Flat Roof Construction Manual

MATERIALS
DESIGN
APPLICATIONS

Edition **DETAIL**

SEDLBAUER
SCHUNCK
BARTHEL
KÜNZEL

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Birkhäuser
Basel

Edition Detail
Munich

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Reproduction:
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Printing & binding:
Aumüller Druck, Regensburg

Bibliographic information published by the German National Library:
The German National Library lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available on the Internet at http://dnb.d-nb.de.

This book is also available in a German language edition
(ISBN 978-3-0346-0580-9)

Publisher:
Institut für internationale Architektur-Dokumentation
GmbH & Co. KG, Munich
www.detail.de

Birkhäuser GmbH
P.O. Box 133, 4010 Basel, Switzerland
www.birkhauser.com

Printed on acid-free paper produced from chlorine-free pulp.
TCF∞

ISBN: 978-3-0346-0658-5 (hardcover)

9 8 7 6 5 4 3 2 1

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Preface

The world's natural resources are dwindling. This fact concerns not only oil and gas, but increasingly also more specialised raw materials such as indium, geranium and antimony, the prices for which have risen at an unprecedented rate in recent years. And climate change continues; it is too late to stop it, at best we can only slow it down. The consequences are already affecting all walks of life and everyday routines – in the way we design, construct, use and recycle our buildings, for instance.
Topics such as lower energy consumption and environmental protection are being discussed more and more in public. And they are now being joined by other aspects such as the closing of materials cycles and the ecological assessment of the entire phase of building utilisation. The concept of sustainability is increasingly becoming intrinsic to modern construction.
All this adds up to a property market and a building industry that are under growing pressure to minimise the environmental influences of construction. Despite this, 30–40 % (depending on which report you read) of our energy resources are consumed in the operation of buildings.

If we project all this on to roof design, then the dominating issue is energy consumption. Thermal insulation measures, as the most effective means of saving resources, are being employed in many variations, for both new-build and refurbishment projects. For example, the transmission heat losses through a roof provided with 20 cm insulation can be reduced by about 80 % in comparison to an uninsulated roof. And the payback times for such undoubtedly sensible measures are only a few years, although they should always be shaped by a certain pragmatism. For instance, where flat roofs are converted into pitched roofs during refurbishment projects because the latter allegedly exhibit better insulation characteristics, or where flat roofs are not planned in the first place because they are allegedly vulnerable to serious damage, especially with thick insulation, then we run the risk of losing part of our architectural culture. If we were to allow flat roofs to disappear gradually from our built environment, then we would lose an ecological potential that has never been fully exploited, i.e. the use of roof surfaces as a climatic micro-cosmos or simply as a water retention basin. As a result, we would find ourselves in a curious situation: ecological opportunities would go unused for ecological reasons – a completely unjustified state of affairs because technology provides us with a wealth of tried-and-tested solutions for building functioning flat roofs with an excellent level of thermal insulation. It is for that reason that the *Flat Roof Construction Manual* focuses on the subject of designing energy-saving flat roofs free from damage.

To begin our study of flat roofs, Part A outlines their evolution. Flat roofs were already well established in many cultures and many climatic conditions before they started to spread across Central Europe and North America as well. Additional usable floor space on the roof plus advantages for fire protection were the main reasons for their new-found popularity. However, it was not until waterproofing materials reached a certain stage of development and codes of practice for the design and construction of flat roofs were drawn up in the 1960s did we achieve the basis for good-quality flat roofs in cold and wet regions, too. From time to time, the flat roof was merely a fashion, one that led to the "roofs dispute" of the early modern movement. But the dispute has been resolved; today, flat roofs and pitched roofs exist side by side as equal partners.

Part B "Structure" investigates the structural aspects of flat roofs. Besides the various loads acting on the flat roof, the chapters of this section discuss potential primary structures and their optimisation. The whole range of structural materials – concrete, metals, timber and glass – is also presented here for the reader.

