PART I

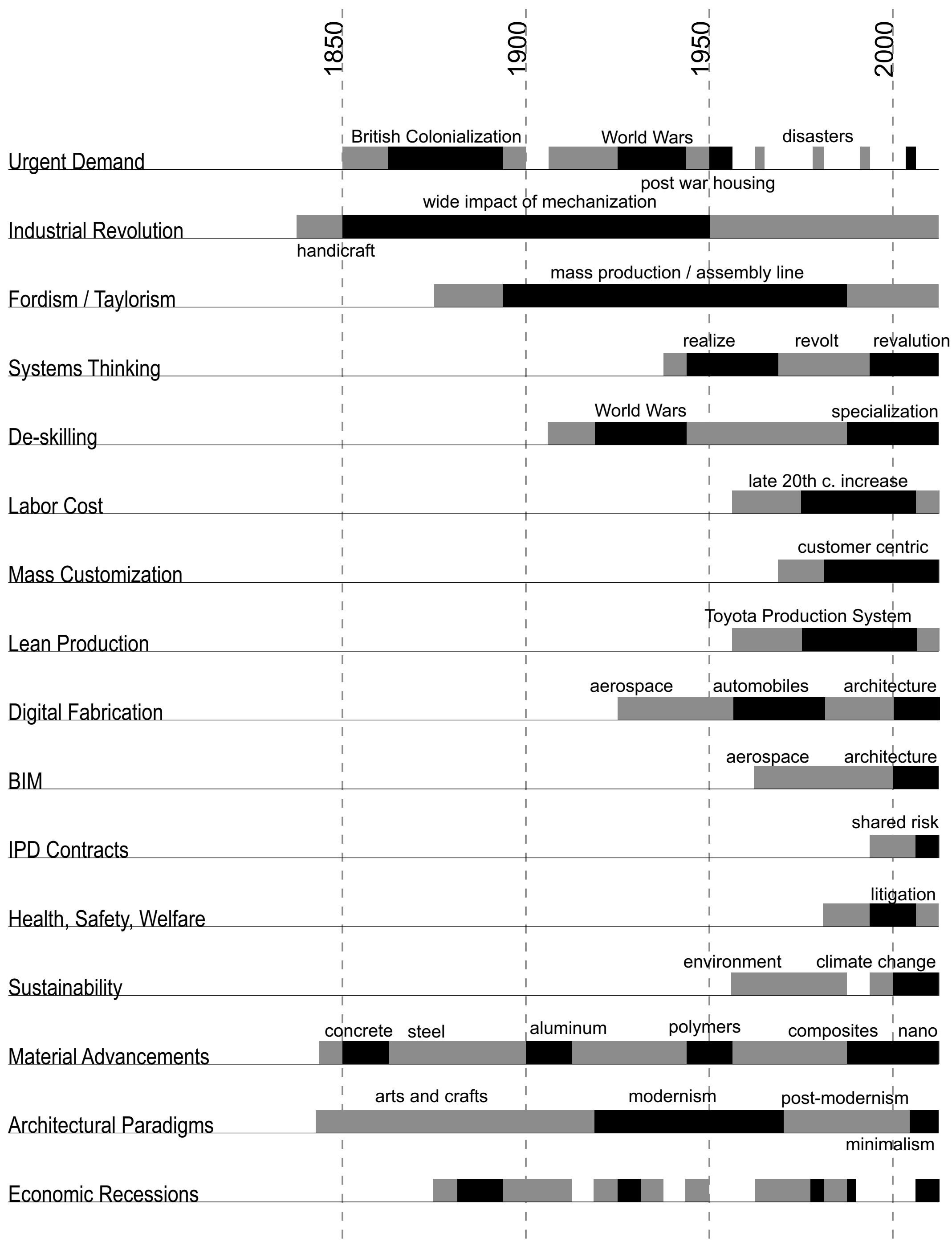
CONTEXT

chapter 1 History of Industrialized Building

"Three things you can depend on in architecture. Every new generation will rediscover the virtues of prefabs. Every new generation will rediscover the idea of stacking people up high. And every new generation will rediscover the virtues of subsidized housing to make cities more affordable. Combine all three—a holy trinity of architectural and social ideals."[1]

—Hugh Pearman

Prefabrication architecture is a tale of necessity and desires. Individuals and communities have constructed shelter from the beginning as a matter of function. In order to build in remote locations, deliver buildings more quickly, or to build in mass quantity, society has used prefabrication, taking the construction activities that traditionally occur on a site to a factory where frames, modules, or panels are fabricated. Barry Bergdoll, curator of the Museum of Modern Art 2008 "Home Delivery," an exhibition that tracked developments in prefabricated housing, differentiates prefab from prefab architecture. He states that *prefab* is a "long economic history of the building industry that can be traced back to antiquity" including the methods employed to build ancient temples and timber structures. Conversely, the history of *prefab architecture* is "a core theme of modernist architectural discourse and experiment, born from the union of architecture and industry."[2] The relationship between need and desire in studying prefabrication is argued as follows: If industrial-manufacturing processes can produce other products and goods for society, then why can't the same process be harnessed to produce higher quality and more affordable architecture?


1850
1900
1950
2000
Urgent Demand
British Colonialization
World Wars
disasters
post war housing
Industrial Revolution
wide impact of mechanization
handicraft
Fordism / Taylorism
mass production / assembly line
Systems Thinking
realize
revolt
revalution
De-skilling
World Wars
specialization
Labor Cost
late 20th c. increase
Mass Customization
customer centric
Lean Production
Toyota Production System
Digital Fabrication
aerospace
automobiles
architecture
BIM
aerospace
architecture
IPD Contracts
shared risk
Health, Safety, Welfare
litigation
Sustainability
environment
climate change
Material Advancements
concrete
steel
aluminum
polymers
composites
nano
Architectural Paradigms
arts and crafts
modernism
post-modernism
minimalism
Economic Recessions

Although not to the extent of other industries, prefabrication has already been realized in many buildings; but can architecture, a discipline rooted in image, exploit the principles of offsite fabrication to make itself more relevant? Can prefabrication be a tool by which architecture can have an impact on all areas of the built environment including and most importantly housing? How might the quality of both design and production concurrently be increased? These are questions that the early and late modernists—Le Corbusier, Gropius, Mies van der Rohe, Wright—as well as design engineers—Fuller and Prouve—have asked. These are the questions architects today including KieranTimberlake, SHoP, Michelle Kaufmann, and others are asking. In order to answer these questions, we will step back and evaluate the historical linkages between industrial manufacturing processes and the production of architecture to understand the context by which we find architecture today and to uncover the lessons learned from previous attempts in prefab architecture.

