Edition **DETAIL**

STAIB
DÖRRHÖFER
ROSENTHAL

COMPONENTS AND SYSTEMS

MODULAR CONSTRUCTION

DESIGN · STRUCTURE
NEW TECHNOLOGIES

Edition **DETAIL**

Staib
Dörrhöfer
Rosenthal

COMPONENTS AND SYSTEMS

MODULAR CONSTRUCTION

DESIGN STRUCTURE
NEW TECHNOLOGIES

Edition DETAIL – Institut für internationale
Architektur-Dokumentation GmbH & Co. KG
München

Birkhäuser
Basel · Boston · Berlin

Imprint

Authors

Gerald Staib, architect
Prof. Dipl.-Ing.
Department for Building Construction and Design
at the Technical University Dresden

Andreas Dörrhöfer
Dipl.-Ing. Arch.
Department for Building Construction and Design
at the Technical University Dresden

Markus Rosenthal
Dipl.-Ing. Arch.
Department for Building Construction and Design
at the Technical University Dresden

Technical essay:

Jan Knippers, Prof. Dr.-Ing.
Institute for Construction and Design, University of Stuttgart

Thorsten Helbig, Dipl.-Ing.

Editorial services

Project management:
Steffi Lenzen

Editorial services and copy editing:
Cornelia Hellstern

Editorial services:
Carola Jacob-Ritz, Michaela Linder, Eva Schönbrunner, Cosima Strobl, Melanie Weber

Drawings:
Marion Griese, Caroline Hörger, Emese Köszegi, Nicola Kollmann, Simon Kramer, Elisabeth Krammer, Martin Hämmel, Daniel Hajduk

Cover design:
Josef A. Grillmeier

DTP:
Simone Soesters

Reproduction:
Martin Härtl OHG, Martinsried

Printing and binding:
Kösel GmbH & Co. KG, Altusried-Krugzell

A specialist publication from Redaktion DETAIL.
This book is a cooperation between
DETAIL – Review of Architecture and
Birkhäuser Verlag AG

ISBN: 978-3-7643-8656-6

This book is also available in a German language edition (ISBN: 978-3-7643-8655-9).

Preface

"Unitised building" and "system building" are concepts that are often considered to conflict with the idea of "creative design". But are these really incompatible opposites? Shouldn't they rather complement each other, or even effectively sustain each other?
Nowadays it is not unusual for prefabricated building to encounter strong resistance; an understandable response when one considers recent history. The origins of these prejudices often lie in the ill-considered employment and application of building with prefabricated elements and systems. One is confronted with the "architectural" consequences of this approach everywhere, for example in the shape of countless prefabricated panel construction buildings in Eastern Europe; no-one wants to repeat these, but, strictly speaking, they do not represent the true purpose of prefabricated building. But with the continuously growing ecological and economical challenges facing the construction industry today, structures based on building systems and prefabricated production techniques are becoming increasingly important.
With this publication we would like to pave the way for a sensible approach to the use of prefabricated elements and systems: away from a view of prefabrication as an end in itself, and seeing it more as an instrument capable of enhancing comprehensive design concepts. Prefabrication doesn't necessarily mean off-the-peg architecture or universally usable elements; quite the opposite in fact: modern systems promote the customised prefabrication of discrete units with high levels of differentiation. This can actively encourage designers' creativity rather than curtail it. The questions to be posed are: What can contemporary prefabrication techniques enable us to do? How do they work? How can we utilised and apply them most effectively?

"Components + Systems" is subdivided into five main sections focussing on the following topics:
A comprehensive introduction to the history of this subject is presented in part A. Although the construction of the nomadic shelters of early history indicate first attempts in this direction, the concept of prefabrication reached its climax in the 1960's with the diverse urban and architectural utopias of that era. The monotonous designs of the architecture of this period, however, also heralded the "demise" of these ideas. It was not until the present time – almost a quarter of a century later – that, faced with a growing necessity for resource-conserving techniques and the desire to increase design flexibility continuously, thoughts again began to turn increasingly to the concepts of systems.
Part B describes the technical and constructional foundation of unitised building. Relevant terms – such as level of prefabrication, type standardisation, module and modular system – are defined and explained for architects within the context of integrated planning. In addition to descriptive presentations of the relevant assembly methods, planning strategies facilitate an initial understanding of this topic.
Part C comprises the applications of various systems in the construction of load-bearing structures and the materials used in such systems. The essential construction principles for unitised building are presented; frame systems, panel systems and room module systems. In this context the level of prefabrication of the elements selected for these methods of building plays an enormously important role for the construction of the individual buildings.
Prefabricated facade systems are dealt with separately in part D. Systems for office and administration buildings often include frames, glazing, supporting construction and sunshading in a single element. These systems are, however, not only to be found in present-day high-rise building envelopes, but increasingly in everyday architecture also.
Finally, part E discusses contemporary trends in the field of computer-based design methods and fabrication techniques. A discussion of potential developments for system building presents new impulses and allows us to look toward the future with great anticipation. Is there a future for system building? If so, what could it look like? Is it possible for us to learn from the mistakes of the past, and to transform them into something positive?

Each chapter is supported by comprehensive detailed examples which present ideas for the successful translation of theory into practice, far removed from the standard "mishmash" and dismal repetition of industrially produced modules. The examples prove, once again, that high levels of prefabrication, functionality and high quality design are not mutually exclusive.
Knowledge of the interdependence and constraints of various organisational systems and building methods, as well as of the assembly of different building elements and of contemporary fabrication techniques, encourages the responsible deployment of prefabricated systems and will enable good quality architecture to benefit from unitised and system building.

Publisher and editorial department,
Munich, May 2008

Contents

Introduction

"Components" and "Systems" – these terms evoke – not only for architects – associations with industrial production, serial fabrication and assembly lines; more precisely, post-war construction techniques. That is, images dominated by technology, uniformity, indeed even monotony.
Although serial production on assembly lines in automotive production plants is accepted as standard procedure, a comparable approach in architecture is widely considered undesirable, burdened as it is by examples from more recent architectural history. Surely, however, this reaction has nothing to do with the concept of "repeating" similar components in architecture as such, but rather with the use of industrially prefabricated elements dominated by technical concerns.

That is, of course, the first emotional reaction. If we allow ourselves to address this issue pragmatically and consider the history of architecture, specifically this particular aspect, we can in fact find many excellent examples of "system building". A fascinating, diverse, multi-facetted aspect of the "making of architecture" is revealed; the relationship between architecture, manual skills and industry, the significance of construction within architecture and the way in which architecture is created. The hopes and expectations that are projected onto industry and technology in the expectation of an architectural revitalisation are revealed. But we also see just how often one-dimensional technical developments have led to dead-ends.

In principle, every building is a composition of walls, floors and roof. Independent systems have been developed for each and every discrete section of a building over the years. For example, the system "wall": studs with infill panels, courses of brickwork in a masonry bond, or modern prefabricated facades which no longer incorporate load-bearing functions but merely enclose an interior space. In this sense construction with elements or systems can be considered to be the very essence of building.

The subject of this book is the development of system building techniques throughout the history of architecture and, more importantly, how they are applied today. It will be demonstrated how these processes of development reflect a tireless search and experimentation that aimed at improving building and construction techniques, initially using traditional materials, later on employing the new materials iron, steel and concrete. This book focuses on the presentation of the various options available today for building with prefabricated elements in building systems, and, additionally, examines the potential and trends in the development of different construction techniques. Frame, panel and room module systems are looked at under the headings of the building materials steel, timber and concrete.

The history of architecture is also one of an extended process of differentiation. The entire classification "structure" has resolved itself into a multi-layered composition of differentiated systems due to shifting demands and increasingly complex energy-related, materials-related, technical and functional expectations. Nowadays individual elements are developed, manufactured and assembled according to highly specific demands.

Two examples that significantly demon-

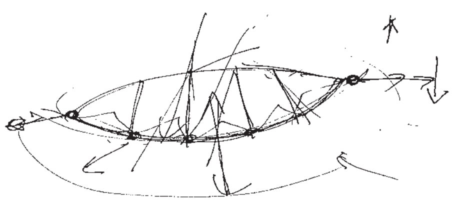
House, Overijse (B) 2004,
Buelens Vanderlinden Architects

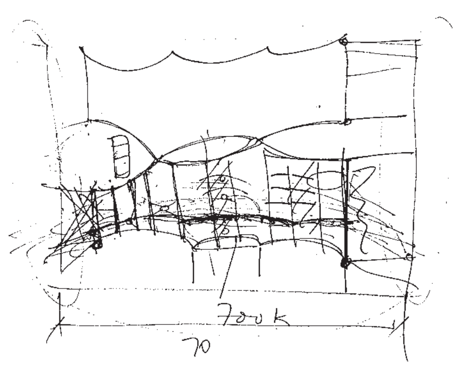
strate this change are the Pompidou Centre in Paris by Renzo Piano/Richard Rogers (1977) and the Hong Kong & Shanghai Bank by Norman Foster (1986). Not only do these buildings show how they function at the highest technical level of their time, but the role played by each building part is also individually legible. Nowadays every larger building can be viewed as a construction consisting of various systems, without, however, each of them being recognisable as independent design elements.
The typically closed systems of the 1960s that determined the design of a building up to and including the internal fit-out no longer exist in this sense. Buildings have developed into compositions that use a variety of specific systems. Standards based on technological typologies have developed for standard elements such as load-bearing systems, facade construction and partition walling, which simultaneously serve as the bases for a wide range of systems. Industrially manufactured building elements have thus become a fundamental component of architecture today.

