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A literature review of the evolution of British prefabricated low-rise housing

Daniel O'Neill

Samantha Organ

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Purpose
This paper explores academic papers and reports and presents a chronology of the evolution of British low-rise prefabricated housing. The paper provides chronological information for construction and surveying researchers undertaking research in associated areas.

Design/methodology/approach
This is a qualitative literature review, providing an exploration and analysis of academic papers and reports on low-rise prefabricated housing.

Findings
A substantial literature was discovered. However, there are gaps in the available literature. The history of British construction technology is a rich research area but is under-researched.

Prefabricated housing has a long history dating back to the 11th Century. Stigmatised from the failures of housing in the 20th Century, it is being increasingly used again in the 21st Century when considering mass housing supply.

Research limitations/implications
This paper provides researchers with an overview of the history of low-rise prefabricated housing in the Britain. It is not a comprehensive in-depth study; such would require numerous larger individual studies.

Originality/value
From reviewing literature it was evident that there was a broad literature, but there was no single journal publication exploring the evolution of British low-rise prefabricated housing.

The research provides an overview, exploration and analysis of the literature while providing a chronology. The evolution of prefabricated housing is chronologically presented. Areas for further research are also recommended.

Keywords
Prefabricated housing, Construction technology, Literature review, Chronology, Evolution.

Paper type
Literature review

Introduction

The purpose of this paper is to provide a chronology of the evolution of low-rise housing. In doing so a chronology of information is developed. This is done through a review of the literature. The review will be in a chronological order with the use of time periods. The literature explored is then analysed. The periods were chosen based

on the literature available and the significance of the time periods. Due to more literature being available in the twentieth century due to records and research, there are larger sections from 1918 onwards.

The following sections are presented in an order to help the reader understand the topic. In the following section, the construction history literature is overviewed and construction history as a field is discussed. This is followed by an explanation of the literature review methodology. The literature review is divided into the following sections: The Origins of Prefabricated Housing (1200s to 1600); Prefabricated housing between 1624 and 1800; Progression of prefabricated housing between 1800 and 1918; Prefabricated housing between 1918 and 1945; Prefabricated housing from post-WW2 to 1959; Prefabricated housing in the 1960s, '70s and '80s; Prefabricated housing from the 1990s to the Present. 'Prefabricated housing – Going Forward' looks at the possibilities for prefabricated housing in the future.

The discussion analyses the findings of the review and chronology, this is followed by conclusions including recommendations for research.

Construction History

Overall, there is much in the existing literature on prefabricated housing, with recent centuries being more heavily researched. From the review of the literature, prefabricated housing is thought to have originated with cruck frame, and was aided by the Norman Conquest in 1066. Prefabricated housing was significantly aided by innovation, the Industrial Revolution and war; specifically, with the push of the technological innovation during the Industrial Revolution and the pull of demand for housing during and following both World Wars. There have been problems with delivering large-scale building programmes, and the word 'prefabrication' has gained stigma. In the near future, the demand for housing and requirement for efficiency and sustainability could be the next development in prefabrication under its new identity: Modern Methods of Construction (MMC).

Construction History is a movement as opposed to a discipline (Meyer and Hassler, 2009), and in Britain it depends on individual researchers, a number of history focused research organisations, and the knowledge of professional bodies (Addis,

2004). This form of research can focus on a variety of building elements across broad geographical and time spans. It can focus on technology, procedures, theories and process of constructing, the contexts, the structures, and conditions of production associated with a building; all identified of central importance (Meyer and Hassler, 2009). These aspects must be acknowledged in exploring the evolution of British prefabricated low-rise housing. Construction History research is more substantial now than in previous decades. The improvements in the past decade compared with earlier decades can be identified by comparing Picon (2005-6) and Dunkeld (1987). However, Holt (2015) still identifies it as under-researched.

In historical research, it is not possible to collect all data, information and knowledge from the past. Thus, there is a limitation to what can be achieved when looking back in the hope of exploring the evolution of construction, a view supported by Yilmaz (2006). This paper explores the evolution of British prefabricated low-rise housing; primarily with the use of academic and technical literature.

Defining and Categorising Prefabrication

Prefabrication has been understood and interpreted in different ways. In the years following the Second World War (WW2) there was an issue regarding the definition of prefabrication - was it a house which could be delivered in pieces and assembled, or did it need to be built entirely in a factory. Piroozfar and Farr (2013) provide insight into the different concepts, terms and definitions attributed to non-traditional methods of construction. They discuss mass production, industrialisation, industrialised building systems, modularisation, prefabrication, off-site manufacturing as individual concepts (*ibid.*). However, regardless of classifications, systemised buildings or industrialised building systems can be traced back to timber frame. The essence of off-site construction is best represented by prefabrication. Building has always been associated with prefabrication (*ibid.*), with prefabricated components being incorporated into traditional construction (Hayes, 1999). Piroozfar and Farr (2013) conclude that the concepts should be known and understood in a holistic manner. For this research, drawing lines between the concepts, or pigeonholing and categorising based on concepts is unpractical and fuzzy, and will not be done.

Methodology

In using literature review methodology for this research, the problems of historical research must be understood. The use of history to use the 'past to predict the future' and to use the 'present to explain the past' makes history unique. Historical research is unique and useful for study. Historical research involves the personality of the researcher more than other types of research (Cohen, *et al.*, 2007). This was understood prior to undertaking research. The problems of historical research are:

- Defining the problem too broadly;
- The tendency to use easy-to-find data;
- Inadequate criticism;
- Poor logical analysis;
- Expression of personal bias; and
- Poor reporting.

(*ibid*.)

After defining the purpose, the methodological process identified in four steps:

1. Search for literature,

An extensive search for literature was undertaken of journals and conferences' publications. The literature reviewed encompassed journal papers, conference papers, technical reports, survey reports, books, and educational literature. This peer-reviewed literature was aided by grey literature. The reviewed literature consisted of documents which had documentary research and analysis methodology. The sources of literature are evident in the references.

Due to the technical nature of the research topic 'grey literature' was required, and this is referenced throughout. Aina (2000: 179) defines grey literature as follows: "*Grey literature is that which is produced at all levels by government, academia, business and industries, both in print and electronic formats but which is not controlled by commercial publishing interests and where publishing is not the primary activity of the organisation*". Grey literature has significance for research, policy and decision-making (Aina, 2000). Luzi (2000) describes the difficulty of retrieval of grey literature, which was once a distinctive feature is being minimised. This has significantly changed since the publication of Luzi (2000), with increased internet use and online publishing. In this research, grey literature is considered that literature which has not been subjected to peer-review by experts.