This chapter reviews the developments in industrialized building that shape our understanding of prefabrication in architecture and building. Chapter 2 will evaluate the relationship between the history of the architectural profession and prefabrication, uncovering the failures and successes. It will end with a summary of lessons learned from failed prefab experiments that may be applied to reassessing the future of prefab architecture in the twenty-first century. The techniques developed in other industries have been transferred to the construction sector to provide more appropriate production solutions to creating shelter. In addition to technology transfer, many societal and cultural factors have affected the development of prefab architecture.

◀Figure 1.1 This table illustrates the historical influences on the development of prefabrication. The value on the influence bar indicates the relative impact. White:—little to no impact; Gray—impact; Black—large impact. Note that many of the influences occur in the latter part of the 20th century with the large majority from 1960 onward.

1.1 British Contributions

The history of prefabrication in the West begins with Great Britain's global colonization effort. In the sixteenth and seventeenth centuries, settlements in today's India, the Middle East, Africa, Australia, New Zealand, Canada, and the United States required a rapid building initiative. Since the British were not familiar with many of the materials in abundance in these countries, components were manufactured in England and shipped by boat to the various locations worldwide. The earliest of such cases recorded was in 1624, when houses were prepared in England and sent to the fishing village of Cape Anne in what is now a city in Massachusetts.[3] The late 1700s and early 1800s was a time of Australian settlement by England. It is reported that the earliest settlement in New South Wales was home to a prefabricated hospital, storehouses, and cottages that were shipped to Sydney arriving in 1790. These simple shelters were timber framed and had timber panel roofs, floors, and walls. Speculation also suggests that infill material could have been canvas or a lighter timber frame infill system with weatherboarding. A similar system is reported to have been unloaded and erected a couple of years later in Freetown, Sierra Leone, to build a church, shops, and several other building types.[4]

English colonial building extended to South Africa. In 1820 the British sent a relief mission of settlers to South Africa, Eastern Cape Providence, accompanied by three-room wooden cottages. Gilbert Herbert writes that the structures were simple and shed-like, with precut timber frames, clad either with weatherboarding, trimmed and fixed on the site, or with board-and-batten siding. Door and window sashes were probably prepared as complete components.[5] These structures were not as extensively prefabricated as our contemporary understanding of offsite fabrication; however, they represent a significant reduction in labor and time compared to onsite methods that preceded. The prefabricated shelters' timber frame and complex joints were structurally and precision dependent on offsite methods.

1.1.1 Manning Portable Cottage

H. John Manning, a London carpenter and builder, designed a comfortable, easily constructed cottage for his son who was immigrating to Australia in 1830. Later known as the Manning Portable Colonial Cottage for Emigrants, the house was an expert system of prefabricated timber frame and infill components. It is described by John Loudon in the *Encyclopedia of Cottage, Farm, and Villa Architecture and Furniture* as consisting of grooved posts, floor plates, and triangulated trusses. The panels of the cottage fit between the grooved posts, standardized and interchangeable.[6] The system was designed to be mobile, easily shipped for furthering the colonial agenda of the British. Manning stated that a single person could carry each individual piece that made up the shelter. The Manning Cottage was an improvement of the earlier frame and infill systems designed by the English in that it offered an ease of erection. The system was simply bolted together with a standard wrench, appealing to the abilities and availability of tools to the emigrants. Herbert writes, "the Manning system foreshadowed the essential concepts of prefabrication, the concepts of dimensional coordination and standardization."[7] Manning's system used the same dimensional logic with all posts, plates, and infill panels being carefully coordinated. It built upon the need for a quick erection system for emigrants but relied upon the British carpentry skills in shipbuilding.

The Portable Colonial Cottage made its way to many settlements by the British throughout the nineteenth century. Its impact on the British-settled

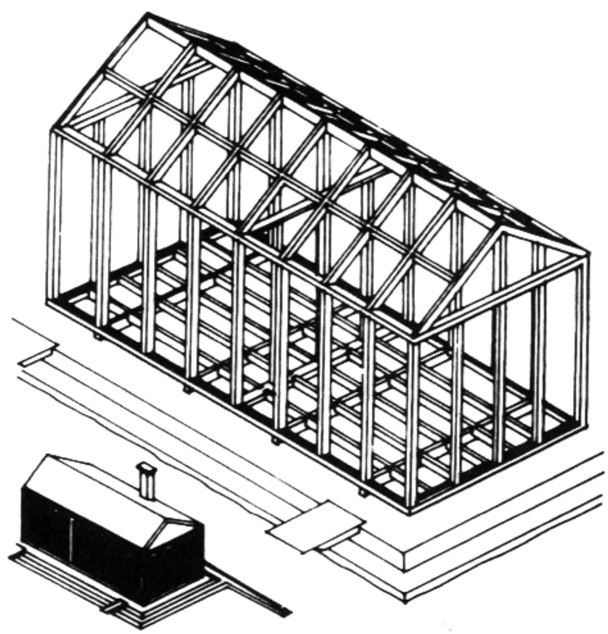


Figure 1.2 The Manning Portable Colonial Cottage for Emigrants was a timber and panel infill prefabricated system. Developed by Manning, this was a quickly deployable solution to the rapidly expanding British colonies in New Zealand and South Africa during the nineteenth century.