The production of individual components within a system no longer inevitably means the production of an entire series of identical elements, as was previously the case for technical and economic reasons. Modern, computerised planning and production techniques are now capable of developing, producing and assembling distinct elements within interconnected systems.
Thus, it is now possible to determine the most appropriate system for each and every constructional or technical part of a building – from prefabricated, lightweight concrete wall elements with factory-fitted service runs, to technically complex, multi-layered prefabricated facades. This differentiation of construction systems also affects the structure of the manufacturing companies. The firms generally no longer offer everything, even smaller and middle-sized producers can now secure a niche in the market by developing and offering optimal solutions for specific areas.

The desire to bring architecture and industry closer together and to take advantage of the resultant opportunities has encouraged the development of systems as an important part of modern, industrialised building. From the very beginning of industrialisation, architects have seen the serial fabrication of components, their interconnection within systems and the associated rationalisation of the construction process as an opportunity to bring about a long overdue revitalisation.
Post-war industrialisation of the construction process, however, led rather to disillusionment regarding building systems. It became clear that deterministic, closed systems are incapable of leading to acceptable solutions.

The range and variety of systems will continue to increase firstly because systems generally develop as direct responses toparticular tasks and secondly because existing systems are continually being further improved and optimised.
This means that the architect's responsibility will increasingly be to minimise the constangly growing discrepancies between knowledge and technical possibilities in the construction industry and developments in other areas such as technology, industry and science. Only in this way can solutions be found that





La Grande Arche, Paris (F) 1989;
Johann Otto von Spreckelsen and Paul Andreu;
freehand sketch: Peter Rice

respond to contemporary conditions and requirements.
Frei Otto examined the methods and principles of nature in order to develop solutions for maximum performance with minimal outlay. Joseph Paxton, working as an experimental gardener in association with engineers and manufacturers, arrived at answers many aspects of which, even today, are still regarded as modern achievements. R. Buckminster Fuller applied the technical possibilities of the automotive and aeronautical industries to the construction industry. Similarly, widely used modern facade techniques, for example structural glazing and point-fixed construction systems, have been based upon technology transferred from these industries to the building industry by present-day architects and constructors, such as Peter Rice and Norman Foster.

This means that those working in architecture must once again focus on the exchange of knowledge and competence, they must remain open to unusual solutions, cultivate a view that extends beyond aspects of building, and take a delight in trying out something new, in experimentation. Collaboration with scientists, developers and engineers from various specialised areas must and will play an important role in these new responsibilities. The interdisciplinary transfer of information, ideas and solutions is an indispensable aspect of architects' work in order to develop a form of building, capable of anticipating and meeting the technical, ecological and social demands that will be made upon it.

The "System Building", this composition of countless individual components and systems, is becoming more and more complex, systems are growing more closely linked, and the differentiation of the individual elements and systems is increasing.
Technical solutions, while certainly vital, are just one of many aspects that define architecture. Technology is therefore not the principle impulse in architectural design. At the beginning of the last century, Le Corbusier described it roughly so; building is always a composition of building elements, everything is available, but it is the architect who makes the choice and is therefore responsible for the architecture. He or she selects the elements and decides how they will be combined to create an architectural entity.

Part A History of prefabrication

figure A

A 1

A 2

History of prefabrication

Nomads and settled dwellers

The prototypes of prefabricated and unitised buildings were first developed many thousands of years ago. While nomadic peoples were predominantly on the move searching for new habitats, they also required shelters or huts, in order to dwell temporarily in one location (fig. A 1). They made these dwellings out of tree trunks, branches, twigs, leaves, animal furs and skins. Archaeologists have been able to date the finds of these constructions as originating some 400,000 years B.C.

To avoid having to search for the required building materials after each and every change of location, the nomads collected materials which could be quickly and easily assembled, after a time dismantled and simply taken with them. It was important that the prefabricated building materials be lightweight, easy to handle and not consist of too many individual pieces. Each piece was deliberately selected to fulfil the desired function, roughly worked and shaped. Lightweight, textile methods of shelter were developed to suit different regions, climates and traditions, and some of them are still in existence today. The first tentative steps of systemised building are recognisable in these unitised nomadic dwellings.

With the advent of crop production and animal husbandry, humankind became independent of hunting and gathering for his livelihood, settled and erected permanent dwellings. Handwork skills were refined and tools were improved upon, allowing a tradition of masonry, stonework and timber constructions to develop over a period of many centuries.

Brickwork

Clay was available nearly everywhere in the fertile alluvial regions of the Near East. Mesopotamians and Egyptians used wooden forms to mould flat, rectangular blocks, thus creating the first artificial building block – the sun-baked brick – which could be manufactured en masse, and enabled entire cities and monuments to be built.

The temple constructions of the Sumerians (3500 B.C.), for example the temple terrace in Uruk, were constructed entirely of clay bricks, including the foundations (fig. A 4). These Ziggurats – named after the Sumerian term for “to be high up” – were considered to be “where heaven and earth met and formed the epicentre of Sumerian religion and, as such, urban life” [1].

Making clay bricks dimensionally stable and weatherproof by means of firing and glazing, created a conveniently sized building unit that could be combined in numerous ways, which has retained its importance in manual building down to the present day. The shape and size of the bricks was determined by the behaviour of the material when drying and firing; the ease of putting the units together and the stability of the brickwork was ensured by the particular system of bonding.

Stone

In building their temples, the Greeks perfected the use of stone to such a level that the individual finished blocks could be put together with razor-sharp accuracy. To fix the blocks they employed

A 3

A 4

clamps and pins of bronze and iron. The principles of the floor plans and elevations were exactly determined mathematically, on the basis of strict rules of order.

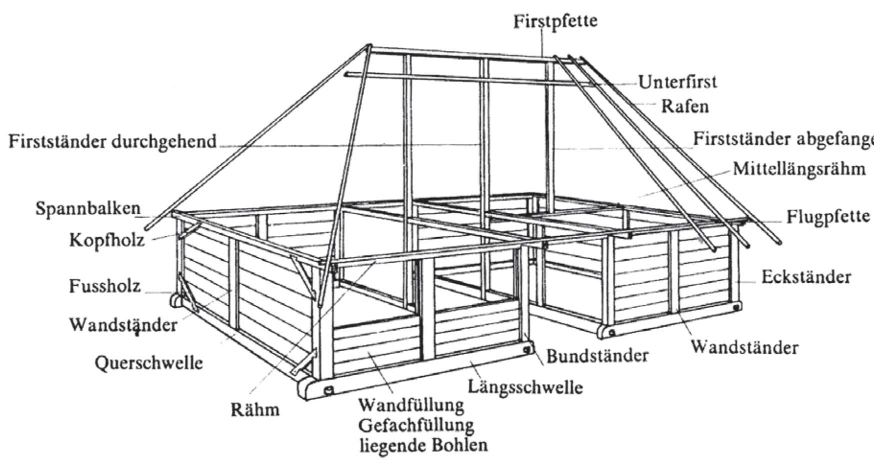
The Romans can be credited with collecting, documenting and spreading a multitude of technical developments throughout the various regions of their empire. *The Ten Books on Architecture* by Vitruvius, from the first century B.C. established themselves as the foundation for the development of construction and contained instructions for modular building systems employing stone elements, which could be used to build temples in farflung colonies.

The Gothic cathedrals of the Middle Ages were a highpoint of prefabricated and unitised stone construction. In the cathedral masonry lodges highly specialised stonemasons planned magnificent filigree church constructions, in which stone was loaded to its structural limits. The basis for the stonework was provided by precise, geometric drawings (without dimensions) which enabled a number of stone masons working together to produce the required quantity of complicated elements. The stonemasons passed on their skills and experience to selected apprentices who in turn carried their knowledge out into the world during the obligatory period that they spent wandering throughout Europe.

