actions
2	Fire Spread	Difficult to ensure that future modifications do not impact on fire safety	• Ensuring that whoever is doing the work is aware of the construction type. • Means of escape are constructed of fire-resistant materials providing secondary containment. • Standards and good practice. • An understanding of each element within the building. • Mandatory fire safety training. • Possible modification detection technology for unauthorised changes?	• Fatalities and injury. • Loss of property. • Lack of business continuity. • Reputational damage. • Potentially more significant losses when compared to traditional construction in terms of a breach of compartmentation given additional pathways for fire spread.	• Sprinklers (not required for every building type). • Fire suppression. • Early warning systems. • Access routes for emergency services and ability to fight any fire internally as opposed to defensive firefighting. • Site-specific information for emergency services? • Dynamic site survey. • Possible inhibitor gas injection system between buildings?	• The expectation that the building would be lost for a significant fire. - Subsequent investigation and cause and effect investigation to question whether the building and procedures performed as expected. • Systematic review of similar construction types within stock - dependant on type of failure. • Proactive rather than reactive future inspections. • Return to fire risk assessment of an existing building - what is the

No.	Hazard	Cause	Preventative Safeguards	Consequences	Mitigation Safeguards	Actions
						increased risk to life? • Review of sub-contractor list.
3	Structural Failure	Lack of clear responsibility or accountability in manufacturing	• Structural inspection regime. • Structural integrity of units. • Asset tagging and traceability of components. • Clear and relevant standards for PVMC. • Innovation in fire protection of materials such as CLT. • Competency of those carrying out risk assessments and validation of that competency. • Occupant reporting processes for issues, defects, etc. • Periodic building condition report.		• Redundancy in structural components.	

Appendix 3. Focus Group Outputs: Focus Group Form Responses

Table 11 gives the questions asked, and responses to, online forms from the stakeholder focus group. Two responses were received one of which was only partially completed. The focus of these questions was the use of VMC (category 1 modular) in permanent buildings or PVMC. There were 12 questions given in four sections with no questions being made compulsory. The data collected was automatically anonymised and some parts of the responses have been redacted to maintain anonymity.

Table 11, Focus Group Form Responses

Questions	Response 1	Response 2
Section 1. For buildings built in the last five years:		
1. How many are built using PVMC (can be approximate)?	-	• Unfortunately, I haven't been able to obtain this information in time to meet the deadline.
2. How many units of PVMC were built (can be approximate)?	-	• Unfortunately, I haven't been able to obtain this information in time to meet the deadline.
3. How many inhabited PVMC buildings are you aware of that experienced fire safety or structural safety issues?	-	• We have not identified or been made aware of structural safety issues in permanent VMC (PVMC) buildings. • We have conducted a programme of fire door and compartmentation surveys across a particular type of accommodation buildings. The number of surveys

Questions	Response 1	Response 2
		undertaken is over 3000. As a result of these surveys an information note has been issued that highlights fire door issues and fire compartmentation issues in such as service risers, service cupboards, plant & equipment rooms, and ceiling/floor void areas in PVMC buildings. We have not gone into the detail of obtaining specified numbers of affected PVMC buildings, but an approximate number would be about 1000 buildings. A site which has approximately 260 modular buildings has identified varying levels of compliance in terms of cavity barrier installations. • There have been two fires that have been started externally to the building through misuse by the end user. • There was a new build project where a high-profile modular contractor could not prove the fire performance of their modules, which delayed the project by 18 months.
4. What were the key causes and consequences of the issues?	-	• For the generic fire door and compartmentation issues, the information contained in the surveys highlights poor workmanship through missing fire stopping or non-compliant installations. We are still to realise what the consequences of these findings are and a programme for remediation.

Questions	Response 1	Response 2
Section 2. For work done on existing buildings in the last five years:		
5.How many are built using PVMC (can be approximate)?	-	• Unable to get information within the timeframe. • From our perspective any refurbishments are likely to be limited to repainting, new carpets etc. in PVMC.
6.How many were remedial works on buildings built with PVMC (can be approximate)?	-	• Unable to get information within the timeframe.
7.What were the key causes and consequences of the remedial works?	-	• Unable to get information within the timeframe.
Section 3. Are you aware of any issues with Building Regulation compliance linked to the use of PVMC?		
8. How many issues are you aware of?	-	• The design details in Approved Document B do not necessarily cover the requirements in PVMC.