North America and the future U.S. construction industry is uncertain, however, it is assumed that the practices of timber architecture from Britain were the beginnings of the balloon frame in the United States. Augustine Taylor is often credited with the invention of the balloon frame in its implementation in construction of St. Mary's Church in 1833 in Fort Dearborn near Chicago. The light frame, including the platform frame and balloon frame, resulted from two primary factors: a plentiful supply of wood in the new country and a rapidly expanding industrial economy with mass-produced iron nails and lumber mills. In the span of one spring and summer, 150 houses were built. Buildings were erected so quickly that Chicago was almost entirely constructed of balloon frames before the fire of 1871. The infamy of the speed of balloon frame construction preceded the building of the entire West, mostly in light wood construction.[8]

1.1.2 Iron Prefab

Another contribution that came out of the British colonial movement was the employment of iron manufacturing for building construction. Components such as lintels, windows, columns, beams, and trusses were manufactured in a foundry and fabricated in a workshop.[9] The components were brought to the jobsite and assembled into structure and enclosure systems. Like its prefabricated timber-framed counterpart, iron construction was not as extensive as prefab today, but fathered the beginnings of the steel structural movement in the United States and elsewhere.

One of the first employments of iron construction in the United Kingdom was in bridge building. The Coalbrookdale Company Bridge in 1807 was almost entirely prefabricated and erected in pieces onsite. This was followed by a host of bridges in England that progressively streamlined the process of production and erection. Pieces were standardized, cast repeatedly, and shipped to the site to be erected by fewer laborers and unskilled laypersons garnering a saving in time and cost in comparison with the traditional construction of handcrafted wood or masonry. Some of the better-known bridges were on the Oxford Canal made at the Horseley Iron Works, at Tipton, Staffordshire. John Grantham reports that this foundry was also the first to produce an iron steamboat. The ships were constructed of heavy plates riveted together to form units. The ships could be assembled, disassembled, and reassembled. One of these manufacturer/fabricators was William Fairbairn, who in the mid-1800s built four "accommodation" boats, now known as cruise ships. This technology was transferred and Fairbairn later built a prefabricated iron plate building. In the mid-1800s English lighthouses and other building types were constructed using prefabricated iron plates and rivets.[10]

Cast iron construction, the precursor to contemporary structural steel construction, used mass-produced cast components that were envisioned as a kit-of-parts. By standardizing manufacturing, the economy of scale helped realize a savings in time and cost. The technology was primarily used as a frame and could be turned into any stylistic expression including Gothic or Baroque. In addition to the bridges, ships, lighthouses, and prosaic buildings, the single most extensive use of the material was in the standardized structure and infill enclosure of the Great Exhibition of 1851 in England, otherwise known as the Crystal Palace. The structure was largely a repetitive system of standardized components that when assembled created a massive skeleton. Joseph Paxton, the project's designer, had a background in green house design and claimed, "All the roofing and upright sashes would be made by machinery, and fitted together and glazed with great rapidity, most of them being finished previous to being brought to the place, so that little else would be required on the spot than to fit the finished materials together." [11]

The palace was certainly not the first in cast iron architecture, nor the last, but it linked the Manning Cottage precut timber frame with the new material of the day, cast iron. The large number of factory-produced components and the details of the Palace are quite astonishing considering the era in which it was realized. In addition, the Crystal Palace is important because it represents a shift in understanding among architects, that beauty may be as simple as the functional means of production. Paxton was more interested in the engineering, fabrication, and assembly process, than in traditional aesthetic references.

1.1.3 Corrugated Iron

The early 1800s also ushered in an additional innovation in metal: corrugated iron. Although prefabrication of frames was relatively well developed in the early part of the nineteenth century, panel and spanning material were underdeveloped. The Manning Cottage and iron trusses of prefab buildings used traditional canvas or wood planking as a means of roofing. Corrugated iron provided a quickly constructed, affordable, and structurally efficient material for roofs and walls. Corrosion obviously presented problems until 1837 when many companies began to hot-dip galvanize metals in order to protect them. Richard Walker, in 1832, noted the potential for corrugated iron for portable buildings intended for export. The corrugated sheet could be nested in multiple layers during transit and were cut into 3 ft × 2 ft panels that easily could be handled by one person, and fastened into place at the jobsite. Along with Manning's Portable Cottage, Walker's marketing and exportation of corrugated iron provided one of the first widely used prefabricated timber and iron building systems in the world.[12]

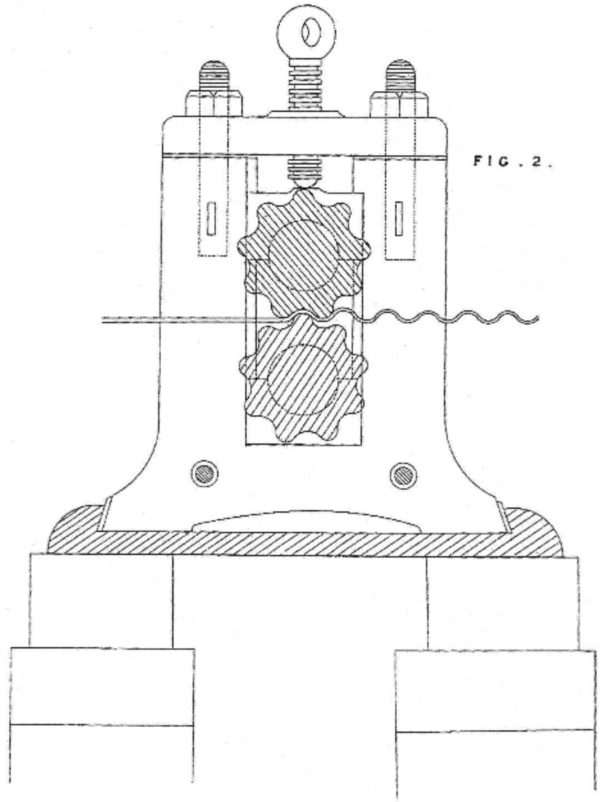


Figure 1.3 This image is of British Patent Number 10399 by John Spencer dated November 23, 1844. It is a corrugated iron rolling machine that became popular because of the wide availability of iron and hot-dip galvanizing in the 1830s.