Timber

The development of timber constructions began with very simple systems. One of the earliest methods was to lean wooden posts against each other at an angle, bind them together and cover them with straw. Another variation was to sink posts into the ground, fill the gap between with loam-coated wattling and to cover the entire result with a simple roof structure. These were the first post constructions – the forerunners of frame buildings. Each individual element was sized and shaped to fulfil its particular task. Different elements were used to carry loads or to enclose space. The next step was to set the posts on large stones or on a kind of base or sill plate to prevent them sinking into the earth and decomposing. This combination of sill plates, posts and toprails formed a constructional entity – a timber frame (fig. A 5). These framed compartments were filled with planks, generally horizontal, less frequently vertical. The consistent development of this technique led to the refinement of half-timbering in which the posts were built closer to each other than in timber frameworks (figs. A 6 and A 7, p.16). The spaces between these narrow frames were filled with wattle, daub or clay bricks.

Another possibility of constructing buildings with timber elements was the log, or block, construction method. In this form of construction the beams are placed on top of each other, and the walls fulfil both load-bearing and partitioning functions. The timbers – round, squared or half-round – are notched or cut 15 to 20 cm from the end and connected at right-angles to form block corner junctions. The timbers are nailed together vertically and sealed with moss. The weight of the stacked timbers produces a solid, dense wall.

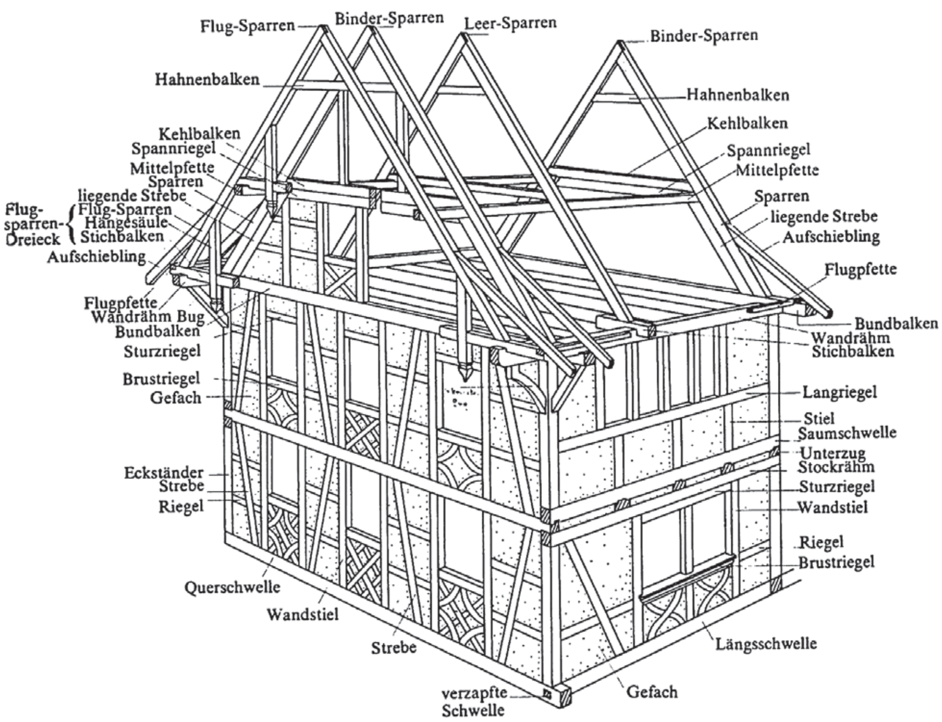


A 5

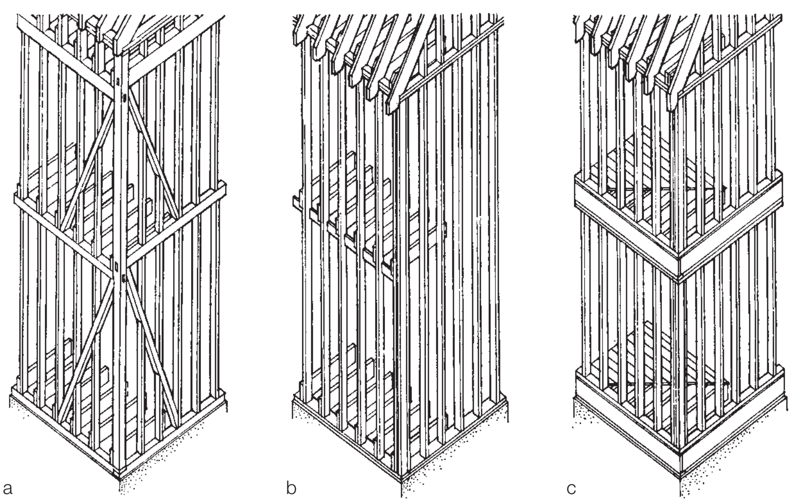
A Yurt: view of what is called the “crown” from below
A 1 Yurt (from the Turkish for housing) Structural system: criss-cross willow lattice, covered by a roof structure of 81 curved rods which run together at a wooden wheel, known as the crown.
A 2 This form of tent developed as a result of climatic conditions, lifestyles and the economic situation of the nomadic shepherd peoples of the central Asian steppes. They can still be found in the region between the Black Sea and Mongolia.
A 3 “The first structure” by Viollet-le-Duc
A 4 Ziggurat of Urnammu in Ur, approx. 2100 B.C.
A 5 Simplified timber frame construction

A 6

A 6 Farmhouses, open-air museum, Bad Windsheim, Germany
A 7 Timber frame construction
A 8 Balloon frame
a braced or eastern frame
b balloon frame
c platform frame
A 9 Floor plan of a house in Atami, Japan
A 10 Shogakuin Villa in Kyoto, Japan



A 7



a b c

A 8

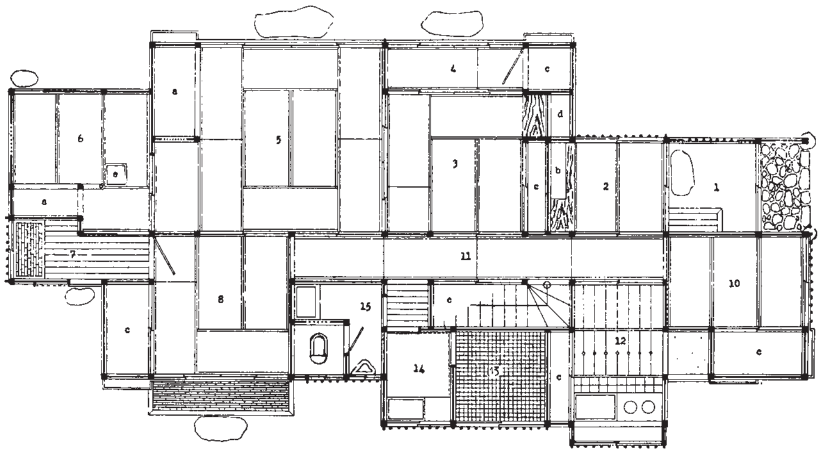
American frame construction

During the settlement of the North American prairies in the 1860's, the immense demand for easily transportable housing and the local wooden house traditions led to the rapid growth of the industrial processing of timber, which was available in large quantities. A simplified construction method was developed that could be manufactured in large series and is still widely used today.

Balloon and platform framing

The geodesist George W. Snow created the "balloon frame" in 1832, a construction still found in housing construction in the USA today (fig. A 8b). It was a further development of the early timber framework structures, the difference being that, instead of posts and beams, timber studs at close spacing were employed. These studs were connected to each other by industrially manufactured nails, were of standardised cross-sections, could be easily produced with circular saws and gang saws, and after a comparatively short drying period could be easily stored and transported. The vertical elements, at centres between 30 and 40 cm, extended the entire height of the buildings; the external walls were clad both internally and externally, while only the upper surface of the intermediate floors was covered with boards. The walls in this type of structure act structurally as plates and openings can therefore be made at almost any desired location. It thus became possible to provide comparable buildings at considerably lower cost and with less labour than required by traditional building construction techniques.

The essential difference between balloon framing and platform framing is that the latter system uses uprights that are just



A 9

A 10

one-storey high. Therefore new studs must be erected on each successive floor level (fig. A 8c).

Timber framed construction

Timber framed construction was developed from these American building systems. The standard spacing between the studs is usually 62.5 cm. By creating multiple layers of a timber section, different elements such as studs, sill plates, beams and top plates can be produced. Individual wall elements are prefabricated with external cladding, quickly connected on site to form a building, and then clad internally with panels.
The advantage common to all timber construction methods was that industrial fabrication techniques allowed more effective exploitation of the tree trunk as well as the acceleration of the building process. The cross-sections were standardised and cut to provide the structurally and constructionally necessary sizes, and thanks to the introduction of iron connections could be technically rationalised rather than remaining masterpieces of traditional carpentry skills.