2. Explore and evaluate the relevance of the literature

There is a broad literature on prefabricated low-rise housing, and any literature which was relevant was included. All documents were written by professional writers. The academic papers are well researched and presented, but there is no metric. The Grey literature supplements the gaps in the academic literature.

3. Analyse the literature

Bowen (2009) details the advantages and limitations of documentary analysis. The authors acknowledge the advantages:

- The method is efficient;
- Many documents are easy to retain;
- The method is cost efficient;
- The review has a lack of obtrusiveness and reactivity

  Documents cited are stable, with the exception of in-house educational material, which may change; and
- There is the advantage of exactness when dealing with documents

  The literature reviewed contains documents which cover long spans of time, and many locations.

The authors encountered difficulty, and acknowledge the flaws of documentary analysis:

- Many documents are insufficient in detail, and this paper relies on other sources to cover the detail;
- There are many publications which could not be accessed due to limits in time and cost. However, many of the documents reviewed were easy to attain; and
- The authors attempted to limit bias in selecting literature. The relevant literature comes from a broad range of sources.

Documentary research is useful in longitudinal analysis, as it can show how situations evolved over time. This is significant for this literature review on the evolution of prefabricated housing. However, caution must be exercised as documents are only an interpretation of actual events (Cohen, et al., 2007). The authenticity and accuracy of the texts were critically assessed before selecting them for this research. The

intentions of the texts' authors were considered. All the documents referenced were written by skilled professional writers of different disciplines.

4. Organise and present the literature.

With acknowledgement of Bowen (2009), the researchers strived to make the literature review analytical and transparent. The periods for analysis were chosen due to the significant changes and developments in prefabrication.

The following time periods and headings were chosen due to the milestones within and the significance of the periods for prefabricated housing, and a timeline produced (Figure 1) based on the findings from the existing literature. They could be rearranged to present a different categorisation of the literature. These were inductively inferred from the literature. A review of the literature will be presented before a discussion is presented and the paper is concluded. In Holt's (2015) recent paper, good scholarship using Construction History is provided through expertly synthesised literature. What follows is an exploration and analysis of literature. A neat 'historical overview' could not be accurately undertaken for this review, as there are overlapping and reoccurring themes. What is presented is a chronological format, and not a systematic, thematic or traditional literature review format.

[Insert Figure 1 here]

The Origins of Prefabricated Housing (1200s to1600)

Ågren and Wing (2014) identify moments in the history of industrialised building, describing modular building and prefabrication, but the origin of prefabricated housing in Britain is not discussed. The University of the West of England (UWE) (2014), in a brief and encompassing overview, describes the changes in architecture and building for housing between the Georgian period and the post-war era. However, from this, it might be considered prefabricated housing developed in post-industrialised Britain, or more specifically after WW2. British prefabrication is much older than this, and can be traced back to the colonisation of North America, and even further to cruck frame construction.

Using timber for prefabricated housing

A period of significant development of timber frame was between 1200AD and 1700AD (Sheridan, 2007), and notably the setting out and building of structures off-site in the 1200s. As highlighted by Marshall *et al.* (2014), England and Wales have been using indigenous timber for thousands of years to provide the main source of structural building materials. Specialist books dealing with off-site prefabricated timber buildings date to the 12th century (Gibb, 1999). Gibb (1999: 8) suggests that it was the 12th century which saw a breakthrough in the use of industrial methods for construction, whereas prior to this, such methods only evolved sporadically and at times were 'totally disregarded'. Piroozfar and Farr (2013) describe how Hewett (1980) identifies the use of off-site fabrication in timber buildings in the 12th century. Timber was the first material used in making prefabricated housing in other countries due to its availability, requirement of limited technology and lifting equipment. The early use of cruck frame in Britain, Germany and the Netherlands is referred to in Salavessa (2012).

According to Hill (2005) it is accepted that crucks have existed since the time of the Norman Conquest in 1066; the cruck design was possibly imported from central Europe and was established in 1200. Salavessa (2012) highlights the Normans' building skills, and use of wood technology developed from naval carpentry. The early dating of crucks has relied heavily on documentary evidence. Hill (2005) questions the origins of crucks, questioning the evidence that crucks developed in the 1100s, and if crucks developed from 'base crucks'. Base crucks were another structural form, similar to cruck frame. Alcock (2006) responded to Hill (2005), describing how the evidence of both study buildings and documents are consistent with crucks having origins in the 12th century, probably the early part of the century, and with base crucks originating about 1200. Hill and Alcock (2007) further explore the origins of crucks with each giving conclusions. Hill says a level of agnosticism would be appropriate for now, however Alcock disagrees and states the origins must be sought in the 12th century. In describing early European timber-framed buildings Salavessa (2012) identifies the 1st century AD as being the period that cruck frame originated in Britain, Germany and the Netherlands. However, there might be a semantic or classification difference in this publication.

Hill (2005) describes how the castle building programme in Wales in the late 13th century could have influenced the decimation of knowledge and skills among the congregations of craft workers and the spread of the method of cruck construction. There is some similarity here with the ideas for house fabrication coming from war-time manufacturing for the British army; spin-offs of sorts. Crude timber frames/crucks were used to build cottages in the 14th century (Piroozfar and Farr, 2013) and Alcock (2013) shows illustrations of crucks from the 1400s. Hill and Alcock's papers give intriguing and expert views on the origins and evolution of crucks.

Prefabricated housing between 1624 and 1800

Over the centuries, Britain has exported and imported materials and components for housing. The earliest evidence of exporting British prefabricated housing was in 1624 and is described in Smith (2009) where the British made housing and shipped it to North America. Smith (2009) describes how later in the late 1700s and early 1800s prefabricated dwellings were made and shipped to Australia. These were timber frame structures, with either timber panel infill or lighter timber infill system or canvas, with weather boarding. A variety of building types were constructed.

Progression of prefabricated housing between 1800 and 1918

Improvements in transportation, brought by the Industrial Revolution (circa 1760 – 1840), aided the movement of standardised, prefabricated materials. The Industrial Revolution had a significant impact on construction, and this is evident it the development of prefabrication. With industrialisation, brick was the first material to be standardised (Piroozfar and Farr, 2013). The innovation of the Industrial Revolution had a significant effect on house construction. Building Research Establishment (BRE) (2004) notes the use of cast-iron houses for shipment to the colonies. In 1820 prefabricated housing was shipped to South Africa. These were basic cottage structures, requiring work to be assembled on site and were not as predetermined as modern fabricated housing (Smith, 2009).

Manning Portable Colonial Cottage

The 'Manning Portable Colonial Cottage' was made in Britain and shipped to the colonies in the 1800s (Smith, 2009). The Cottage system comprised of predetermined

components which could be assembled by unskilled labour, with the use of a wrench, and was an improvement on previous systems. The individual components were easy to carry. The Cottage focused on standardisation of components, and fast erection - factors which become associated with prefabrication. The development of corrugated iron sheeting in the early 1800s was utilised in prefabricated buildings; it was economical, provided good spanning on frames, and several layers could be easily stacked and transported (*ibid*.).