Corrugated iron was employed in the Gold Rush of San Francisco in the mid-1800s. Because of the influx of people in search of new money, housing was in urgent demand. Entrepreneurs on the East Coast responded with using the latest iron technology from England and manufacturing simple shelters. Naylor from New York shipped more than 500 house kits made of corrugated iron during this time. Many of these homes were advertised in magazines and other publications so that patrons could order the shelter of their choice directly.[13] Corrugated iron in buildings did not end with the kit homes of the Gold Rush era. The use of the panel had a large impact on the proliferation of Quonset huts during World War II, and later in industrial buildings, storage facilities, and even rural churches. Considered archaic by contemporary construction standards, what is not generally understood is that corrugated iron has its roots in fulfilling a need in transportable, quickly erected architecture that was prefabricated and shipped to be erected elsewhere. Its use in urban and rural temporary structures has continued since its inception.

Figure 1.4 One of the most common applications for corrugated iron has been by the U.S. (Quonset hut) and British (Nissen hut) militaries during World War II.

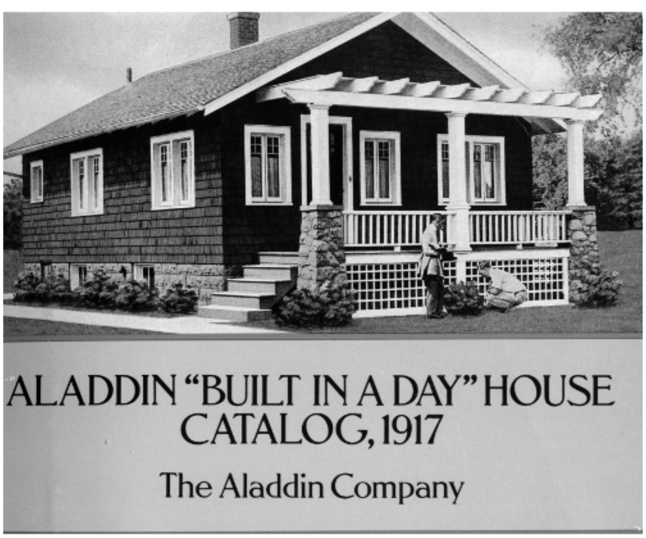
1.2 Mass Production and Kit Homes in the United States

Ordering kit homes from a catalog did not cease with the Gold Rush. At the turn of the twentieth century, amidst the rapidly increasing industrial revolution and the full adoption of balloon framing, kit homes from precut timber for light frame houses became common. Among them was Aladdin Homes, formed in 1906 by W.J. and O.E. Sovereign, brothers who believed that mass-production concepts could be used to produce mass housing. The Transcontinental Railroad, connecting the East and West coasts, was completed in 1869 and facilitated the proliferation of such companies. With the rapid expansion of the United States to the West, there was an urgent need for quick, affordable, and easily constructed housing. Aladdin homes followed the precedent of mail-order, knock-down boats that buyers could purchase and assemble themselves. Clothing had also become mass-produced with patrons ordering via mail service based on standardized sizes. The brothers believed that the housing industry could benefit from the same concept that had been used in these industries. Therefore, they marketed what they called the “Readi-Cut” system in which all the lumber necessary to build a complete home was precut in a factory and delivered. This process was to remove the waste associated with onsite framing, increase speed of manufacture, improve precision, and thereby allow purchasers to only need a hammer and time for erection. Although Aladdin was the first to pioneer the precut lumber systems of production for balloon-framed homes, Sears Roebuck and Co., with their marketing and financial power, were able to sustain prefabricated efforts through the 1930s.[14]

Sears Roebuck's success was in large part due to its ability to offer a variety of housing options and financing. Offering model-based housing, whether from a catalog or built model home village, remains the method that many homebuilders sell today, complete with onsite financing and upgrade options. Sears took Aladdin's ideas and created a strong business model backed by national retail capital and experience in mail order shipping. In the end, both Sears and Aladdin failed and pulled both their catalogs and production from operation. This failure is in large measure due to the Great Depression and housing crisis of the early 1920s and 1930s. As a mortgage broker as well as a product developer, it is reported that Sears lost over $5.6 million in unpaid mortgages during this time.[15] Sears and Aladdin did not claim to make advances in architectural design, rather, their contribution to prefabrication was in providing a more efficient ready-to-build system of components, a strong marketing strategy, affordability, and variety within a standardized product to the consumer. Although not explicitly working to impact the future of prefabrication in architecture, implicitly these frame systems hid their industrialized production under wood siding and roof shingles. Housing architecture in the United States during the early part of the twentieth century was marked by veneers and finishes that worked to hide the method by which production was assumed.[16]

1.3 Fordism

The advances in pre-cut light-frame systems were developments that took advantage of new processes and technologies for production. The advents of Henry Ford's Model T assembly line process provided lower cost yet higher quality automobiles. He



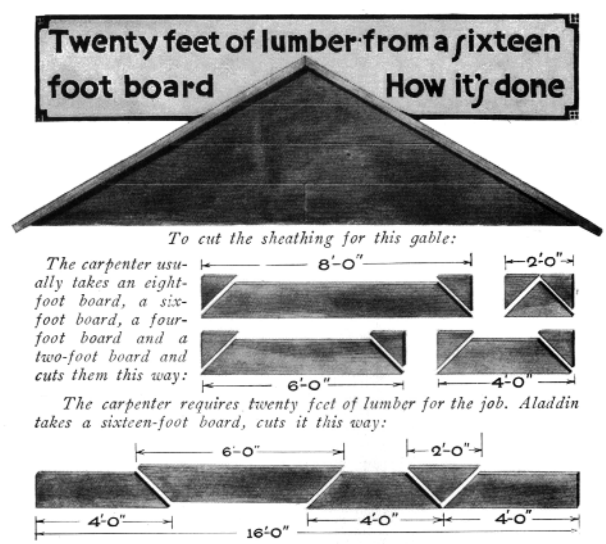


Figure 1.5 The Aladdin "Built In A Day" House, circa 1917, boasted lower cost per square foot of house in material due to its "Readi-Cut" system that maximized yield from standard lengths of lumber.

was able to provide a more precise product and also decrease labor and time per unit output. This process of standardization and assembly line production was transferred to the housing industry and, by 1910, a number of companies began to offer prefabricated houses in a variety of scales and quality.