The traditional Japanese house

Among the various types of timber construction, the traditional Japanese house holds a unique position as a single-storey timber frame construction (fig. A 9). Due to their basic dimensional order and the design and construction of the building elements, these exemplary structures provide inspiration for countless modern architects.
The construction techniques, building elements, organisation, form and size of the rooms were determined and rationalised many centuries ago. The basic module is the “shaku”, which originated in China, a unit of measurement approximately the same length as an English foot i.e. 30.48 cm. All building elements are based on this fundamental unit which thus determines the layout of the structure, the room dimensions and the relationship of the elements to each other. The distance between the columns is dimensioned using a different unit, called the “ken”, which was introduced in the Japanese Middle Ages. There are regional differences in the length of the ken; in Kyoto it is equal to 6.5 shaku and in Tokyo 6. The spaces between the columns can be filled, according to the individual requirements of the users and, depending upon the time of day and the season, with wall elements, translucent or opaque sliding doors or even bamboo curtains (fig. A 10). The timber elements are prefabricated with great skill and craftsmanship, without the use of additional connection materials and have flexible joints so that they cannot be damaged by tremors and earthquakes. The Japanese house is an early example of a basic modular arrangement, and of standardisation and unitisation in timber construction.

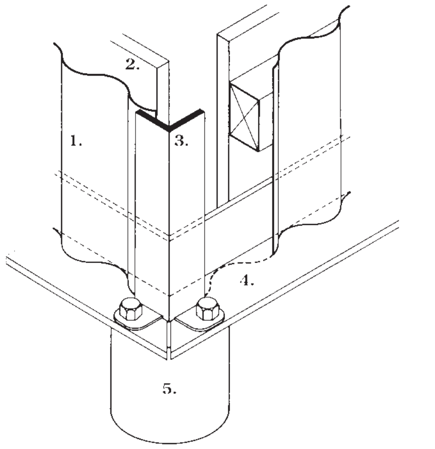
The military and colonial expansion

Unitised modular construction systems were of paramount importance in two specific areas: the military and colonial expansion. Many developments in the building industry sprang from these needs. Mobile military forces required accommodation and storage facilities. Tents were lightweight, transportable structures that could be quickly erected and dismantled and had proven their worth over the centuries. In the 18th century, however, routes and transport methods improved dramatically within Europe. The needs and demands of the military increased at the same time, leading to the development of larger, demountable buildings constructed of boarded timber frames. During the Austro-Ottoman War (1788–1791) entire mobile military hospital buildings, stables and accommodation facilities for troops were transported across the Danube into the war zone. However, in the procedure of speedily erecting and dismantling temporary structures (later to be called barracks) fixing the board cladding by hand proved to be too time-consuming. The invention of corrugated iron sheeting in 1837 made the entire process simpler and more efficient. The cladding for a building with a ground-floor area of 4.1 by 6.1 m could be packed into two crates measuring 31 by 62 by 275 cm. The corrugated panels were screwed to cast iron substructures and the outside face was galvanised in order to reflect sunlight, the internal walls were clad with wooden panels.

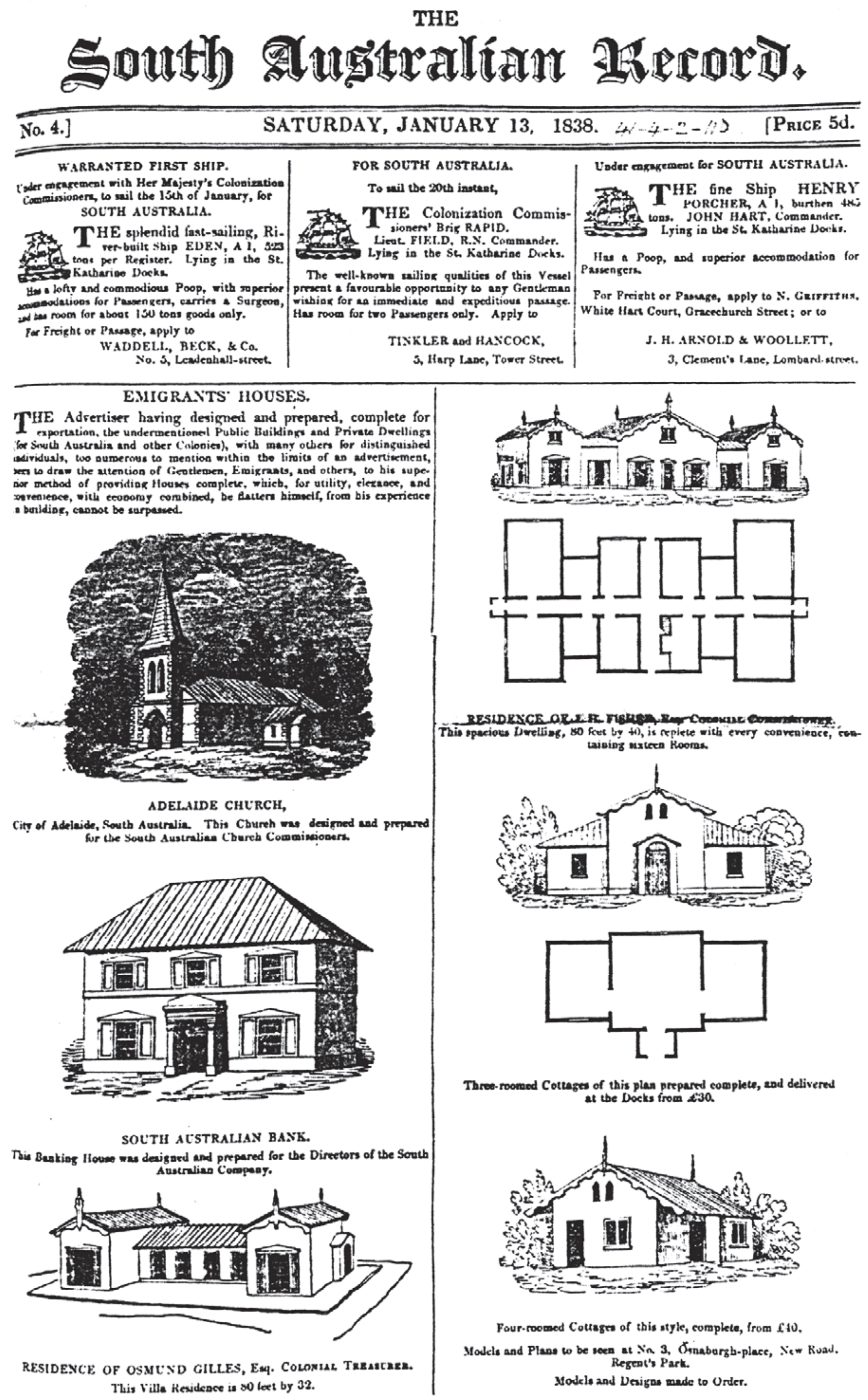
The company Christoph & Unmack, founded in 1892 by the steam engine constructor Christoph and located in Niesky, was the first to offer similar construction sets in Germany. In 1882 Christoph purchased a patent from the Dane Doecker for a construction system for military hospital barracks that was based on a timber structure and clad with felt boarding and sailcloth. He subsequently expanded this system for export to the tropics, for example by using a double layer roof.

Simply fitted-out shelters for the early settlers in the British colonies were initially manufactured in England and subsequently prefabricated; they were then dismantled into small, lightweight elements and shipped overseas in the form of com-

A 11



A 12



THE

South Australian Record.

No. 4.] SATURDAY, JANUARY 13, 1838. [PRICE 5d.

WARRANTED FIRST SHIP.

Under engagement with Her Majesty's Colonization Commissioners, to sail the 15th of January, for SOUTH AUSTRALIA.

THE splendid fast-sailing, River-built Ship EDEN, A 1, 523 tons per Register. Lying in the St. Katharine Docks.

Has a lofty and commodious Poop, with superior accommodations for Passengers, carries a Surgeon, and has room for about 150 tons goods only.

For Freight or Passage, apply to
WADDELL, BECK, & Co.
No. 5, Leadenhall-street.

FOR SOUTH AUSTRALIA.

To sail the 20th instant,

THE Colonization Commissioners' Brig RAPID.
Lieut. FIELD, R.N. Commander.
Lying in the St. Katharine Docks.

The well-known sailing qualities of this Vessel present a favourable opportunity to any Gentleman wishing for an immediate and expeditious passage. Has room for two Passengers only. Apply to

TINKLER and HANCOCK,
5, Harp Lane, Tower Street.

Under engagement for SOUTH AUSTRALIA.

THE fine Ship HENRY PORCHER, A 1, burthen 485 tons. JOHN HART, Commander.
Lying in the St. Katharine Docks.

Has a Poop, and superior accommodation for Passengers.

For Freight or Passage, apply to N. GRIFFITHS, White Hart Court, Gracechurch Street; or to

J. H. ARNOLD & WOOLLETT,
3, Clement's Lane, Lombard-street.

EMIGRANTS' HOUSES.