Part C "Building physics" is a comprehensive and well-founded presentation of the building physics principles that affect flat roofs.
The chapter on thermal insulation explains the facets of energy-saving construction on the basis of steady-state and non-steady-state

thermal conditions and shows a number of practical solutions.
In buildings, moisture is the most significant cause of damage, and this is especially true for flat roofs. One of the main sources of this are errors in the design and construction of components. This means that sustainable building without damage cannot be even contemplated without a hygrothermal evaluation of the flat roof design. Non-steady-state moisture processes within the construction are therefore illustrated and explained.
The section on fire focuses on selecting the most suitable materials, classifying the fire resistance of various forms of construction and the legislative requirements.
But sustainable building includes much more besides just energy efficiency issues, e.g. socio-cultural factors such as the comfort of users. Therefore, sound insulation is also considered in detail in this book. The health, well-being and, in workplaces, productivity of building occupants are the primary criteria of acoustics. And the aim is not just to reduce noise or prevent noise pollution, but rather to create suitable conditions for users proactively. Aspects such as airborne sound insulation to protect against external noise, impact and structure-borne sound insulation to control internal noise, and sound absorption within rooms all play critical roles here. The individual criteria are discussed in relation to flat roof design and practical solutions are proposed.

Part D “Design principles” describes the most important materials used these days for the individual layers in a flat roof construction. The catalogue of materials extends from waterproofing (bituminous, plastic, elastomeric and liquid) to insulating materials, glass and impermeable concrete, which tends to play a special role in practice. Additional layers, e.g. those necessary in green roofs, are also discussed.
Having explained the individual layers of the construction, these are then combined to create the customary forms of construction for flat roofs. The main variants are: positioning the waterproofing above the insulation, below the insulation or between layers of insulation.
Other important subjects in this section are green roofs and roofs designed for foot or vehicular traffic. Such roofs provide supplementary uses, but they do place greater demands on the construction. Forms of flat roof construction encountered less frequently in practice - impermeable concrete, glass and metal - are also examined here.These roofs may satisfy certain architectural or engineering needs but do represent a challenge in terms of building physics. Practical solutions for joints and junctions, rooflights, safety features and drainage are among the further topics covered in Part D. Care and maintenance as well as the refurbishment of flat roofs – as the logical extension of design and construction – are also introduced to the reader.

Part E “Construction details” complements the chapter on forms of construction. The clear drawings illustrate the essentials of the constructional and building physics requirements. The details so important to the various forms of flat roof construction, e.g. edges, junctions with walls, penetrations and drainage, are dealt with here in depth.
The examples of construction details shown in this part of the book should, however, be understood as illustrating principles and not universally applicable solutions. They are intended to explain in a practical way how the comprehensive requirements placed on different flat roof designs can be solved, and therefore should be regarded as a starting point for everyday design and detailing tasks.

The projects shown in Part F “Case studies” demonstrate the diverse design options for flat roofs. The projects were selected in the first instance according to design and architectural aspects, but the diversity of potential forms of construction and materials was another priority. The examples have been taken from different locations with correspondingly different conditions with respect to climate, technical regulations and standards of building. Once again, the details in this section therefore do not represent universally applicable solutions, but rather details that must be adapted to suit each respective situation.

To conclude this preface, I would like to thank all my colleagues in this field and all the institutions and persons whose competence and dedication have contributed to the production of this book.

Klaus Sedlbauer
June 2010

Part A Introduction

Fig. A Roof edge detail, temple in Lhasa, Tibet (CN)