The principles of standardization, mass production, interchangeability, and flow that pervade manufacturing can be traced to Ford. Standardization is the limitation to the variety in product produced so that machines may be able to output set lengths, widths, and assemblies. This removes the waste associated with variability options and the margin of error in end products. Mass production is a sister concept to standardization. It claims the economy of scale, that the more of something that is produced, the cheaper and higher quality it can become. Ford also invested heavily later in the production of automobiles in interchangeability. This concept refers to the ability for parts to be used on a number of different end products. A prime example of this is a 2 × 4 in the construction of houses. The houses might all be different, but all are built from this standardized, mass-produced part. Products such as threading for bolts became standardized in the Ford factory, making connections easier and faster. Flow is the assembly line concept where products are driven on a line at which laborers perform a limited number of tasks in the operation. This repetition of task reduces time.

The industrialized world understands these principles implicitly because it is in many ways the decree by which we operate as a society. These principles have become accepted as standards in and of themselves. They have been used by manufacturers of products in many industries, including the building industry. Stephen Batchelor states that the impact of Ford's principles of production on technology development is considerable:

> "but in the wider world it is seen as one of the key ideas of the twentieth century, which has fundamentally altered the texture of Western life. The arts—music, literature, theatre, painting, sculpture, architecture and design—have all been affected."[17]

There are problems with the acceptance of Fordism as a way of life. In addition to its effects on form in the arts, mass production is but one of many manufacturing strategies that can be conceived from today's technology. Therefore, as Sabel and Zeitlin argue, the production of products in the future, including prefabricated architecture, will be determined not by the technologies that have been developed by Ford and others under the mass-production paradigm, but by the social struggles of the day.[18] Just as social context was formed by the impacts of Ford's production theory, Ford's production theory is just as much a product of social desire. Consumerism is one of the social contexts in which mass production has thrived. But in recent years, the issues with the housing crisis, the constant thirst for the new, has placed the economy and its people in a terrible predicament. Although short-term desires have been met, long-term stability has not. The sustainability of this model is not everlasting in terms of both economics and environmental ethics. Mass production also presents problems with labor monotony, potentials of exploitation of the poor, and a lack of variety in the man-made landscape. More will be discussed on the perils of Fordist production and prefabrication later in the text. New paradigms are emerging that question this production method; however, suffice it to say that the impacts on the American social beliefs are long lasting.

1.4 Wartime Housing

Prefabrication in the United States was used to further the expansion westward in the late nineteenth and early twentieth centuries. Many advances in applying Fordist mass production to the development of kit houses were exploited. This time of innovation was the first major paradigm shift in the location of production of buildings from site to factory. As the great economy deflated, much of the production during the 1920s and 1930s also declined. This period was not marked by large mass-housing initiatives, marketing strategies, or even the successful business practices that marked the early twentieth-century movements. On the contrary, it displayed one-off prototypical experiment houses that tested Fordist mass production, using automobile and shipbuilding technology in building construction.

In 1932, Howard T. Fisher developed the General Houses Corporation to produce postwar housing. The product differed from the Sears and Aladdin types in that they did not aim to mimic aesthetics of the past or tradition, but were intended to reflect the manner in which they were developed, the means of prefabrication. Fisher's houses were centered on taking advantage of the Fordist mass production; his homes were to be assembled literally as an automobile. General Houses would implement building components from supply companies that were in the market place servicing other industries. Fisher's greatest technological achievement was in the development of a metal sandwich panel wall system that used similar technologies from the airplane industry developed during the war. He also had the support of industrialists General Electric, Pittsburgh Glass, and Pullman Car Co. His efforts, similar to the architects of the time, were to produce modern buildings, flat roofs, and do it in an industrial aesthetic. Fisher was extremely optimistic about the public's taste, and his marketing strategy to sell the most innovative and contemporary housing in convenience and aesthetic is attributed to his company's near demise. Ironically, years later the company was successful in producing traditional-style houses in nine states. Fisher's innovations provided a new chapter in prefab thinking—that a house can be factory bound and offsite assembled from components provided by different companies, much like an automobile of this time was produced.[19]

General Houses gave way to a number of similar companies looking to produce modern houses for the masses. Among them are notably the American Houses developed by McLaughlin, an architect, and Young, an industrialist. Their 1933 "Motohome" also had difficulty gaining success until McLaughlin retooled and developed more traditional wood precut homes. These houses were remarkably similar to Fisher's company in that they had flat roofs and used a metal sandwich panel system for exterior walls. While General Houses and American Houses developed an innovative panel system, the Pierce Foundation prefabricated a services core that housed kitchen, bathroom, and all plumbing fixtures. The core also held heating and air conditioning services. American Houses implemented the Pierce Foundation's service core in their prototype. The service core in the American Houses showing was one of the first identifiable modular examples in prefabrication building. This prefabricated service module mirrored Buckminster Fuller's Dymaxion House pod, which will be discussed in Chapter 2.[20]

Used in military applications in airplanes and ships and in the automobile industry, steel's aesthetic appeal for designers and builders alike was alluring. Builder George Fred Keck developed both the

"House of Tomorrow" and the "Crystal House" for the Chicago World's Fair in 1933. On display were a number of examples of steel used in housing. Keck's prototypes featured steel frame and glass infill walls. The House of Tomorrow comprised a 12-sided, 3-story structure that resembled an airplane hangar more than a house. Keck used prefabricated steel elements to develop the steel superstructure, enclosure panels, and railings. It is reported that 750,000 people visited this house during the first year of exhibition but not one buyer was secured. The Crystal House built upon the steel frame concept and could be erected in an impressive three days. It too was unsuccessful in market and sold for scrap to pay off Keck's bills.[21]