Use of Corrugated iron sheeting in prefabricated housing

Thomson (2006) presents the history of prefabricated corrugated iron buildings in rural Scotland. Thomson and Banfill (2005) describe how the process of applying corrugated plates to buildings was patented in 1829. However, the patent text implies that the process was just an improvement of an existing method. The process of galvanising the sheets with a layer of zinc was later patented in Paris in 1837. In 1843 the sheeting was used on a roof in the London Borough of Southwark In 1844, a method for passing sheets between grooved rollers to make corrugations was developed (*ibid.*). Corrugated iron would have a significant use in prefabricated housing. In 1851, Morewood and Rogers' catalogue showed a variety of prefabricated buildings, including cottages. In 1849 and 1851 prefabricated buildings were exported to California and Australia to serve people involved in gold rushes. There were a number of large firms set up in the latter half of the 1800s to develop corrugated iron buildings. Catalogues showing a variety of buildings were often provided by the firms. Cooper's catalogue includes specifications for foundations, floor construction and ventilation (Thomson and Banfill, 2005). From the aforementioned text, we know of the construction of corrugated iron buildings in the Scottish Highlands and Islands; the following sentences give some details. Wall linings frequently consisted of tongued and grooved boarding, while the floors were finished with timber boards. The corrugated sheets were fixed to timber purlins or bolted to iron. Due to the absence of traditional wet trades, the buildings were erected fast. Corrugated iron housing was used in a variety of locations throughout the world, including Australia, South Africa, America and Scotland (*ibid*.).

Corrugated iron is a familiar material in rural Scotland (Thomson, 2006). Thomson and Banfill (2005) describe how corrugated housing was used in the Scottish

Highlands and Islands as it was easy to transport, easy to fix, required fewer roof timbers, and could quickly be erected and made weather-tight. In such an environment it is obvious that constructability was a core objective. Thomson and Banfill (2005) describe the prefabricated buildings as an industrialised product which either filled a market gap or competed with local materials for building. As of 2003, a number of these dwellings being still in use (*ibid.*).

Prefabricated housing between 1918 and 1945

There has always been an evolution of house construction methods. Most construction methods have been 'branded' new at some time. However, before the 1900s, the rate of change was comparatively slow. In previous centuries, there was time for methods to be evaluated, but the demand from 1918 onwards did not allow time for rigorous evaluation of the quality of homes (BRE, 2004).

Technology plays a big role in architecture, and its innovation. Piroozfar and Farr (2013) acknowledge the influence of technology in the twentieth century. Both World Wars had a significant affect on prefabrication in Britain. Hashemi (2013) states system building negatively affected the socio-economic conditions. Hashemi (2013) describes how industrialisation was criticised by society for valuing quantity over quality. The author is focused on "*industrial building and main drivers behind the fundamental shift from traditional to prefabricated methods of construction*" and gives a good description of the background and aftermath effects of system building (Hashemi, 2013: 48).

Some of the inter-war years prefabricated housing proposals would be surprising by modern standards, and this is briefly discussed in BRE (2004). The 1920s systems comprised of two categories: the first utilised steel, timber, and large component precast concrete; the second comprised of small scale on-site precast and in-situ concrete systems. The former is wholly significant to this paper while the latter is partially significant. The first category used the knowledge and skills of factory and shipyard production while the second used the skills of unskilled and semi-skilled construction labour (BRE, 2004). In the 1920s, Scotland was introducing similar methods as used in English cities: concrete, steel and timber systems (Stationary Office, 1988).

The BRE has produced a large amount of technical literature on prefabricated housing in Britain. BRE's (2004) publication 'Non-traditional houses: Identifying non-traditional houses in the UK 1918 - 75', included information on metal framed housing, precast concrete housing, and timber framed housing. This text is the most comprehensive technical document on non-traditional methods reviewed. The BRE (2004) cites many BRE publications and gives recommendations for further reading. The text gives a comprehensive list of house types, beyond the scope of this paper.

Importing prefabricated housing and new technology

After the First World War (WW1) there was a shortage of traditional building materials (BRE, 2004). In the 1920s manufacturing capacity, specifically pre-casting technology, was taken advantage of to provide housing. With time, hundreds of house types would be built using precast components (Concrete Society, 2008). System-built timber frame houses were introduced in the 1920s. Between 1920 and 1944, approximately 2,000 timber frame dwellings were constructed, using six main systems, and these are described in the BRE (2005). According to the BRE (2005) the systems with timber stud frame external walls were built between 1927 and 1941. Britain, having exported housing to the colonies, imported prefabricated housing in the 1920s to meet demand, with 700 houses with components from Sweden being erected in London (*ibid*.). Pepper and Yeomans (2006) identify the introduction of 'flat pack' Scandinavian timber frames to meet the housing demand in the post-WW1 years. In 1945, Swedish housing was imported in sections to English and Scottish designs. According to Mcintyre and Stevens (1995) approximately 4,500 of these timber dwellings were erected between 1945 and 1951. Swedish timber housing evidently remains in Scotland and was identified as an example for retrofit for the Scottish Housing Quality Standard (Energy Saving Trust, 2008). Importing from Scandinavia was not new. Scotland has imported timber from Scandinavia from as early as the fourteenth century (Newland, 2011). Stationary Office (1987) provides details of prefabricated houses built in Scotland, including the USA Temporary Bungalow which was imported from America, and proved to be a poor temporary system. Nash *et al.* (1954), reporting on fire safety concerns of the system, describe there being 8,000 USA Temporary Bungalows in the UK. In discussing the 'USA Bungalow for the Temporary Housing Programme', Vale (2003) states the British

programme contracted 30,000 dwellings, but only 8,462 were sent (this contradicts Nash *et al*. 1954), with samples being brought and erected in 1945. Timber housing had been imported from America previously. Vale (2003) describes the importing of prefabricated timber dwellings from America, as part of WW1 emergency measures, to provide housing for Austin Motor Company workers. Vale (2003) also describes the erection of two hundred imported dwellings in 1917, giving a brief description of the construction. McIntyre and Stevens (1995) describe Canadian Timber dwellings which were imported in the late 1940s. These are just some examples of imported systems to meet war-time demand.