The evolution of the flat roof

Christian Schittich

A 1

A 2

Roofs of earth and loam – archetypal forms

At the start of the 20th century, as the flat roof gradually started to spread across Central Europe too, its most devoted advocates, great names such as Adolf Loos or Le Corbusier, turned it into almost a myth. Not just because it rendered possible the cubist building form so sought after in those days for aesthetic reasons, but primarily because of its usefulness. Because, used sensibly, a horizontal termination to a building returns to its occupants that area consumed by the building itself in the first place. Flat roofs are more than just the indispensable upper termination to a building, more than just protection against the weather or other outside dangers. Whenever technically feasible or wherever climatic conditions allow, people have always used the flat roof as a welcome extension to their living space, as an ancillary and circulation area, or as a terrace, but also for lighting and ventilating the rooms below. Traditionally, flat roofs are found mainly in hot regions with low rainfall, and are less common in climate zones with moist, hot conditions or heavy snowfalls. The building materials available locally is another important reason for this. For wherever rainfall is scarce, supplies of timber are often in short supply as well. And the construction of a flat roof consumes much less of that valuable resource than is the case with complex pitched roof structures, and if necessary much smaller cross-sections will often suffice. For example, just one layer of naturally crooked, short branches is adequate as a loadbearing layer for a short span, or just a few joists if the span is longer. On top of this, depending on local availability, sticks or brushwood, reeds, bamboo or dried palm leaves, but in some places even stone flags. Usually also a layer of sand, leaves or pine cones to regulate the interior climate and moisture levels. Waterproofing is assured with the materials available in the immediate vicinity: earth and loam, which is compacted, smoothed flat and often also impregnated. Nevertheless, traditional flat roofs require permanent maintenance. In many regions that work is usually carried out once a year, after the rainy season. Over the centuries, people have devised ingenious waterproofing methods. For example, in Sana'a, the capital of Yemen, where traditionally the *qadath* is used, a type of waterproof screed made from a mixture of water, lime and basaltic lava plus a sophisticated impregnation of cooking fat (Figs. 1 and 2).
For the Pueblo people of south-western USA it is the need for constant expansion that is crucial as well as the consumption of materials and the usability of the space. This is because their houses, the pueblos, are based on an additive system: individual rooms, roughly equal in size, are added horizontally or vertically, like a modular system, to meet family or other needs (Fig. 7). The specific uses of the various rooms can be varied at any time, room functions swapped around.

A 3

A 4

A 1 Traditional flat roof in Yemen: laying the short crooked branches over tree trunks and …
A 2 … laying the loose fill.
A 3 House in Lhasa, Tibet (CN)
A 4 A house of the Hunza people, Kashmir (PK)
A 5 Roofscape of the monastery complex at Laprang, Qinghai (CN)
A 6 House, Sada (YE)
A 7 Taos Pueblo, New Mexico (USA)

"One worker uses his metal scraper to push materials from each pile, in a mix ratio of approx. 60 % ash to 40 % lime, to a first pair of workers. These two ... start to crush their portions and at the same time mix them to create a more or less homogeneous mass. Once this mixture has achieved a certain granular consistency it is ... pushed across to the next pair of workers until it has ... become a creamy, relatively dry paste. It takes about an hour for one portion … to pass through this system. The monotonous rhythm of the hammering is accompanied by storytelling or, more frequently, by the antiphonal songs of the workers ... Five or six workers squat ... on the ground tamping the *qadath* [a traditional screed] brought in to them with sharp-edged stones in a semicircular pattern. At the same time this unfinished surface is constantly splashed with water from a … straw brush, the *meknesse*. It takes one man about two hours to tamp one square metre ... The surface of this first layer is rough and marked by the pattern of the tamping action. After being allowed to dry for 2–3 days, the process is repeated with a second layer ... During the 7–10 days it takes for the *qadath* to cure, the surface is frequently wetted with limewash (two handfuls of lime dissolved in a bucket of water), again using the *meknesse* ... Once the screed has set, the surface is polished with palm-sized stones; these stones are family heirlooms handed down from generation to generation ... The now almost white surface of the *qadath* is treated with hot fat to give it its final, waterproof, satin-like finish ... The floor finish produced upon completion of these numerous manual processes has now acquired its key properties; it is waterproof, abrasion-resistant, mildly elastic and … will last for well over a century."

Jan Martin Klessing [1]

The houses of the Hunza people in the part of Kashmir belonging to Pakistan are typical of the barren regions between the Caucasus and the Himalayas (Fig. 4). Their small, densely packed, one-room houses are entered via a square opening in the roof, which also serves to admit daylight and air and allows smoke to escape from the inside. The opening can be closed if necessary.

On steep mountainsides flat roofs are often the only level areas available outside. They are used for all types of domestic work, occasionally for threshing grain and even as bedrooms on hot summer nights. But they are especially important for drying fruit because the inhabitants of barren mountainous regions rely on an elaborate stockpiling lifestyle owing to the long cold winters and the relatively small numbers of livestock that can be kept.

Flat roofs are also widespread in Tibet, for the aforementioned reasons. The flat roofs of the small farmhouses in rural districts – waterproofed with a flattened layer of loam – serve as an extension to living and working areas, and there are often rooftop terraces at different levels. Flat roofs can also be found on the splendid townhouses of Lhasa, Xigazê or Gyanzê (Fig. 3), where they also function as pathways. The great monastery complexes are particularly impressive; here, several thousand monks live in town-like structures made up of closely packed cubic buildings. In the centres of these complexes it is only the shrines and temples that are crowned with golden roofs in the Chinese style. But these roofs are not just designed to provide protection against the weather; the pitched roof is artificially elevated to create a symbol.