1.5 Postwar Housing

The advances in the postwar era are not identified by technique, but rather are marked by business improvements. As World War II was coming to a close, returning soldiers increased market demand for housing. In 1946, the U.S. federal government passed the Veteran Emergency Housing Act (VEHA), giving a mandate to produce 850,000 prefabricated houses in less than two years. This initiative sparked numerous efforts in postwar housing design, including architects Walter Gropius and Konrad Wachsmann's "Prepackaged House" proposal, which will be discussed in Chapter 2. Although this mandate did not reach its envisioned breath of impact and completion, it gave rise to a number of prefabrication housing companies over the course of a decade. Among these companies were Lustron Corporation, Levitt Town, and Eichler Homes.

In 1948, Lustron Corportion began producing all-steel houses in airplane factories left vacant after the war. The houses were traditional in form, simple, with modest gable roofs and porches, but innovative in that they were constructed of entirely prefabricated enamel steel on the exterior and interior. Carl Strandlund, an industrialist from the prewar years, took the concept of automobile process to housing even more literal than experiments in the 1930s with metal sandwich panel technology. The method and even material in this case were literally to be fashioned after automobile manufacturing. Just as a car, the house had contained too many pieces to be feasible in construction. The components did not always make sense in their sizes in relation to manufacturing standard sizes of sheet metal and therefore created unnecessary waste. In the end, the houses were too expensive for modest income buyers. After only 2,500 homes were built, the company closed in 1950. In addition to the method of production being problematic, Lustron homes were cold, both visually and in temperature. Employing little insulation, the metal house would heat up in the summer and freeze in the winter.[22] In a recent tour of a salvaged home at the MOMA exhibit in 2008, many patrons were over-

Figure 1.6 The 1948 Lustron House was an all-enameled steel building system that used the automobile metal sandwich panel technology. This Lustron home still stands in Madison, Wisconsin.

heard remarking about the impersonal machine-like quality of the house.

William Levitt took advantage of the VEHA. Instead of producing homes in the factory, Levitt systematized the onsite process. Using principles of assembly line production and adding a separation of construction planning and execution borrowed from Taylorism, Levitt organized crews to maximize production efficiencies and material use.[23] A developer by trade, Levitt produced entire subdivisions of housing, and in 1945 he developed Levittown in Pennsylvania. The homes were unremarkable, very similar, and were the plausible foreshadowing model of cookie cutter developments in the United States.

In California, Joseph Eichler similarly developed a systematized method for onsite construction by developing entire communities of housing. However, having grown up in a Frank Lloyd Wright house and being a lover of the arts, Eichler was appalled at the lack of variety and aesthetic appeal in Levitt's product. Eichler, therefore, hired architects on the West Coast to design courtyard and exterior-interior relational plans that employed post-and-beam design and large expanses of glass. These homes were designed and built on a rigid grid, and featured standardized mechanical and plumbing systems that allowed for variety within a set system. Eichler was not only interested in style being influenced by California modernists, but was a socialist, wanting to open modern architectural design to the middle class of housing. In comparison to Lustron, Levitt, and many others already discussed, Eichler's mission was somewhat successful, building developments in Sunnyvale, Palo Alto, and San Rafael.

Eichler began in the mid-1940s and, by 1955, had become so efficient at delivering modern homes that, despite the marginal increase in cost of material of an exposed post-and-beam structure, could sell a house at a comparable price with the same amenities as conventional housing. The impact of these homes on prefabrication technique is next to none; however, in studying what prefabrication promises—increased quality and reduced cost—it was influential. At the end of the day the reason these homes succeeded and continue to succeed from one owner to another is attributed not only to their aesthetic appeal and unparalleled location, but to the commitment, attention to detail, design, and quality that Joe Eichler himself was willing to offer to the process.[24]

Figure 1.7 Systematized onsite building construction was developed in the mid-twentieth century and continues today as the pervasive method of residential construction. This house in Utah is modeled after mid-century Eichler houses. There are neighborhoods throughout the western United States that are built within the principles of courtyards, large expanses of glass set within a post-and-beam structure.

The postwar housing program in the United Kingdom mirrored the United States. Nissen huts, the UK equivalent of the U.S. Quonset hut, provided much-needed shelter during and after the war. Models including Arcon, Uni-Seco, Tarran, and Aluminum

Temporary, or AIROH, were temporary bungalows under an organized government initiative to supply housing for the war-stricken country. The United Kingdom used innovative technologies of the time, including steel framing and asbestos cement cladding, timber framing, precast concrete, and aluminum. The homes were not overly stylized, and employed prefabricated kitchen and bathroom systems. It was at this time that many of the wartime and postwar prefabrication housing companies in the United States provided and influenced housing in the United Kingdom during their rebuilding efforts. In particular, the Tennessee Valley Authority project for the Roosevelt Dam in 1944 employed prefabricated temporary shelter for workers on the dam. This technology was used in the United Kingdom. for its recovery efforts, learning from the Americans' methods as well as receiving actual houses that were produced in the United States and were shipped across the Atlantic for rebuilding efforts. The difference in the UK programs when compared to prefab initiatives in the United States, is that the houses were intended to be temporary, focusing on speed rather than quality.[25] In addition to the TVA temporary housing program, an additional temporary housing initiative began mid-century in the United States, known as the mobile home industry.

1.6 Mobile and Manufactured Housing

In 1954, the mobile home industry expanded with the need for affordable rapidly constructed housing. Similar to the UK temporary housing programs, mobile homes were completely built as a module on a chassis in a factory and then trucked to site. Mobile homes kept their wheels, making them capable of transport, but in most cases were never moved. By 1968, mobiles accounted for a quarter of all single-family housing in the United States.[26]

Recreation vehicles such as the Airstream gained popularity in the 1920s and 1930s and during World War II. This housing type was affordable and transient, an ideal model for those struggling to find work in different regions. These trailers were used as temporary housing for migrant and emigrant workers during WWII, thus furthering its widespread use. After the war, many companies that began as recreational mobile trailer manufacturers shifted into producing permanent mobile housing. As this temporary housing type slowly became a more accepted means of permanent housing, it eventually became larger and more sophisticated in its methods of production and marketing.