THE Advertiser having designed and prepared, complete for exportation, the undermentioned Public Buildings and Private Dwellings (for South Australia and other Colonies), with many others for distinguished individuals, too numerous to mention within the limits of an advertisement, begs to draw the attention of Gentlemen, Emigrants, and others, to his superior method of providing Houses complete, which, for utility, elegance, and convenience, with economy combined, he flatters himself, from his experience in building, cannot be surpassed.

ADELAIDE CHURCH,
City of Adelaide, South Australia. This Church was designed and prepared for the South Australian Church Commissioners.

SOUTH AUSTRALIAN BANK.
This Banking House was designed and prepared for the Directors of the South Australian Company.

RESIDENCE OF OSMUND GILLES, Esq. COLONIAL TREASURER.
This Villa Residence is 80 feet by 32.

RESIDENCE OF [illegible] FISHER, [illegible]
This spacious Dwelling, 80 feet by 40, is replete with every convenience, containing sixteen Rooms.

Three-roomed Cottages of this plan prepared complete, and delivered at the Docks from £30.

Four-roomed Cottages of this style, complete, from £40.

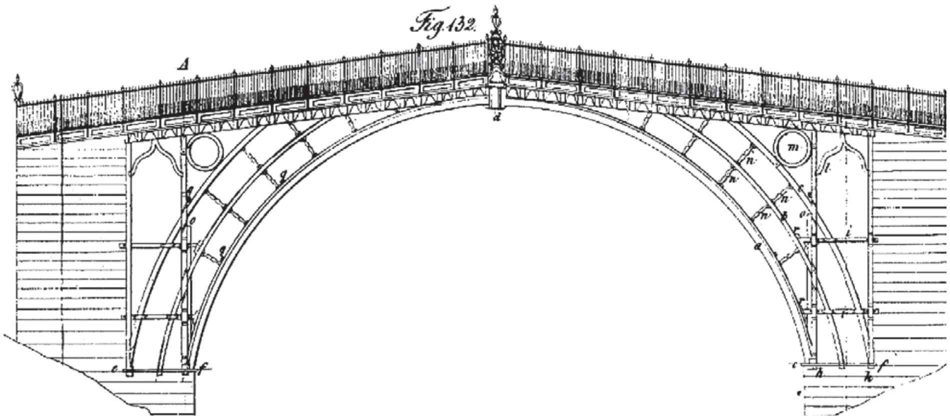
Models and Plans to be seen at No. 3, Osnaburgh-place, New Road, Regent's Park.
Models and Designs made to Order.

A 13

pact building kits. One of the first such kit houses exported to Australia in 1788 was erected within the space of a week. Over the course of time a huge market developed for systems used for different building types (fig. A 13). For example towards the end of the 18th century a hospital, a warehouse and various smaller dwellings were shipped from England to Sydney. Initially these “portable cottages” were still built by hand of timber and were often decorated according to the taste of the time; however, due to increasing insurance premiums for wooden houses and the wide range of areas where iron could be used, it eventually became the predominant building material in the 1840’s.

Iron – the first systems

At the beginning of the industrial revolution high quality iron became readily available in great quantities. By using coke instead of coal in the foundries, it was possible to manufacture better quality iron at higher temperatures. Cast iron, and later wrought iron and steel introduced new possibilities for building. Iron established new standards of architectural quality, with regard to both construction techniques and the external appearances of the buildings. The dimensions of the buildings could be increased, and the sections of structural elements reduced. The development of systems based on as many identical prefabricated elements as possible resulted from the fact that the cast and rolled materials were readily available as semi-finished products in the factory. It had become possible to calculate and dimension the building elements according to the actual loads applied and, particularly with cast iron products, to design them in accordance with the



A 14

fashions of the era. The high performance building material that we know today could only be produced after the Englishmen Henry Bessemer (in 1855) and Sidney Gilchrist Thomas (in 1879) – among others – refined the process of manufacturing low carbon steel from pig iron. This material, in the form of rolled sections, became the fundamental element of later frame structures. According to Christian Schädlich, "the iron industry (…) performed the function of a pacemaker for the general industrialisation of the building industry. It developed those elements of industrial technologies relevant to building: from the dismantling of the product into large elements, their prefabrication in the factory and mechanised assembly, to the standardisation of dimensions and forms for the purpose of serial production, and on to new organisational structures of the construction business." [2]

The possibilities of prefabrication were particularly useful for bridge construction in the early years of industrialisation. The arched bridge over the River Severn in Coalbrookdale is one surviving (fig. A 14). The Darby brothers who built the bridge between 1775 and 1779 were, with their family company the Coalbrookdale Company, instrumental in guiding the development of iron production and processing for generations. Five cast-iron arches, with crown heights of 13 m, span approximately 30.5 m across the river. Each of the half-arches arches was cast in one piece and connected according to the principles of timber construction. The arched form, under compression, was ideal for cast iron, although the cross-sections of such members could not yet be accurately calculated at that time. This structure, built entirely of iron, was a first step on the road to industrialised construction.

Iron frame construction

The flax mill built in 1796/97 by Charles Bage, for the company Benyon, Bage & Marshall in Castle Forgate in Shrewsbury, is considered one of the first buildings where the internal frame was constructed entirely of serial-fabricated cast iron columns and joists, although the external walls and floors were built of solid masonry. The columns could be easily erected at large centres, and were ornamented in the popular architectural style of the era.
The progress of prefabricated iron construction was heterogeneous; the structural, technical and therefore also architectural developments occurred at several different locations in a multitude of building projects.

The first important developments on the path towards pure iron frame structures occurred in the construction of greenhouses. With the colonisation of far off lands, many exotic plants were transported to Europe. Light-drenched palm houses and conservatories became highly desirable. Unfettered by questions of style and architectural meaning, those designing such buildings could concentrate on rational solutions to structural, technical and climatic problems. This was how the first unitised systems – later to be transferred to other building types – were designed.

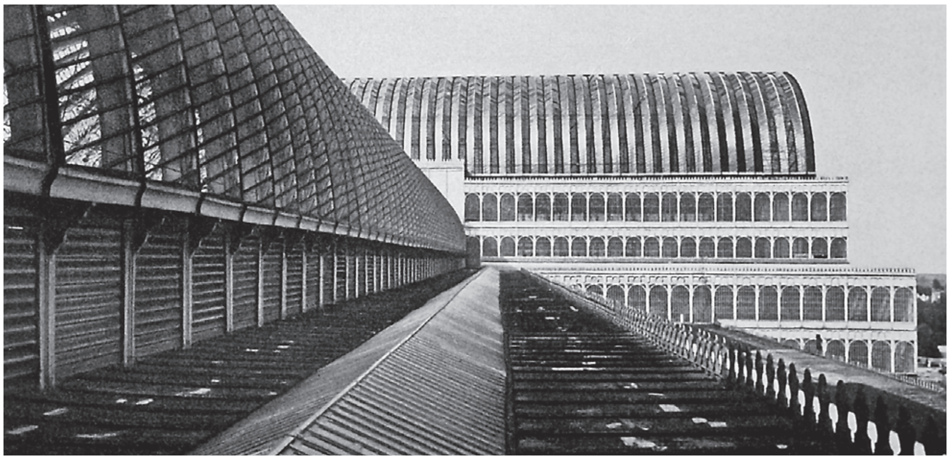
The glasshouses

Based upon his experience with glasshouses, gardener Joseph Paxton developed the Crystal Palace for the World Exhibition of 1851 in London in collaboration with the engineers Fox and Hender-

A 11 Cottage, South Melbourne (AUS) 1853
A 12 Detail of footing, connection of the corrugated iron to the external steel construction, cottage, South-Melbourne (AUS) 1853
A 13 Advertisement in the "South Australian Record" of January 13,1838, Peter Thompson Emigrants Houses (AUS) 1838
A 14 Bridge over the Severn near Coalbrookdale (GB) 1779, Thomas F. Pritchard/John Wilkinson/Abraham Darby
A 15 Crystal Palace, Hyde Park, London (GB) 1851, Joseph Paxton
A 16 Glass Palace, Munich (D) 1854, August Voit Inspired by English models, this iron and glass structure has a number of small further structural developments.The main difference to the English predecessors is the differentiation between load-bearing and non-load-bearing elements in the facade.