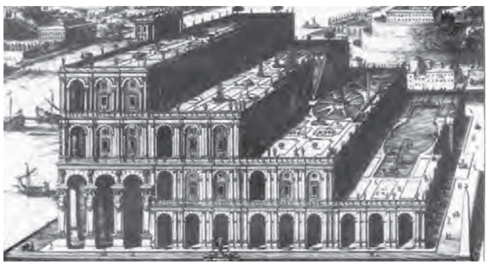
A 5

A 6

A 7

"We come now to treat of Pavements, which also partake somewhat of the Nature of Coverings … Those which are open to the Air ought to be raised in such a Manner, that every ten Foot may have a Declivity of, at least, two Inches, to throw off the Water, … if the Pavement is to be upon Rafters, cover them over with Boards, and upon them lay your Rubbish or Fragments of Stone a Foot high, and beaten together, and consolidated with the Rammer. Some are of Opinion, that under these we ought to lay Fern, or Spart, to keep the Mortar from rotting the Timber."

Leon Battista Alberti [2]



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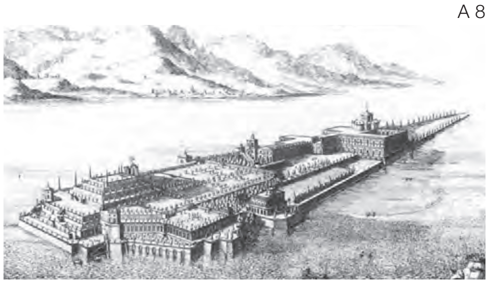

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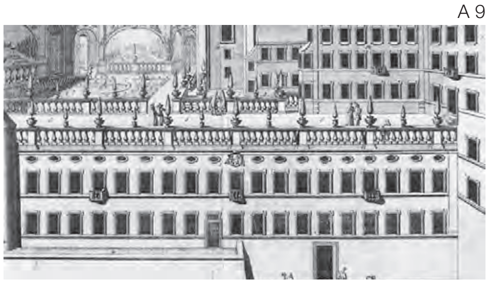

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Renaissance and Baroque: the first flat roofs in Central Europe

Whereas the flat roof has been in use in many countries around the Mediterranean, in Asia and in the Americas since time immemorial, it remained an insignificant building form in Central and Northern Europe for thousands of years. It was not until the Renaissance, as unambiguous, geometrically straightforward building forms and facades started to replace the Gothic architecture of pointed arches and flying buttresses, that people started to express a wish to see a horizontal upper termination to a building. But as true flat roofs were still very complex in terms of their building technology, clay tile and stone flag roofs with a shallow pitch were concealed behind tall parapets und balustrades, which often appeared to be autonomous components. At the same time, leading architects such as Leonardo da Vinci or Leon Battista Alberti started experimenting with the feasibility of flat roofs. The legendary Hanging Gardens of Babylon too, which the Greeks had included in their Seven Wonders of the World, had again inspired the imaginations of scholars and architects since the early days of the Renaissance, motivating them to creative interpretations and attempts at reconstruction (Fig. 8). For example, Pope Pius II had hanging gardens built for his palace in his "ideal city", Pienza, in 1462. This was followed by numerous copies throughout Italy, culminating in the development on the Borromean Islands in Lake Maggiore, where around 1630 Count Carlo III Borromeo started to transform the Isola Bella into a system of 10 garden terraces (Fig. 9). Not long afterwards, in the heyday of the Baroque, we start to see the first rooftop gardens north of the Alps. But they remained sporadic, confined to expensive prestigious structures because of the enormous amount of work required to provide the thick insulating and drainage layers made from expensive waterproofing materials such as copper, lead and tar. One impressive example that still survives is the garden that the Prince-Archbishop of Passau had built for his palace around 1700 – a spacious south-facing terrace on the north bank of the River Inn, with trees and bushes in tubs, flower beds and fountains (Fig. 10).