A major shift in the transition from mobile to permanent housing was the move from an 8-foot-wide to a 10-foot-wide trailer, allowing for more comfortable living. This shift had not only technical adaptations, but also social implications being accepted widely. The

Figure 1.8 A late 1970s single-wide mobile house with flanking porches near Salt Lake City, Utah, built to HUD code.

10-foot-wide was no longer a trailer, but a house, intended to be transported to the site and remain. This change continued to progress as 12-foot-wide and even 14-foot-wide mobile homes were manufactured in 1969. In 1976, large mobiles called "double-wides" were introduced. Each module was pulled to site and set in place making a 28-foot-wide home. In 1976, the code changed, distinguishing permanent homes as being those designed to the standard code (i.e., IBC) and mobiles to the HUD code. Today, the HUD code homes have changed their name from mobile to manufactured housing. Sometimes confused for manufactured housing, modular homes are built to IBC code, are without a chassis, and are set onsite permanently.[27]

In the United States, architects and society generally deem the mobile home as insignificant. This is due to its lack of design variety and construction quality. Mobile dwellings have been the victims of hurricanes and tornadoes, becoming a talking point for construction professionals, many of whom would like to see manufactured housing fall forever. But the mobile home meets the basic needs of shelter, and at a cost the majority of citizens can afford. Despite society and architects' loathing of this building type, it is estimated that the manufactured home industry accounts for 4 percent of the market share for new single-family housing in the United States.[28] Per square foot it is the cheapest option available for new homeowners bar none. It has succeeded because it is *not* a part of the waste-laden architecture and construction industry methods of delivery. It has emerged autonomous and has thrived on its own terms of supply and demand for nearly a century.[29]

The manufactured home does not profess to be more than it is and its owners do not expect more of it. It is built to a lower code. Because of this, prefabrication, the method by which manufactured housing is realized, has come under attack as a subpar method of construction for all housing. It is only recently that manufactured methods of housing production are being evaluated to create different levels or degrees of quality in mainstream housing. This can be most easily seen in the work of modular housing companies and prefab architects like Michelle Kaufmann and Joe Tanney at Resolution: 4 Architecture. The key tenants of these homes center upon the advantages that the manufactured housing industry teaches—that building in modules considerably reduces the overhead and onsite labor and can dramatically reduce initial cost. Unlike mobile homes, Kaufmann and Tanney have used modular housing to infuse a higher level of sustainability, quality control, and craft. More will be discussed concerning modular construction and other architects working in this area in Chapter 9.

1.7 Precast Concrete

The history of site-cast concrete in the Industrial Revolution is clearer than precast. Early indications that precast was used can be found in the evidence of precast fountains and sculptural pieces in early Roman and later during the nineteenth century. Precast has also been found in burial vaults in cemeteries across the United States dating back the turn of the twentieth century. Despite the advances made by the Romans, concrete was lost to the world for 13 centuries until, in 1756, British engineer John Smeaton used hydraulic lime in concrete. Later, in the 1840s, Portland cement was first used. Joseph Monier made concrete flowerpots with wire reinforcement. The greatest advance to concrete construction was taking this concept into reinforcing steel, allowing greater uses of concrete in construction. Advanced pouring techniques and the availability of raw material make concrete accessible for a myriad of functions. The first use of reinforced precast is attributed to French businessman E. Coignet, who developed a system of components similar to elements in the construction of the casino in Biarritz in 1891. Five years later, François Hennebique is attributed with the first precast *modulare,* developed for gatekeepers' lodges.[30] Although not technically precast, Thomas Edison developed a reinforced concrete housing prototype in 1908 with a technique for a single-pour house using cast iron formwork.

The development of prestressed concrete is congruent with precast developments. Prestressing at the plant allows precast elements to be stronger, lighter, and an overall better use of material. Although a San Francisco engineer patented prestressed concrete in 1886, it did not emerge as an accepted building material in the United States until a half-century later. The shortage of steel in Europe after World War II coupled with technological advancements in high-strength concrete and steel made prestressed concrete the building material of choice during European postwar reconstruction. North America's first prestressed concrete structure, the Walnut Lane Memorial Bridge in Philadelphia, Pennsylvania, however, was not completed until 1951.

In conventional reinforced concrete, the high tensile strength of steel is combined with concrete's great compressive strength to form a structural material that is strong in both compression and tension. The principle behind prestressed concrete is that compressive stresses induced by high-strength steel tendons in a concrete member before loads are applied will balance the tensile stresses imposed in the member during service. Therefore, prestressed, precast concrete was first widely used in civil engineering projects such as water culverts and bridges. Architect Louis I. Kahn and engineer August Komendant employed prestressed concrete on the Richards Medical Laboratory at the University of Pennsylvania campus, one of its first uses in architecture in 1971. Prestressed precast today is common, however, and continues to be used more often in larger commercial and industrial buildings that warrant its great strength and mass, as well as its financial investment.

Figure 1.9 Edison's 1908 single-pour concrete system was deployed as a fast and affordable housing option. Using elaborate cast iron formwork and machinery allowed for up to three-story houses to be cast in a single pour. The iron formwork proved cumbersome and difficult. It was not until Charles Ingersoll, a wealthy New Jersey manufacturer who brought the idea of making the forms out tof wood, that Edison's single-pour concept was built. Construction began in 1917 in Union, New Jersey. Fewer than 100 houses were actually realized.