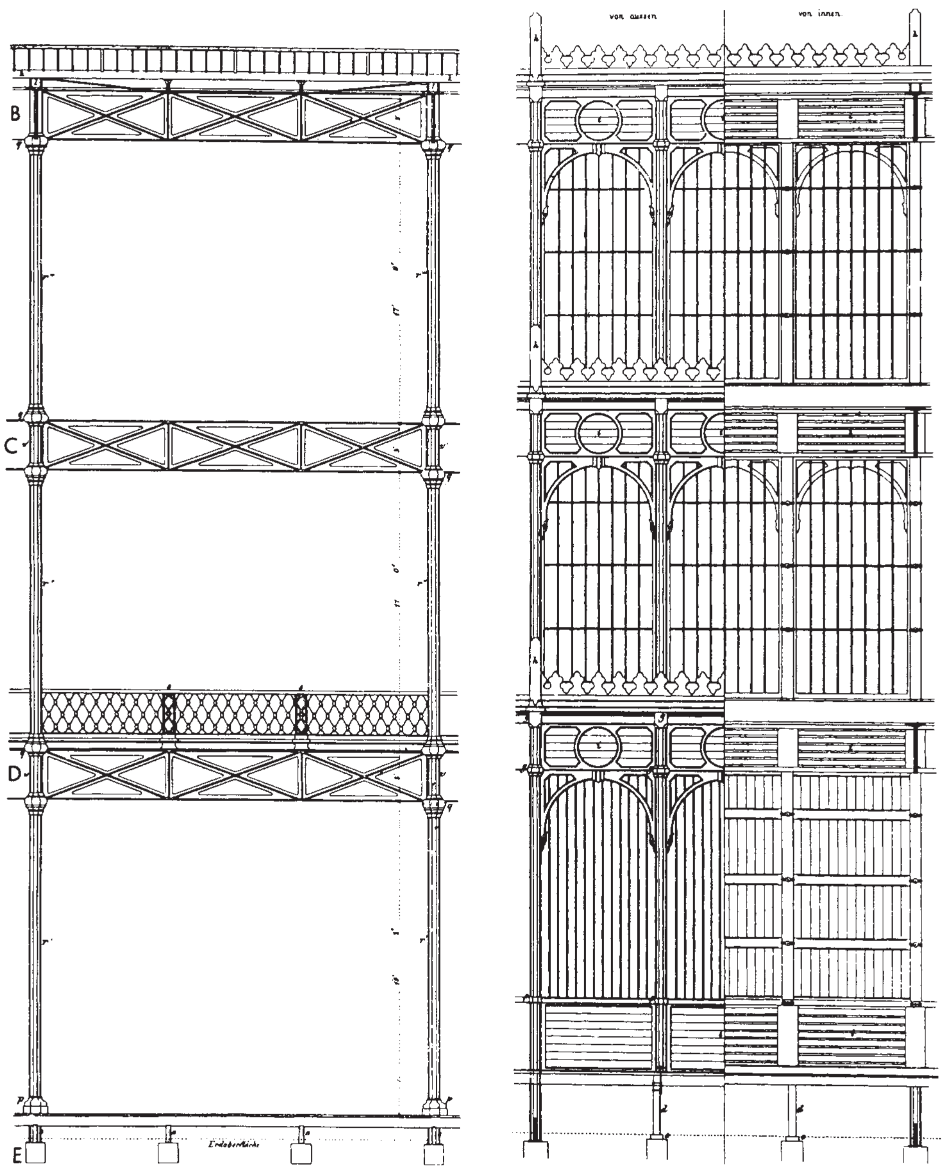
A15

A 16



A 17

A 17 Crystal Palace, Hyde Park, London (GB) 1851, Joseph Paxton
A 18 Frame structure Crystal Palace, London
A 19 Bogardus Factory, New York (USA) 1848, James Bogardus
A 20 Section through a corn mill for Turkey (GB) 1840, William Fairbairn
This building is considered England's first building entirely constructed of cast and wrought iron; prefabricated in England, shipped to Turkey and erected in Istanbul.
A 21 Chocolate factory, Noisel-sur-Marne (F) 1872, Jules Saulnier
The construction is reminiscent of timber framing and has infill elements of glazed bricks, some of which are coloured.
A 22 Cast iron arched elements, Bibliothèque St.-Geneviève, Paris (F) 1850, Henri Labrouste
A 23 Bibliothèque St.-Geneviève

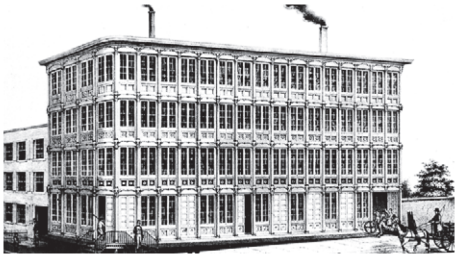


A 18

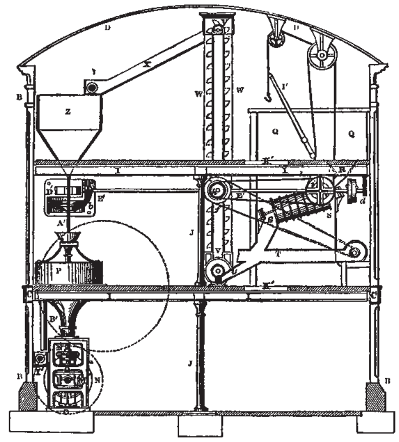
son in an extremely short period of time – a consummate building system, both architecturally and technically (figs. A 15 p. 19, A 17 and A 18). A minimum number of different standardised units were connected to create a frame based upon the principles of modular arrangement. Thereby the "production and connection of the prefabricated parts" should, in Paxton's own words, "function like a machine." [3]. Although the Crystal Palace measured 564 m by 124 m with an overall height of 40 m, there were only two different forms of column for the ground floor and two for the first floor, and the trusses were of consistent depth despite the different distances apart. The folded "ridge and furrow" roof – a stable roof construction with a high level of light transmission that rested upon a structure of timber sections and valley beams – was designed using countless identical elements. The basic module for the frame was derived from the maximum size of glass pane that could be mass-produced at that time. The architect and constructor Konrad Wachsmann described the Crystal Palace as a "visible turning point (...), through which the entire development of building history started on a new course." [4]. The glass palace demonstrated not only the possibilities of industrialised, rationalised building through the fabrication of building elements, but also the development of the building process as flow production. It showed how designers, engineers and production companies could work together as a team, and initiated new discussions in architecture as a result of its structural clarity and unbounded space.

High-rise iron construction

James Bogardus, an American businessman and constructor, erected a four-sto-



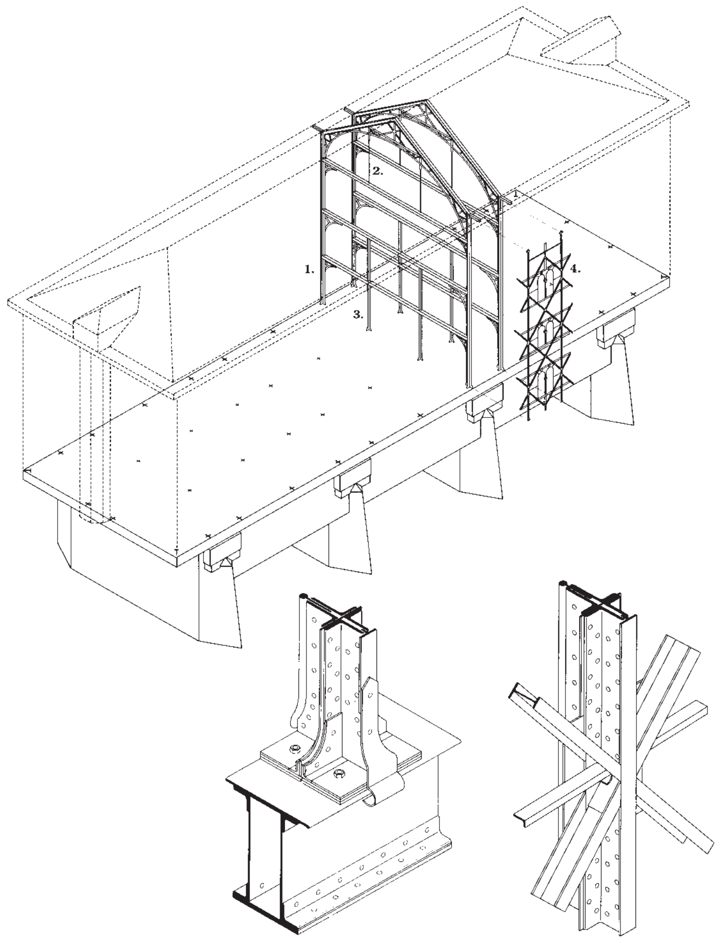
A 19



A 20

rey company headquarters (fig. A 19), in New York in 1848, after being inspired by a visit to England where he most likely saw Fairbairns corn mill (fig. A 20). The facade was constructed entirely of prefabricated cast iron elements, and was therefore a precursor of the later curtain wall facades. The goals were firstly to create a permanent, economical and fire-resistant construction and secondly to imitate the classical forms of stonework "in the Italian style", in a more cost effective and less massive manner.