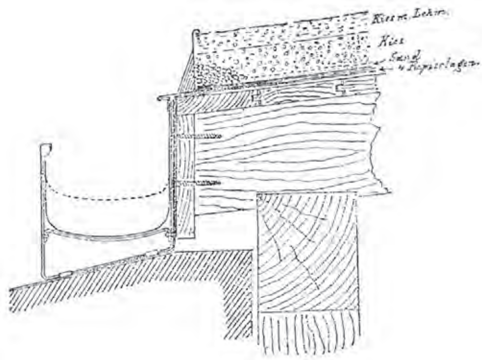
In a treatise written around 1722, Dresden's Councillor of Building and Commerce, Paul Jacob Marperger, urged the use of flat roofs – which he called terraces – not purely as luxury commodities for edification, but primarily for purely practical reasons, for the general public as well. Even though his ideas at that time remained essentially utopian, he dedicated himself passionately to the universal adoption of usable flat roofs and therefore anticipated many of the arguments that would be voiced 200 years later by the flat roof advocates in the "roofs dispute" of the early modern movement. Marperger listed aesthetics among his reasons as well as the saving of timber or the reduced fire risk, and mentioned the diverse usage options or the gain in space for building owners "when instead of a tall roof his house would have another storey". [3]

Wood-cement roofs and early reinforced concrete

However, the crucial breakthrough in the feasibility of such ideas came about 100 years later in the form of the wood-cement roof, developed by master cooper Samuel Häusler from Silesia. His inexpensive design involved bonding together several layers of oil paper with pitch or tar in situ and subsequently covering these with sand and gravel (Figs. 13 and 14). This type of roof became quickly established in the second half of the 19th century, primarily for ancillary buildings in the cities, also because of the much lower fire risk when compared with pitched roofs with their timber roof structures, and the relatively good thermal insulation properties. At the same time, in the age of Romanticism, the rooftop garden was gaining in importance. In 1867 the Royal Master Mason of Berlin, Carl Rabitz, recommended the adoption of flat roofs in his brochure entitled "Natural Roofs of Volcanic Cement" – also because of the possibility of creating rooftop gardens. Using wonderful illustrations, he describes balmy summer evenings on his own terrace with the wine flowing under a sky of stars (Fig. 11).
The next key impulse in the evolution of the flat roof was provided by reinforced concrete in its

"Just what terraces are / will not be so rightly unknown to anybody / to wit atop of houses / mansions and palaces such uncovered outdoor places laid out / over either the entire house / or one part thereof and apart from it / and on which one / can amuse oneself in the fresh air during pleasant evening hours chiefly in the mellow summer months / and can see over other houses far and wide / from some of them even to the open fields beyond / and can find pleasure there in orangeries / or other potted plants …"

Paul Jacob Marperger [4]



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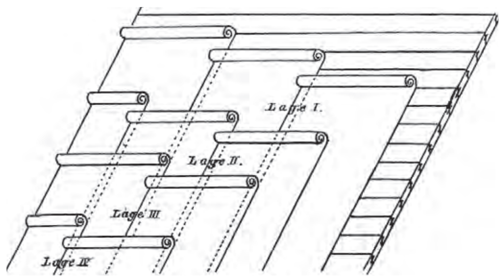