Timber frame construction was favoured for its manufacturing qualities and for its design flexibility. Among its advantages over other systems, timber frame was fast to erect and required lighter foundations. The introduction of plywood aided the development of timber-framed housing in the 1930s (Hashemi, 2013). Cities such as Manchester, Bristol and Liverpool were leaders in using prefabricated methods before WW1. Come the 1930s prefabricated cost efficient timber bungalows, clad in sheeting materials were generally accepted by the public (BRE, 2004). The developments in war-time technology, such as the development of resin-bonded plywood had a significant impact. Manufacturing technology was imported to help in the production of housing. The portable temporary bungalow required steel panel presses to be ordered from the USA (*ibid.*).

Steel housing in Scotland

Stationary Office (1988) states 2,500 steel houses were erected in Scotland. Stationary Office (1988) lists the major house types erected between 1923 and 1955: The Atholl, Cowieson, and Weir; these were popular steel houses used between 1926 and 1928. Weir Steel should not be confused with Weir Timber housing.1927 was the first time since WW1 that the number of house completions passed 20,000 units; 1,100 of these units were steel houses. Temporary housing was a big consideration for local authority housing programmes. The temporary systems selected were chosen for their ease of erection. Cost and constructability were the main criteria. The main systems allocated by Government to local authorities in Scotland were Aluminium, Arcon, Miller, Pheonix, Seco, and Tarran. Between 1945 and 1949, 32, 176 temporary units

were built in Scotland, and temporary housing built in this period was popular with tenants (*ibid*).

Producing systems to meet demand

Gay (1987) identifies the prefabrication programme as a poor solution to the housing problem of the 1940s. Preparation began early, but post-WW2 housing was poorly planned. In the 1940s bricks and timber were in short supply. Gay (1987) suggests that the approach to delivering housing was unstructured during this time, with neither a drive to reorganise the building industry to supply a limited number of prefabricated housing components, or the development of the industry to provide housing by traditional methods with skilled labour. Instead individual companies produced many different systems. Gay (1987) identifies the capitalist/individuality of the industry being a fault, whereas a more unified, national, government-driven approach would have delivered better results.

Post-war housing would be in low supply if dependent on traditional methods, so non-traditional methods of construction were turned to as an alternative.

Gay (1987) outlines four factors which brought about the prefabrication programme:

- Introduction of enthusiasts for prefabrication into the administration;
- Pressure of industrial interests, as industry was worried about work shortage after the war years;
- Collective administrative memory, as non-traditional methods were used after WW1; and
- Emergence of the Ministry of Works which supported prefabrication.

The lifespan of temporary housing

Temporary housing was forecast to last up to ten years; with concerns that this period would be prolonged. The concern was justified as Gay (1987) reports on housing being in use three decades after construction. Prefabrication suited Churchill's philosophy of 'action this day', but was not suited to the delivery of long-term housing. There was an issue with the lifespan of some housing systems. According to the BRE (2004), one timber frame system did not last the '10 year design life' of a

temporary unit. The housing programmes of the War years developed many systems, with varying levels of technological advancement. According to the Stationary Office (1988), in Scotland, the 10 year period was well exceeded in most cases, and built with poorer technology than exists today, many house types have stood the test of time.

Traditional and prefabricated methods

The brick industry collapsed after WW1; this was not allowed to happen after WW2 (Gay, 1987). Traditional construction was employed during the war years in parallel with prefabrication. With prefabrication considered a temporary solution – traditional building and prefabrication were conflicting policies (*ibid.*). This affected the development of prefabricated housing.

From Hayes (2000) it is evident Churchill was a supporter of prefabrication and other non-traditional methods of construction during the interwar period. Churchill was a supporter of 1920s steel housing and was interested in technology (Gay, 1987). The interwar years brought a scientific approach to design and construction with the prefabrication and mass production of houses. There was optimism about ingenuity and technology in the delivery of prefab housing. During and after WW2 innovators were attached to construction to provide housing. Technology and science were focused for to reduce labour, time and cost. All alternatives to traditional brickwork and the greater 'wet trades' were considered. However, some wet trade focused systems (e.g. No Fines) were used. Limited research on unfamiliar methods was a problem. Some methods were more cost and time efficient than others. Comparisons were often made between prefabricated and traditional building. There was scepticism about prefabricated systems before and after WW2. Subsequent research has identified the practical limits of prefabrication as a source of construction efficiency. The search for new systems of house construction inspired greater interest for research on building methods during this period (Hayes, 1999).

Prefabrication was considered by some as being able to address housing shortages (Hayes, 2000). In Leicester, for example, there was a view that prefabricated concrete systems could solve the housing crisis. This view of prefabrication being able to elevate the shortages of housing was one shared with other countries. Further, there

existed the view that prefabricated housing would provide shelter for the poor, and that the homeless would not be concerned with the type of materials from which these homes were constructed (*ibid.*). Cities had individual plans in adopting non-traditional housing; it would be generalising to say all of England adopted the same approach (*ibid*.). Considering the number of methods, it is not reasonable to generalise all prefabrication methods or the greater non-traditional methods as the same. This is occasionally done anecdotally.

Demand for housing due to WW2

With the beginning of WW2, it was assumed thousands of housing units would be needed for families after the bombing (BRE, 2004). During WW2, many local authorities were working on prefabricated systems. Providing housing was a challenge in the post-war years. Although Hayes (2000) suggests that the public response to prefabrication was not unfavourable, the early post-war years did not inspire public confidence in non-traditional methods. Indeed, Piroozfar and Farr, (2013) identify the disapproval associated with prefabrication in the UK. This is down to the problems with post-war housing, and the broader cultural view of prefabrication, something which has been identified as different comparative to other countries. Hayes (1999) shows that there was government propaganda, with associations of housing methods with technical inventiveness and 'military operation', and that equating non-traditional housing with modernity and efficiency is false. Industry professionals aligned non-traditional methods with progress and modernity.

Hayes (1999) and Piroozfar and Farr (2013) suggest that the poor opinion of prefabricated housing in Britain in relation to other cultures can be attributed to a conflict between 'traditional architecture' and prefabricated production, as seen in Scotland. It is evident that there was a conflict of interest in architects' opinions of prefabrication, partially, due to the fear of it leading to the requirement of fewer architects due to greater standardisation and generic design.

Local authorities had influence over the reconstruction in the post-war years. Adoption of systems was influenced regionally, with enthusiasts in different regions (Hayes, 1999). The 1940s saw architects leading non-traditional house design. At this

time BISF (British Iron and Steel Federation) housing became prominent (BRE, 2004). The selection of the best prefabricated housing systems was undertaken through the construction of prototypes and then reducing these by selecting the best for wider-scale use. The most widely produced non-traditional house in the 1940s was BISF, designed by Gibberd, 36,546 were supplied (Hayes, 1999).