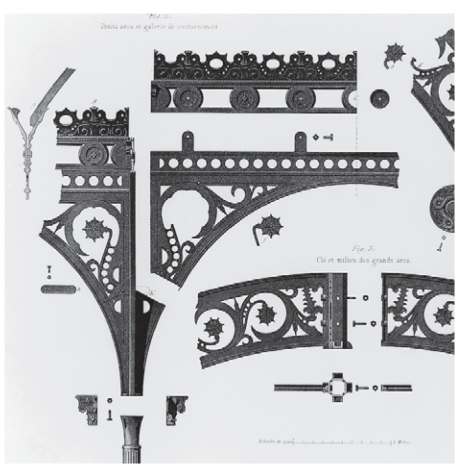
Both James Bogardus and his competitor Daniel Badger produced and assembled cast iron external walling for four to six storey business premises, warehouses and office buildings. The prefabricated elements could be selected from a catalogue. The system was designed to be dismantled and rebuilt in other locations when and as desired. The building's load-bearing system was initially constructed of masonry with a timber beam floor, but was later built entirely of cast iron. This form of architecture reached its zenith in the mid 19th century.



A 21

Prefabricated concrete construction

Alongside iron another new building material appeared at this time. The gardener Joseph Monier managed to make cement flowerpots more stable by inserting wire in them. He continued to experiment with this technique, in this way developing the first reinforced concrete elements. An additional high-performance building material became available to the building industry; one suitable for monolithic constructions of great stability. In erecting the casino in Biarritz in 1891, the French businessman E. Coignet was the



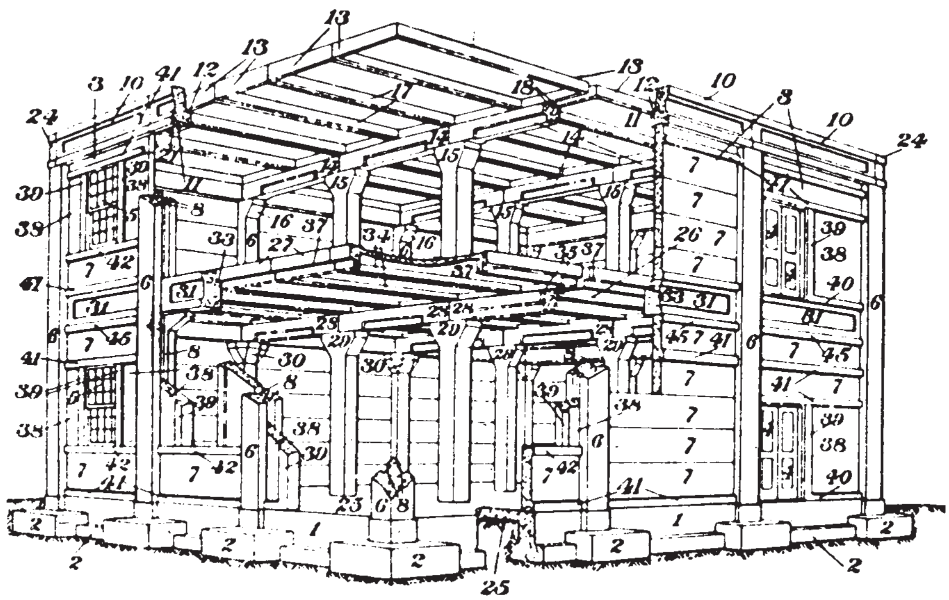
A 22

A 23

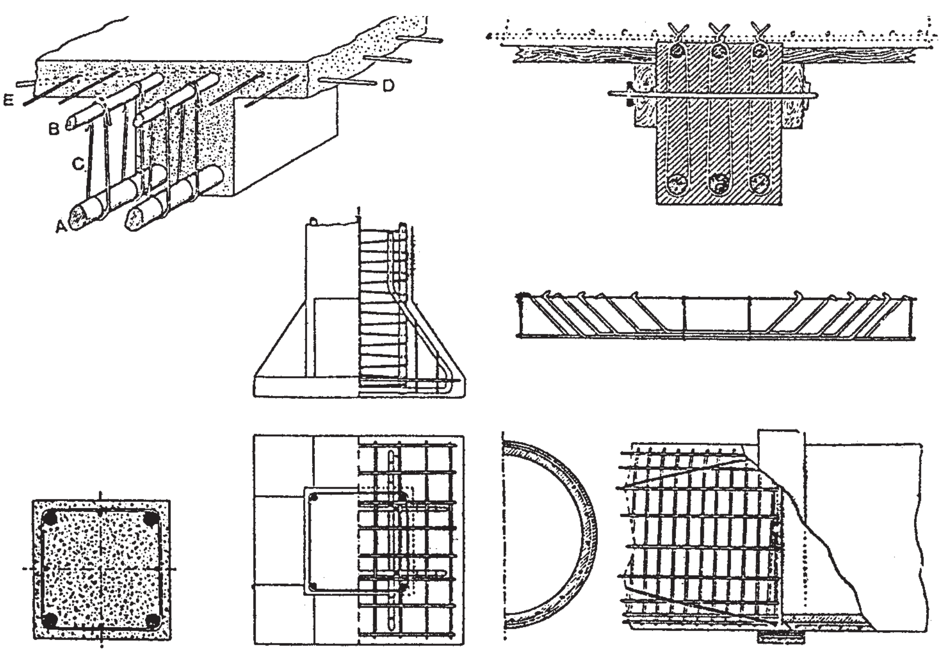
A 24

A 25

A 24 House in Letchworth Gardencity (GB) 1904, John Brodie
The prefabricated storey-height, room-sized concrete panels were assembled on site by crane.
A 25 Placing a Hennebique House in position, 1896
A 26 “Unit Structural Concrete Method”, 1916, John E. Conzelmann;
Pre-cast frame system with wall, floor and roof panels of reinforced concrete, originally used for industrial and railway buildings, later for housing.
A 27 Reinforced pre-cast concrete element, France, 1854, François Coignet
A 28 “System Dom-ino”, 1914, Le Corbusier



A 26

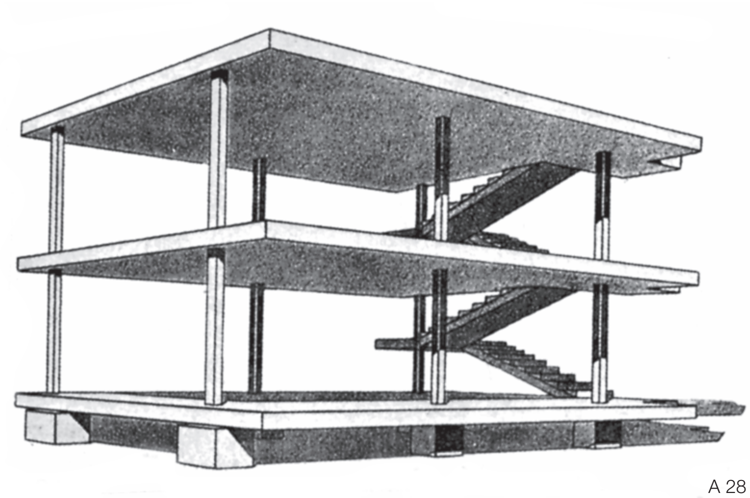


A 27

first to use prefabricated concrete elements (fig. A 27). Another businessman and constructor, François Hennebique, developed gatekeepers lodges for the French national railways five years later – these structures were the first concrete modular units (fig. A 25).

Rationalisation, serial production, type standardisation and mass housing construction

Under the influence of industrialisation new standards of quality were established in the building industry with regard to construction, space and form. There were now new, faster ways of using machines to manufacture products industrially in large series, which were therefore no longer the individual results of manual labour. The forms of industrialised products – machines, ocean liners or automobiles – and the simple, unadorned engineered structures that had been created in the 19th century greatly influenced the thinking and action of the architects of the day. Architecture, it was believed, needed to be fundamentally renewed in formal, social and economic terms, with the assistance of industry. Buildings should be produced in series in factories, standardised and prefabricated, so that they could be assembled on site according to the principles of modular construction.
It was hoped that these new production methods would help solve the pressing problems facing the housing industry. The flow of people to the larger European cities, especially in France, Germany and England, grew continuously throughout the 19th century. The increasing housing shortage, particularly for the poorer working classes, and the appalling conditions



A 28

in the ghettos, demanded immediate solutions and new, economical building methods. The demand for better organised housing estates and affordable, well-ventilated and well-lit housing became more and more insistent. A number of politicians and designers, influenced by the industrial developments in America, recognised that quantity and quality in housing construction could only be achieved by employing the appropriate production techniques. Industrially manufactured building elements and faster assembly techniques, in addition to properly, rationally organised building sites, had to replace the conventional, manual building process.

The United States, with its unadorned silos and technical buildings, free of all architectural input, and its rationally organised industries became the example for Europe. Frederick Winslow Taylor, born in 1856, developed what was known as "Scientific Management", also called Taylorism. This was a scientific approach to management based on breaking down work processes into their individual elements and analysing these in detail in order to then reorganise the production so that it became faster, more rationalised, more efficient and more economical. Henry Ford introduced assembly line production into the automotive industry in 1913, based on this principle. His concept of the modern production of automobiles also revolutionised modern culture. The architects of the avant-garde were also greatly influenced by mass production in the automotive industry. The notion of producing houses in much the same way as cars became an ideal. Rationalisation and standardisation were to become decisive concepts within the field of architecture.