1.8 Digital Production

Prefabrication, the process of building in a factory, implies a Fordist mass-production model. However, today's methods of production in automobile manufacturing have moved dramatically beyond notions of standardization, economy of scale, and flow. Today's processes of production, through the use of digital technology for both design and fabrication by means of computer aided design and computer aided manufacturing (CAD/CAM) systems, are proving to be a paradigm shift in production ideology. This enlightenment is affecting not only prefab technology development, but the social constructions by which buildings are produced, their contract structure, and the interface of players. Digital fabrication is potentially a method by which the promises of prefabrication—complementary increase in design and production quality—may be realized.

Two forces gave rise to CAD/CAM technology. First is the link to the Industrial Revolution and mass production already discussed in this chapter. The other is that of digital automation. Automation is more computer technology than manufacturing. It is the process of creating machines that are automata, or have been purposely built to mimic the process of skilled human labor, controlled by instruction given via numerical command or computer numerical control (CNC). Although today the two principles of CAD/CAM including computers and production are hardly distinguishable as separate entities in many industries, including automobile and aerospace, this separation theoretically is necessary to more effectively use these new methods to advance prefab architecture. Of all the areas of CAD/CAM technology implementation and development for the production of goods, the building industry is the slowest to evolve.

Developed in the military, the Air Force after World War II sought to expand its manufacturing system to produce repetitive and complex geometric components for planes and weapons applications.[31] But the history of CNC goes much deeper, entering into our infatuation with making the qualitative quantifiable. Lewis Mumford in *Technics and Civilization* shares the history of Benedictine monasteries in which numerical control emerged as a technique of regularization for the behavior of the monks. Mumford states that this marked a change in the human perception of time, relinquishing our physiological bodies from the rhythms of solar movements and seasons to being dictated by numerical control.[32]

Numerical control found its way into clock towers of European towns as a method to regularize trade. Bookkeeping methods advanced in tandem with trade calculation, and soon after, the notions of perspective drawing, cartography, and planetary science expanded. This all has come into fruition by virtue of the implementation of mathematics to understand spatial and social ends. This infatuation has not receded; in fact, the Industrial Revolution opened the door to modern-day computation through a 1 0 1 0 sequencing. Numerical sequences became important to America in the materials, patents, and communications systems related to the telegraph and railroad era.[33] By the turn of the nineteenth century, these standards became known as the "American System of Management and Manufacture."[34]

One of the first developments in automation can be traced to Joseph Marie Jacquard, who developed a

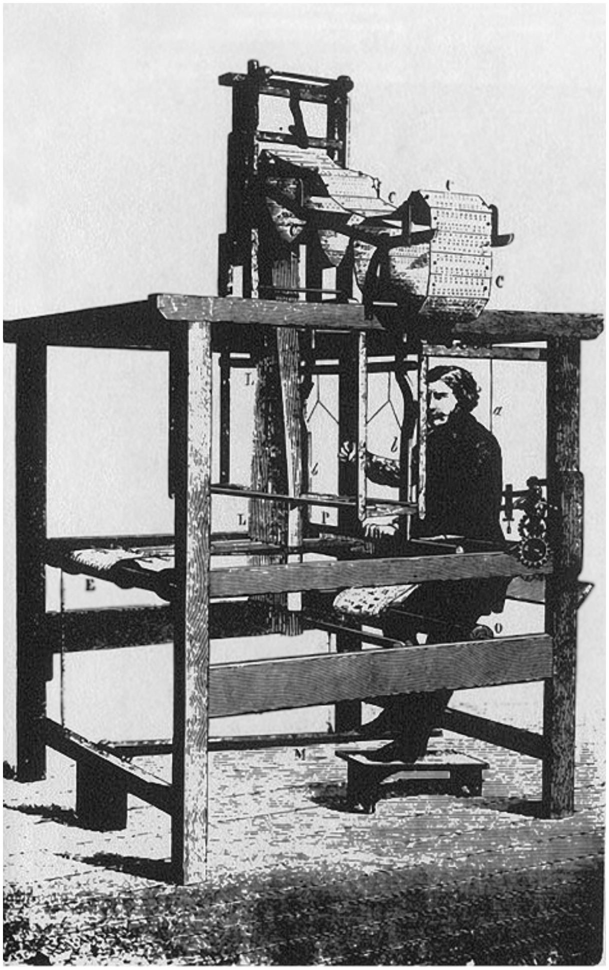


Figure 1.10 Jacquard, in 1801, developed a numerical control system for automating weaving patterns in a loom allowing textile design and manufacture. This was accomplished by using punch cards as the numerical input similar to numerical sequencing drives in contemporary computing.

machine that read punch cards in order to control the weaving pattern in a loom in 1801. The Jacquard Loom is an excellent example of the theory of programmable machines. Punch card technology stayed relatively rudimentary in its effects on building and manufacturing until computers became widely available. Early systems developed by Herman Hollerith in the mechanical tabulator based on punch cards were not that different from the Jacquard punch card system until advances were made to coded tapes, and ultimately into the hard drive of machines by uploading information. It was not until the 1950s that computers were used for manufacturing production, opening up possibilities for digitally controlled machinery.[35]

Up until the 1990s, numerical control was limited to only those who could afford the technology. Today, small manufacturers and fabricators use CNC machinery for their day-to-day operations. The advances that led to this proliferation can be attributed to the following:

- Development of smaller, more powerful computers that were affordable and able to process data at much greater speeds and to realize a return on their investment,
- Software that made the process of design to fabrication more accessible, and
- A general knowledge of how geometry could relate to production via numerical control.[36]

New machines during the 1990s were also developed to accommodate a variety of scales at different price tags. The decade brought a host of software applications from mechanical engineering such as CATIA, and other parametric platforms that allowed individuals to rationalize the design process of highly irregular nonplatonic geometry. Many product and mechanical engineering applications linked data concerning materials and methods of production with the human interface so that design decisions and their impact on production logistics could be integrated. This same idea is now being implemented into architecture and construction practice by way of building information modeling, or BIM. On the surface, digital design and manufacturing has the potential to offer innovative solutions, increase quality, and stabilize cost. The promise of prefabrication that was touted by Ford and others may be realized in this new paradigm as society and the building professions continue to shape its future direction.