The complexity of prefabricated housing

Both McKean (1995) and Piroozfar and Farr (2013) describe a conflict between aesthetics/architecture and manufacturing/production. Hashemi (2013) also describes the aesthetic issues, particularly associated with cladding prefabricated systems. In Scotland, McKean (1995) describes how prefabrication was preferred in the post-war years, but how this interfered with a more national form of architecture.

BRE (2004) identifies how dramatic interventions in the course of history rarely have the expected effect. The development of housing from 1918 to 1945 is multi-layered and should not be judged simply in reflection but in the context in which it was situated. The considerable demand, limited time, lack of resources and Britain's war involvement must be considered.

Prefabricated housing from post-WW2 to 1959

Phases of increased use of prefabrication have typically followed "*periods of economic uncertainty, profound demographic change and technological advances*" (McGrath and Horton, 2011: 245), such as the period following WW2. There were a substantial number of technological innovations particularly evolving in prefabricated housing after WW2. Technological innovations are described by Smith (2009) as a reflection of sociocultural innovation. Prefabricated housing after WW2 was influenced by multiple factors. Domestic construction was generally limited through controls on both building materials and taxes on site development (English Heritage, 2011).

Accommodation, material and skills shortages

A significant shortage of accommodation during (English Heritage, 2011) and after WW2 (BRE, 2002) resulted in an extensive market demand for housing. This contributed to the adoption of the mass production philosophy (Piroozfar and Farr,

2013). There was a political drive for structural economic change, and the efficiency of industry was perceived as the method of providing this (Hayes, 1999). Churchill announced that prefabricated housing would be delivered and erected using 'exceptional methods' in a military-like operation (Hayes, 1999). Aware of the positive propaganda of delivering homes to returning soldiers (Gay, 1987), he promised over half a million prefabricated houses in 1944 (English Heritage, 2011), but just 156,623 single-storey prefabricated houses in eleven standard government designs were actually constructed in 1944 (English Heritage, 2011). Four types of prefabricated bungalows with a design life of ten to fifteen years included Arcon (38,859 units), Uni-Seco (28,999 units), Tarran (19,041 units) and Aluminium (54,000 units) (Hashemi, 2013). Many of these lasted beyond their original design lives (*ibid.*). The Government also set objectives for the provision of separate dwellings for any families wanting one, in addition to recommencing the slum clearance which started prior to WW2 (BRE, 2002). Demand for housing was high.

The shortage of materials and skilled labour had some effect on the uptake of non-traditional housing (English Heritage, 2011; Hayes, 1999). Not all materials were in limited supply – although softwood timber was in limited supply (English Heritage, 2011) further exacerbated by restrictions placed on timber imports by the government in an attempt to improve national economy, there was a surplus of steel and aluminium (BRE, 2002). Material shortages were apparent during the period immediately following the war when timber was often dimensionally smaller than that used prior to WW2 (McIntyre and Stevens, 1995). These shortages were considered to be less of a problem than shortages in skilled labour (BRE, 2002; McIntyre and Stevens, 1995). The skilled labour needed for traditional construction was to be supplemented by the labour and capacity of the industrial sector, which had excess capacity following the end of WW2 (BRE, 2002). The 'excess capacity' of industry facilitated the development of prefabricated systems. Development was also driven by the popularity of the flexibility a number of these systems could offer the occupants in relation to the layout for current and future needs (Schneider and Till, 2007). There were also shortages of mechanical plant during and after WW2, which resulted in the need for 'rigorous planning' and an allocation system (Hayes, 1999: 286), and therefore, systems minimising the need for or reliance on such plant were beneficial.

Temporary and long-term solutions

Prefabrication, particularly during WW2, has been suggested as being based on short-term thinking and administrative failure in parallel with political drive, high visibility and due to the need for a solution in the context of limited resources (Hayes, 1999). Although some systems were designed to provide a temporary solution, most were originally designed to provide long-term housing (BRE, 2002). Solutions were based on scientific research, which was more weighted against traditional construction methods (Hayes, 1999). Profit, self-promotion and fashion within architecture also had an influence on the use of prefabricated housing, whereas local authorities were granted little autonomy in relation to local housing policy (Hayes, 1999).

Support and resistance for prefabrication

There was resistance amongst the site staff immediately after WW2 (Hayes, 1999), which in parallel with specialist plant shortages resulted in the reduced uptake of prefabricated systems and methods (Hayes, 1999). Post-WW2 domestic construction was also influenced by the availability of large sheets of plate glass and of central heating (English Heritage, 2011). Other innovations included the use of separate claddings such as brick; and 'volumetric' systems - where whole accommodation units were prefabricated in a factory before being assembled on site (McIntyre and Stevens, 1995). New construction was also affected by the absence of live-in servants (English Heritage, 2011); new houses did not require space to accommodate servants. A significant increase in prefabricated housing systems was seen immediately after WW2, which included timber framed housing, a significant proportion of which were imported (BRE, 2001; McIntyre and Stevens, 1995).

Non-traditional housing was heavily subsidised by the Government until 1947 (Hayes, 1999). After this, it often failed to compete economically with traditional forms of construction (*ibid.*). By 1947, those who assessed and approved system building, known as the BURT Committee, disbanded, but had recommended over 100 non-traditional systems for development (*ibid.*). BURT had favoured prefabricated systems using concrete and steel materials in the face of timber shortages, but by the mid-1950s such shortages were less significant (UWE, 2014), with the controls over timber were lifted in 1953 (BRE, 2001).

Public reaction to these non-traditional systems in the 1940s was not unfavourable (Hayes, 1999). The initial and continued popularity of the temporary bungalow Hayes (1999) attributes to the modern conveniences it provided; its visible cottage style; and its private outdoor space. Such systems were also promoted by the media, particularly in the architectural press (*ibid.*). Policy makers have also been reported as viewing traditional construction methods as unfavourable because they were considered 'crude' and 'dirty' (Hayes, 1999). Despite this, many local authorities found the aesthetics of modernist, non-traditional housing unacceptable, thus brick clad or rendered systems were often favoured (*ibid*.). However, these early post-WW2 systems mostly contained a limited level of thermal insulation in the walls (McIntyre and Stevens, 1995) and some local authorities encouraged local councillors to vote against non-traditional systems for their poor thermal and sound performance, and due to condensation issues (Hayes, 1999). Despite this, local authorities had limited autonomy regarding housing strategies, and those permitting the construction of non-traditional systems in their jurisdiction could be granted bonus allocations in the 1950s from the government, justified on the basis of labour savings (*ibid.*). These systems could also be promoted by deferring planning applications for traditional housing construction (*ibid.*).