In his work *Vom sparsamen Bauen* (Economical Building) of 1918, architect Peter Behrens demanded the mechanisation of the building process, and said that "the industrialisation of building elements (by these he meant windows, doors, etc.) must be undertaken in a far more wide-ranging and generous way" [5].
By using the standardised dimensions and forms of fabricated products for building small houses, Behrens believed that the foundations could be laid for industrialised mass production, which in turn could pave the way for a general decrease in the cost of a small house [6]. In order to reduce costs further, he also called for the introduction of the principles of Taylorism in the area of small house construction.

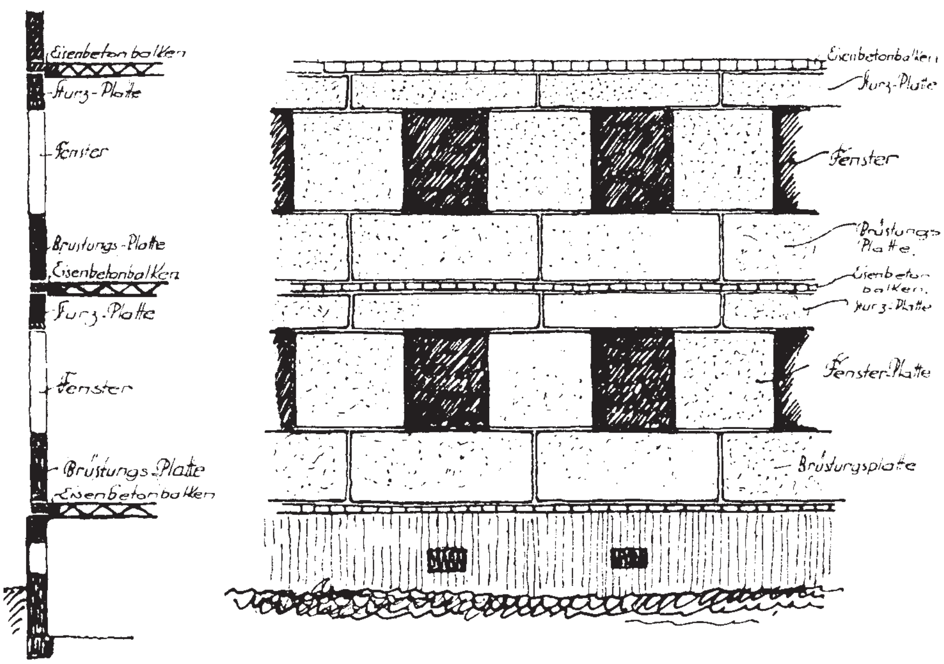
In 1928 in the Declaration of La Sarraz, the Congrès Internationaux d'Architecture Moderne, otherwise known as CIAM, spoke out in favour of rationalisation and standardisation as necessary economical methods of production.

Le Corbusier quickly incorporated technical and formal developments from industry, thereby influencing a great number of architects. In *Towards a New Architecture* he wrote in the chapter "Houses Produced in Series" that: "a new era has begun; a new spirit is abroad in the world. Industry, as forceful as a river surging towards its destiny, gives us the new solutions appropriate to the new era. The law of economy dictates our actions. The problem of housing is a problem of our times; the balance of our social order depends upon solving it. Re-evaluation of existing values is the re-evaluation of the essential elements of the house. Serial construction relies on analysis and experimental research. Large industry must address building and produce individual building elements in series. The intellectual requisites for serial production must be created." [7] In 1914 he developed the "Dom-ino House Project" (fig. A 28), a system based on concrete columns and flat slabs. Prefabricated, serially produced windows, doors and walk-in closets could be put together individually by the users. This house, in which the frame basically consists of columns (pilotis) and cantilevering floor slabs, was to revolutionise building construction. He named another house type that he designed in 1921 the "Citrohan", "in other words a house like a car, designed and constructed in much the same way as a bus or ship cabin" [8].

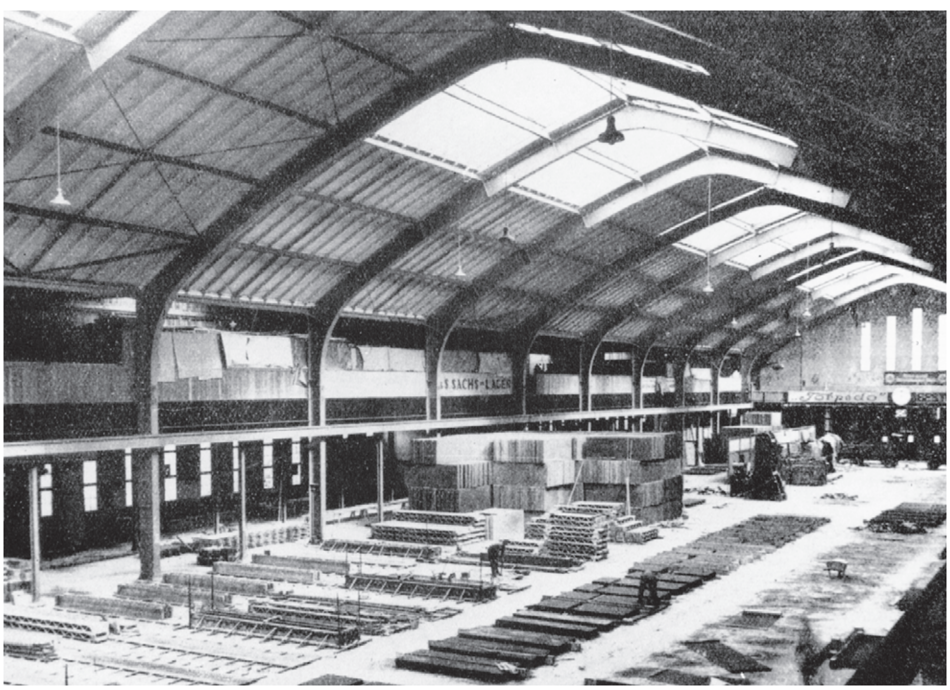
The driving forces for the reform of housing construction in Germany at the time were Martin Wagner, Ernst May and Walter Gropius. Martin Wagner, the director of city planning in Berlin, had been calling for the rationalisation of building and standardisation of dwelling types since 1918. Construction costs, he said, must be reduced in order to provide affordable accommodation. Traditional building companies should be taken over by rationalised industrial companies with organised trade unions, and manual labour replaced by machines.
Because in building the "Britz" and "Uncle Tom's Cabin" housing estates in Berlin the construction process was improved by the use of conveyor belts and excavators, and rationalised by the restriction to only four dwelling types, costs could be reduced, but the construction methods employed were still traditional. The housing estate at Berlin-Friedrichsfelde is an exception, however. There, in 1926, storey-height concrete panels were used according to the "occi-

A 29

A 29 Aerial view of Westhausen housing estate, Ernst May, 1932
A 30 Panel construction system “System Stadtrat Ernst May” from the Ernst May house construction factory, Frankfurt/Main (D) 1926
A 31 Fabrication hall, Ernst May house construction factory, Frankfurt/Main (D) 1926
A 32 Exhibition Stuttgart 1927, single family house no. 17, Walter Gropius, steel frame
A 33 House no. 17, ground floor plan
A 34 House no. 17, first floor plan



A 30



A 31

dent process”. This was a large-panel construction system that had been patented in Holland and had been previously used in a garden city development in Amsterdam. Panels 25 cm thick and measuring between 25 and 40 square metres, with maximum dimensions of 10 by 4 m had to be manufactured on site due to their immense size and were then erected by cranes. The external panels consisted of three layers; aggregate concrete on the outside, slag concrete on the inside and slag in the cavity between. The internal wall panels were of slag concrete both sides. Manufacturing these elements was a highly complex process and over time serious building defects appeared.

Frankfurt am Main was an important pioneer in the field of rationalised and industrialised construction. Ernst May, the director of city planning in Frankfurt, wrote in 1929 in an article entitled *The Apartment for Minimum Existence* that “apartments should be built in adequate numbers, where the rents do not exceed the weekly wages of the workers.” Similarly in his *Guidelines for Rationalisation of Housing Construction for the Minimum Existence*, he wrote with respect to the process of dwelling production, that “the production of dwellings should be organised in much the same way as the production of all other mass produced articles in the economy, that is exemplary well-worked out models (or types) should be fabricated in series, concentrated in a minimum of different locations.The mechanisation of the housing industry in particular should be encouraged. The goal must remain the factory produced dwelling – including internal fittings – that can be delivered as a complete product, and assembled in a few days.” [9]