Questions	Response 1	Response 2
9. What were the key causes and consequences of the issues?	-	Generally speaking, the following issues have been identified that relate to Building Regulations: • A lack of professionals unwilling to move away from the design guidance in the Approved Documents. • Building Control professionals that did not check modules in the factory and some used the term 'contractor confidence' to justify reduced inspection regimes. • Modular contractors that still suffered from a transient labour force which meant issues with quality assurance. • Modular contractors not acknowledging their product was different to traditional construction and that it needs further fire testing to determine compliance. • A lack of identification/definition of roles and responsibilities in the construction process when the modular contractor was a sub-contractor. • Modular contractors relying on a single structural assessment to determine structural assessments across a number of buildings, as it provided a basis for the configuration of module units. • Meeting project completion dates puts pressure on manufacturers to deliver.
Section 4. Safety Issues		
10. In your knowledge		

Questions	Response 1	Response 2
how do fire safety issues compare with non-PVMC (traditional) construction?		
a) Is the frequency of issues more or less for PVMC? – (Response options: Less, Marginally less, Approximately equivalent, Marginally more or More).	• Less	• Marginally more
b) Are the consequences of issues more or less for PVMC – (Response options: Less, Marginally less, Approximately equivalent, Marginally more or More).	• Less	• More
11. In your knowledge how do structural safety issues compare with non-PVMC (traditional) construction?	-	-
a) Is the frequency of issues more or less for PVMC? – (Response	• Less	-

Questions	Response 1	Response 2
options: Less, Marginally less, Approximately equivalent, Marginally more or More).		
b) Are the consequences of issues more or less for PVMC – (Response options: Less, Marginally less, Approximately equivalent, Marginally more or More).	• Less	-
12) Is there any feedback on the focus group or other relevant information or references you like to add?	• Extremely useful to get together and listen to experiences and potential risks associated with PVMC units. It would be beneficial to liaise with NFCC to understand if PVMC are being involved in fires in buildings in each FRS.	• Fire safety compliance is through appropriate assessment and testing procedures, but my concern is that these routes do not necessarily represent a true fire scenario. Traditional construction has accepted levels of fire resistance without the need for additional testing, so you can have some confidence in a level of performance. I am not sure we get a level of confidence in performance from PVMC, as you are reliant on test results, interpretation of that data, continued use of materials and details in accordance with the results. • It is quite a large area to cover, and the only way to address the issue is with the help of and engagement with the modular industry.

Appendix 4. Comparison of Findings with 'Research into Risks in Volumetric Construction' report

The evidence found in this current report (Section 3, Section 4 and Section 5) have been mapped against the potential risks identified in the report 'Research into Risks in Volumetric Construction' commissioned by the Department for Levelling Up, Housing and Communities' [2] in Table 12 to Table 17.

Table 12, Procurement and Project Management.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
Risks deemed to be elevated in, or specific only to volumetric construction:		
1. Standard contract forms not applicable to MMC.	No evidence found	No evidence found
2. Lack of integrated project management and defined processes.	No evidence found	No evidence found
Risks deemed to be applicable to traditional construction as well as volumetric construction:		
1. Supply chain resilience: risk of insolvency.	• Closure of Urban Splash [76] in 2022 and Ilke homes [77] and Legal and General Modular [78] in 2023 - Literature Review	No data.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
	(Section 3.2.4.).	
2. Lack of early engagement of supply chain (including key roles: structural fire engineer, building control).	No evidence found	No evidence found

Table 13, Design.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
Risks deemed to be elevated in, or specific only to volumetric construction:		
1. Shortage of skilled DfMA designers.	No evidence found.	No evidence found.
2. Perceived gaps in design standards and codes.	• The design details in Approved Document B do not necessarily cover the requirements in VMC, but generally speaking the following issues have been identified that relate to Building Regulations - Focus group (Appendix 3) • [191] and [194] CROSS-UK reports (Section 4.2)	No data.

Potential risks identified in the research report ‘Risks in volumetric construction’ report’.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
3* Lack of knowledge relating to the structural design of VMC.	• Modular contractors relying on a single structural assessment to determine structural assessments across a number of buildings, as it provided a basis for the configuration of module units. Focus group (Appendix 3). • [191] and [194] CROSS-UK report (Section 4.2).	No data.
Risks deemed to be applicable to traditional construction as well as volumetric construction:		
1.Lack of integration between key individuals could undermine design.	No evidence found.	No evidence found.
2.Insufficient time for design; early design freeze is a critical success factor.	No evidence found.	No evidence found.
3. Potential for conflict between energy efficiency and fire safety design requirements.	No evidence found.	No evidence found.
4. Design defects: risk that defects are 'built in’.	No evidence found.	No evidence found.

* Indicates additional information from the current project.