By the 1950s, the visibly modernist systems of the 1940s had fallen from favour (Hayes, 1999), instead, there was a reverence for materials and the use of 'natural' architecture, the use of large windows and a mixture of materials (English Heritage, 2011). By the 1950s, the most widely manufactured non-traditional system in the 1940s – the BISF house, had been designated by government officials as 'uglier' than traditional housing (Hayes, 1999). Scepticism regarding non-traditional construction methods was visible at all levels of the built environment and the public (*ibid.*). The construction of non-traditional housing was blighted by site delays, the inability to stay within expected costs, an inability to estimate realistic on-site man-hours, and poor finishing contributed to a poor image of this form of construction (*ibid.*). The Government, however, continued to promote non-traditional construction (*ibid.).* In parallel with the redevelopment of the city centres, there was also a drive towards high-rise construction from the mid-1950s onwards (BRE, 2002). However, although with much enthusiasm and confidence from the promoters of industrialised housing systems, a large proportion of the public remained suspicious of these systems. These

suspicions were heightened after the collapse of the large panel system, Ronan Point in 1968, resulting in changes to the structural legislation, such as regulations relating to the mechanical connections between prefabricated structural components (Peason and Delatte, 2005). Although a high rise example, Ronan Point was one example of prefabricated construction dramatic failures fostering mistrust and suspicion amongst the public in prefabricated construction more generally. Although prefabrication was successfully used during the 1950s and 1960s for a variety of building types, it has been acknowledged as catalysing social issues and resulting in structural issues in the residential sector (Piroozfar and Farr, 2013). Similarly, the reputation of off-site technology was damaged by the need to demolish the CASPAR II development in Leeds in 2007 (McGrath and Horton, 2011) as a result of structural issues.

Prefabricated housing in the 1960s, '70s and '80s

During the 1940s, '50s and '60s there was a shift towards industrialised buildings within the construction industry (BRE, 2002). Modernization and non-traditional methods founded on the philosophies of Bauhaus, an art and design school founded in Weimar in 1919 by Walter Gropius (1883 – 1969) (Dominiczak, 2012; Periton, 1996), contributed to a 'factory manufacturing methodology', particularly in social housing (Hayes, 1999). The modern movement has been suggested as making 'headway' for manufactured buildings, which were perceived as synonymous with 'progress' and 'modernity' (Hayes, 1999). From the 1960s and throughout the '70s, volumetric construction was used, employing prefabricated construction in the form of frames (timber or steel) or concrete 'boxes' (BRE, 2002).

A number of volumetric construction systems were used into the late 1970s and early '80s (BRE, 2002). Systems such as crosswall construction fell out of favour by the mid-1960s as this form of construction, which uses masonry for the gable and party walls and a timber infill panels, was slower to erect in comparison with 'pure' timber frames (UWE, 2014). This was further catalysed by the introduction of the Building Regulations in 1965 in the UK, which resulted in the replacement of local bye-laws which had restricted the use of timber for party walls and cladding. Timber framed construction was used particularly by local authorities from 1965 due to the comparative ease of construction, the flexibility this form of construction afforded, and the popularity amongst occupants for the functionality of the properties

(Keyworth, 1984). O'Neill *et al.* (2015) reports the use of British systems and expertise in Ireland in the 1960s.

Modern timber frames

During the 1970s and '80s, timber-framed systems such as modern platform frames came to dominate making up a third of the market (BRE, 2002). Private housing developers typically had not previously adopted system build technology but started adopting timber frame construction in the latter half of the 1970s as a result of the financial constraints ensuing from high interest rates and the problems associated with this (Keyworth, 1984). Timber frames were broadly identical aesthetically to traditional construction and were therefore more accepted by speculative developers (Hashemi, 2013) and the public. Additionally, in comparison with traditional construction, they were quicker to erect, enabled cost savings on elements such as foundations due to being a lighter form of construction, were cheaper, had a lower U-values, and required fewer on-site man-hours (Hashemi, 2013), all significant benefits in the context of 17% interest rates. Adverse media coverage through an episode of World in Action in 1983 resulted in a downward turn in its use in England and Wales, although BRE research has since been unable to evidence the assertions of the media (BRE, 2002) that there were concerns regarding the water tightness and robustness of such systems (Lovell (2007) and was even discussed in the House of Commons (Hansard, 1983). In contrast, in Scotland, timber-frame construction remained a significant proportion of new housing starts at around 40% (Cavill, 1999).

Prefabricated housing from the 1990s to the Present

Resistance and suspicion from the public relating to innovations in the construction industry, where housing deviates from a traditional appearance has been attributable to the negative associations with post-WW2 prefabricated housing (Edge *et al*., 2003). These negative attitudes were based broadly on the quality of the building materials and the poor workmanship of this form of construction (Parliamentary Office of Science and Technology, 2003) during the post-WW2 period. However, prefabrication became a key aspect encouraged by the Government as a result of the Latham Report in 1994 and the Egan Report in 1998 (McGrath and Horton, 2011), and again after the publication of the Barker Review in 2003. The Barker Review resulted in the Government encouraging Modern Methods of Construction (MMC) to

help produce the quantity of quality housing needed in the UK (Pan *et al.*, 2008; Parliamentary Office of Science and Technology, 2003), with the introduction of policy promoting this form of construction in 2004 (Lovell and Smith, 2012).

The term 'MMC' is described in the literature as referring to a range of construction methods (Marshall *et al.*, 2011; Kempton and Syms, 2009). It is a term that incorporates a range of off- and on-site construction methods (Danby and Painting, 2007), which was first applied in the UK (Steinhart *et al.*, 2013). Although it refers to construction methods different from traditional construction (e.g. brick/block walls) (Kempton and Syms, 2009), it has also been referred to as non-traditional, modular construction, off-site manufacture, and prefabricated construction (*ibid.*). In the UK the phrase 'MMC' is used in preference to 'prefabricated' systems to avoid the stigma attached to the latter term (Steinhart *et al.*, 2013; Lovell and Smith, 2010), the UK Government promoting the term 'MMC', stressing the high quality and durability of these systems (Lovell, 2007). In this paper, the term MMCs refers to off-site MMCs. The intention of the industry using the term MMC was in order to reflect the technical improvements of prefabrication, and to incorporate both on and off-site construction methods (Parliamentary Office of Science and Technology, 2003).

The adoption of MMCs or modular housing amongst housebuilders has been recognisably slow (Rahman, 2014; Pan *et al.*, 2008), although it is predicted to increase in light of the pressures on the industry "*to improve quality, time, cost, productivity, and health and safety*" (Pan *et al.*, 2008: 56). The additional drivers for the development of MMCs included "*political, economic, social, technological and environmental factors*" (Pan *et al.*, 2008: 57). MMCs are thought to be capable of achieving higher building standards, and thereby deliver higher building performance (Piroozfar *et al.*, 2012). It has been considered to have the capability to provide affordable, efficient construction (Lovell and Smith, 2012). The improvement in performance comparative to traditional masonry construction, however, is difficult to evaluate (Piroozfar *et al.*, 2012). Further, there is some debate over whether MMCs provide the 'environmentally friendly' construction methods (Piroozfar *et al.*, 2012) necessary in the face of the current drive for low carbon housing.

One of the main advocates of MMCs has been the Government (Pan *et al.*, 2008). However, government influence has been more effective in social housing than the private housing stock, with no direct incentives for those constructing private housing to adopt MMCs via planning and building regulations (*ibid.*). Some of the larger private house builders have, however, invested in MMC factories, thereby increasing production (*ibid.*). Holden (2008) suggests that the only apparent 'drawbacks' of such technology is perception alone, which is suggested by Kempton and Syms (2009) as grounded in cultural differences with 'other countries' seemingly more accepting of MMC construction in the residential sector. Indeed, Rahman (2014) highlight that MMCs have been used on a wider scale in Germany and Scandinavia, and in Japan, 40% of its new housing are constructed using MMCs. Although this perception barrier is also identified elsewhere in the literature (e.g. Kempton and Syms, 2009; Pan *et al.*, 2008), the literature highlights a number of additional barriers to MMCs. This includes higher capital cost and the difficulties in achieving economies of scale (Azman *et al.,* 2012; Pan *et al.*, 2008), perceived performance, investment agenda, and customer expectations (see Kempton and Syms, 2009 for a summary of these barriers). Overall, industry professionals' experiences of non-traditional construction have "*made them feel negative towards MMCs*", extending to design, maintenance, and impact of tenants on the longevity of MMCs (Kempton and Syms, 2009, p.42). Rahman (2014) also identify barriers such as cost-related issues, skill and experience, motivation and culture, design standards, market demand, industry-related issues, flexibility, and project-specific issues such as on-site space limitations.

As highlighted by Lovell and Smith (2010), although there has been much debate about whether prefabricated housing costs more or less than traditional forms of construction, increasing evidence suggests that prefabrication costs around 10% more than traditional construction initially. Gibb (2001) suggests that, when considering prefabricated components, units are often perceived as more expensive if accounting for factory set-up and overhead costs. However, where the number of units being produced increases, the unit cost decreases significantly (*ibid.*). Where assessing costs based on a lifecycle assessment of two case study properties, Monahan and Powell (2011) suggest that, MMC properties can deliver a 34% reduction in carbon emissions over traditional construction methods.

Prefabricated housing – Going Forward

Prefabrication in the form of 'MMCs' has already been applied to achieve high energy efficient performance in new housing (Ross, 2005). Advantages of MMC construction have been identified as improved quality; increased thermal performance and energy efficiency; improved acoustic, thermal and energy efficiency performance; and a reduction in post-construction snagging and defects (Kempton and Syms, 2009). In addition to this, a reduction in waste, defects, time, costs, health and safety risks, environmental impact alongside improvements in profits, predictability and life performance have been emphasised by Rahman (2014). However, improvements in life performance have been indicated by Kempton and Syms (2009) as a potential issue in social housing in relation to the longevity of the product and resultant impact on the tenants.

In international research, Linner and Bock (2012) describe Europe as being behind Japan in the industrialisation of prefabricated housing. British prefabricated housing has a significant gap to close if it is to reach the production capacity and good reputation of Japanese prefabricated housing. It is also evident that Japanese prefabrication benefited from Lean production practices (*ibid*.); with lean being a central topic of the British construction industry in recent years with technical and academic publications, it is probable that lean and prefabrication will intertwine in future due to the nature of prefabrication, and the housing demand. As the development of technology such as three-dimensional printing continues, the application of this to construction has already started, from architectural models (Dimitrov *et al*., 2006) to larger components, and even structures (Buswell *et al*., 2007).

Prefabrication is not 'new'

It should be noted that prefabrication has been branded 'new' many times. According to Schneider and Till (2007) there was a belief which started in the 1930s and 1940s which continues to the present day that prefabrication and emerging technologies were capable of providing mass housing. Hashemi (2013) compares modern enthusiasm with prefabricated housing to that to the twentieth century and suggests history is repeating itself with supporters of prefabrication claiming the advantages;

which are similar to that of the past. The author also identifies the low public confidence due to the past mistakes, and in relation to the future planning of prefabricated housing, asks: what are the long-term quality and costs of developments?

Discussion

Prefabrication is often associated with timber. The use of timber to make prefabricated housing in the 12th century is interesting, and the work of researchers to identify the origins and classifications of crucks is research that will continue. There is a broad existing academic literature here.

In the literature reviewed there was little found covering the period between 1624 and 1800. However, the export of prefabricated units is interesting and would be an interesting area of academic research in Construction History.

The progression of prefabricated housing between 1800 and 1918 was interesting. With technology and the development of systems, we get closer to the standardised and industrialised prefabrication we see today. The use of corrugated iron is well documented.

The academic and grey literature, documenting the evolution of prefabricated housing between the World Wars is substantial. The BRE has significant literature on this. The importing of housing and technology was interesting in this period. The demand for housing is well charted. It was in this period that failures to deliver housing led to protest against social housing, and ultimately stigmatisation. There were also objections to the aesthetic of such housing. This is a significant topic for research, more for Architectural History than Construction History. The topic of traditional versus prefabricated housing is a topic talked about today. Considering the vagueness of 'traditional', given what was reviewed, the meaning of what is regarded traditional is a topic for further discussion. The lifespan of the 'temporary housing' should also not be simply categorised as poor construction.

There were significant innovations in delivering houses, regardless of other factors. Overall, the delivery of housing between wars is well documented by the BRE, other organisations, and academics. It is this period that shows the complexity of the topic.

Delivering housing after WW2 was difficult, and this is documented. Prefabricated housing was deemed inferior to 'traditional' and the aesthetics of prefabricated housing were criticised. Scepticism of non-traditional housing grew and is still influencing thinking.

From the 1960s onwards prefabrication became more industrialised, and volumetric systems were used. The British had significant experience in prefabricated housing at

this stage and British systems were used in Ireland. The literature here is in-depth, and housing built in this period is now the topic of housing retrofit reports. It is over this period, the authors feel, the definition of prefabricated housing, with other words such as 'modular' and 'volumetric' become interchanged. This will be a topic of debate similar to that of 'traditional' and 'non-traditional'.

Modern Methods of Construction is not a wholly new method to deliver housing. As before, with the war-time demand, these methods will be used to deliver affordable housing. With housing delivery a prime topic in the construction industry, there will be significant indigenous academic research and industry reports produced. There has been a significant body of literature produced covering such methods.

Prefabricated housing is viewed differently internationally. It can be deemed efficient and high-quality, but in Britain, there is still a stigma from past failures.