Table 14, Manufacture.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
Risks deemed to be elevated in, or specific only to volumetric construction:		
1. Design variants incompatible with mass customisation.	No evidence found.	No evidence found.
2. Damage prior to transit which is undetected.	No evidence found.	No evidence found.
3* Lack of suitable skilled labour force leading to poor workmanship.	• Modular contractors that still suffered from a transient labour force which meant issues with quality assurance - Focus group (Appendix 3).	No data.
4* Lack of knowledge relating to how the VMC structure works.	• Modular contractors relying on a single structural assessment to determine structural assessments across a number of buildings, as it provided a basis for the configuration of module units. Focus group (Appendix 3). • [194] CROSS-UK report (Section 4.2).	No data.
5* Lack of knowledge around proving compliance for fire safety and certification.	• There was a new build project where a high-profile modular contractor could not prove the fire performance of their modules which delayed the project by 18months - Focus group (Appendix 3).	No data.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
6* Lack of Building Control checks in factories.	• Building Control professionals that did not check modules in the factory and some used the term 'contractor confidence' to justify reduced inspection regimes - Focus group (Appendix 3).	No data.
7* Lack of identification of roles and responsibilities if modular contractor was a subcontractor and not the lead contractor.	• A lack of identification/definition of roles and responsibilities in the construction process when the modular contractor was a sub-contractor- Focus group (Appendix 3).	No data.
Risks deemed to be applicable to traditional construction as well as volumetric construction:		
1.Deviation from original design.	No evidence found.	No evidence found.
2.Unauthorised product substitution.	[192] CROSS-UK report (Section 4.2).	No data.
3. Health & Safety risks.	No evidence found.	No evidence found.

* Indicates additional information from the current project.

Table 15, Transportation.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
Risks deemed to be elevated in, or specific only to volumetric construction:		
1. Damage and/or water ingress in transit.	No evidence found.	No evidence found.
2. Lack of process ownership between factory and site; ambiguity relating to responsibilities and accountability.	No evidence found.	No evidence found.

Table 16, Site installation.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
Risks deemed to be elevated in, or specific only to volumetric construction:		
1. Interface between offsite and onsite: misalignment.	No evidence found.	No evidence found.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	**Evidence identified in the current research project that the risk exists.**	**Evidence identified in the current research project that the risk is more than in other construction types.**
2. Mismatch in tolerances, typically used in the factory and typically used onsite, creating issues for installation.	No evidence found.	No evidence found.
3. Damage incurred to modules onsite, which may or may not be detected and remedied.	No evidence found.	No evidence found.
4. Limitations of access for inspection/onsite.	• Building Control professionals that did not check modules in the factory and some used the term 'contractor confidence' to justify reduced inspection regimes – Focus group (Appendix 3).	No data.
Risks deemed to be applicable to traditional construction as well as volumetric construction:		
1. Skills and knowledge gaps onsite.	• For the generic fire door and compartmentation issues, the information contained in the surveys highlights poor workmanship through missing fire stopping or non-compliant installations - Focus Group (Appendix 3).	No data.
2. Ineffective crane and lifting operations onsite.	No evidence found.	No evidence found.

Table 17, Occupancy and beyond.

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
Risks deemed to be elevated in, or specific only to volumetric construction:		
1. Risk of disproportionate damage in the event of fire or flooding; modules may be difficult to access to replace or repair.	• Building safety incidents do highlight a potential for timber modular structures to have an increased risk compared to general PVMC, due to concerns over the fire performance of timber frames. However. issues with the fire performance of timber frames are also reported for other construction types - Literature Review (Section 4.3).	No data.
Risks deemed to be applicable to traditional construction as well as volumetric construction:		
1. Discrepancies between 'as designed' and 'as built'.	• For the generic fire door and compartmentation issues, the information contained in the surveys highlights poor workmanship through missing fire stopping or non-compliant installations - Focus Group	• Limited data on cavity barriers missing or not installed correctly, from a limited number of manufacturers and from one sector. However, the data is not considered to be a statistically reliable representation of all

Potential risks identified in the research report 'Risks in volumetric construction' report'.	Evidence identified in the current research project that the risk exists.	Evidence identified in the current research project that the risk is more than in other construction types.
	(Appendix 3). • We have conducted a programme of fire door and compartmentation surveys across a particular type of accommodation buildings. The number of surveys undertaken is over 3000. As a result of these surveys an information note has been issued that highlights fire door issues and fire compartmentation issues in such as service risers, service cupboards, plant & equipment rooms and ceiling/floor void areas in VMC buildings - Focus Group (Appendix 3).	PVMC builds - Focus Group (Section 5.2).
2. Limited occupant and building performance evaluation.	No evidence found.	No evidence found.
3. Potential for risk introduced as a result of repair & maintenance.	No evidence found.	No evidence found.

Permanent Volumetric Modular Construction (PVMC) is an approach to construction where modules are built off-site, transported to site and assembled together to create permanent buildings. To support HSE BSR in fulfilling its duty to keep under review the safety and standards of all buildings in England, evidence on the in-occupation safety of buildings constructed using PVMC is required. It is important to understand the nature of potential building safety issues in PVMC, their likelihood of occurrence and their consequences. This report describes an initial review of evidence linked to the building safety of PVMC. Through conducting a literature review, data search and a stakeholder focus group a number of incidents are reported to have occurred in PVMC. No data has been found that can give a reliable representation of the scale of the PVMC market or the likelihood and consequences of potential building safety risks. The evidence to date does not support any conclusions about the relative safety of PVMC versus other construction methods. The results from this report are to inform the HSE BSR and the construction industry of the available evidence. This report also offers a range of potential additional work that could be undertaken, to further evidence any possible building safety risks in relation to PVMC.

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