Going forward it is expected, based on past literature, old arguments will continue to arise: cost and quality of 'traditional' versus that of 'non-traditional', 'traditional' versus 'prefabricated, volumetric, modular'.

Overall there is a broad literature on Construction History topics due to journals, conferences and the work of organisations. From this literature review the level of scholarship generally high. There is a substantial broad literature on the construction technology of housing in Britain. The topic of the evolution of house construction technology is a niche area of Construction History research. This paper was done partly to help other researchers get an overview of the academic and grey literature covering prefabricated housing.

Conclusion

This paper has explored the existing literature relating to prefabricated construction methods in low-rise housing.There is a significant body of academic and technical literature on British prefabricated low-rise housing. There has been significant development of these methods since the 12th century, particularly during the Industrial Revolution and the 20th century, with further development in the form of MMCs in the 21st century. This was influenced by technological advancement, transportation developments, political drive, housing demand, and the availability of labour and materials. The heavy focus on prefabricated methods in the 19th, 20th and 21st centuries is partially attributable to it being recent, the volume of existing housing in stock and the availability of recorded information. A lot of this stock is now the subject of retrofit.

Changes have occurred with exporting and importing of systems - prefabricated systems were initially exported from the 17th century from Britan to North America and to the British colonies, and then imported to Britain from Scandinavia and Canada in the 20th century. This perhaps demonstrates the ease of transportation of such systems, and the potentially wide range of prefabricated construction types across the UK incorporating materials such as timber, concrete and steel.

The popularity of such systems, so popular in places such as continental Europe and Japan, is thought to be influenced by culture, and perhaps indicates the need for a cultural shift in the UK. There have been phases of public and/or professional scepticism of non-traditional housing in the UK. This was particularly seen during the 1950s and 1960s. Due to exceptionally high interest rates in the 1970s, prefabricated timber-framed construction offered advantages such as faster erection over traditional construction. However, negative media coverage in the 1980s on apparent failures or defects in timber-framed systems adversely affected the uptake of this method of construction in England and Wales, but not in Scotland where timber-framed construction remained the methods of a significant proportion of new housing starts.

Prefabricated systems have seen phases of a political drive: from Churchill in the 1920s and post-WW2, the Latham and Egan reports in the 1990s, to the Baker review in the 2000s. These systems have been seen as a method of efficiently delivering the large quantities of housing demanded in the UK. In the 2000s ‘prefabrication’, alongside other forms of non-traditional construction, was rebranded as MMCs to avoid the stigma attached to the term ‘prefabrication’.

Many of the academic and technical papers have different focuses, and suffer literature ‘blind spots’. The BRE publications are based on scientific criteria rather than subjective aesthetic preferences and do not consider the view of occupiers or architectural critics. Neither has the cost and difficulties of retrofitting been considered in this literature. However, such systems have been found to perform as well as traditional construction, with some exceptions. Recognising these ‘blind spots’ is not to criticise the papers or their authors, it is an analysis of the literature. Comparing this present research to that by Hashemi (2013) who undertook similar research, Hashemi (2013) cites a broad literature. However, this was not focused

specifically on low-rise prefabricated housing. Hashemi (2013) concluded with significant questions regarding quality and cost considerations for future developments. This present paper explored the literature covering the evolution of prefabricated low-rise housing – which covers a broad timespan, providing a chronology and exploration of the literature on the evolution of prefabricated low-rise housing.

This paper fulfils its purpose. This provides a resource to researchers who wish to explore the evolution of prefabricated housing. It should be noted that there are books on specific time periods and longitudinal analysis. Further detailed research could be undertaken by identifying and analysing a specific time period or event.

Recommendations for further research

Construction History is under-researched, as stated in Holt (2015). It is evident that the history and evolution of construction technology are subsequently under-researched. There are many research topics that could be chosen from this paper and the literature referenced. Prefabrication has a long history in Britain, and it was charted in detail in the 1900s. There is ambiguity in its origins, and this will possibly be researched further in the future. There are many time periods which could be selected and explored. However, the history of importing and exporting housing from the 1600s to 1900s requires further study. This is an area recommended for further research. Prior to research, the early exporting of housing to the colonies was unknown to the authors who have significant knowledge of housing. It might also be unknown to other researchers.

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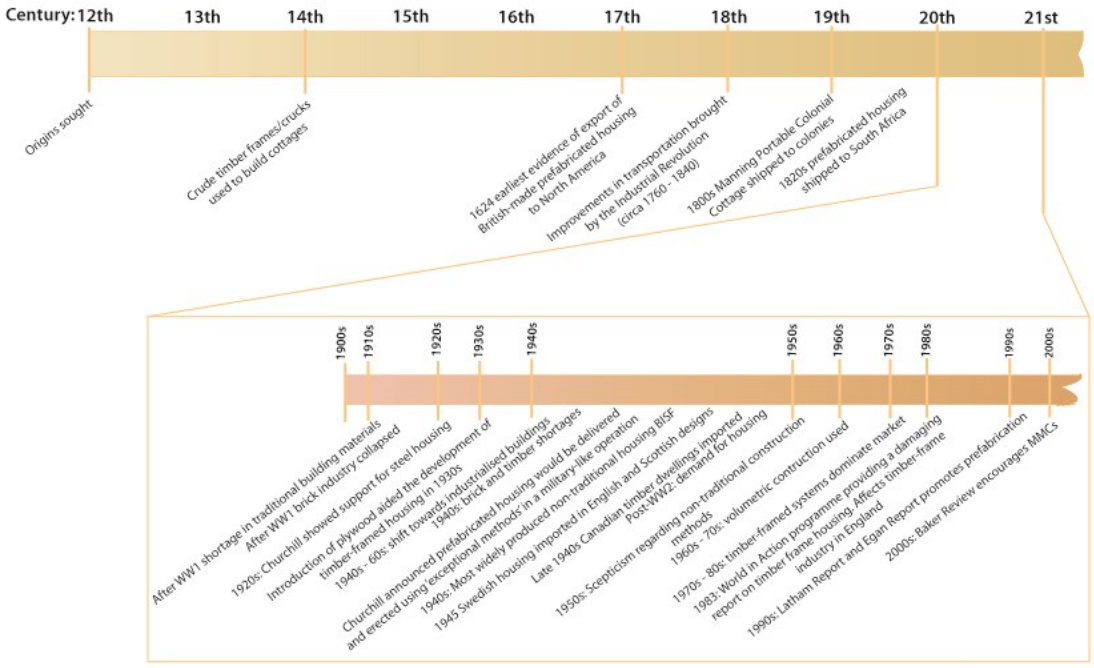

Figure 1: Timeline overview of low-rise housing based on reviewed literature