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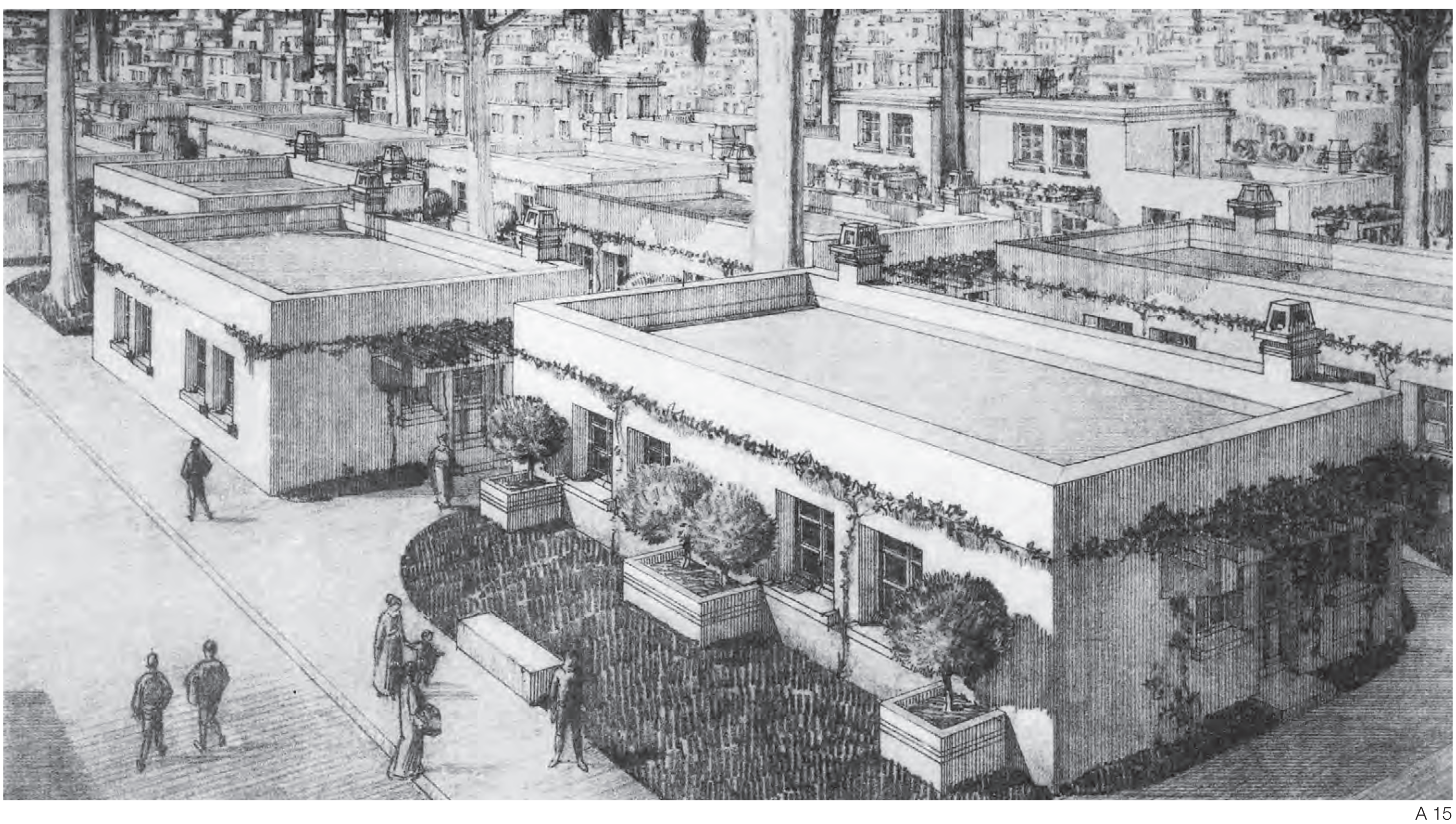
early forms, which enabled not only the simple construction of flat suspended floors and roofs, but in the eyes of the avant-garde also demanded an architecture to match the material. One of the pioneers in the use of the new material, the French engineer François Hennebique, demonstrated all the constructional and structural possibilities of the new material with technical virtuosity on his own house at Bourg-la-Reine near Paris (1900–1904). However, despite the cantilevering storeys and garden terraces at various levels, the design language was still essentially that of the 19th century; other architects of this period were employing a much more radical architecture, e.g. the young Tony Garnier in his designs for his "ideal city", the "Cité industrielle" (Fig. 15).

In 1907 the Swiss architects Otto Pfleghard and Max Haefli together with the engineer Robert Maillart designed the Schaffhausen-Thurgau Sanatorium in Davos with flat roofs and sun terraces on the topmost floor (Fig. 12). With its uncompromisingly modern architectural language, the building was well ahead of its time. As early as 1899, these architects had designed a hospital in reinforced concrete which Sigfried Giedion later described as follows: "It is certainly also the first time that flat roofs (asphalt) with internal drainage have been used for residential buildings." [5]

A 8 The Hanging Gardens of Babylon, Athanasius Kircher, engraving, 17th century
A 9 Isola Bella in Lake Maggiore, J. B. Fischer von Erlach, copperplate engraving, 1721
A 10 Garden terrace of the Prince-Archbishop's palace in Passau (D), c. 1700
A 11 Rooftop garden of the Royal Master Mason of Berlin, Carl Rabitz, Berlin (D), c. 1867
A 12 Schaffhausen-Thurgau Sanatorium in Davos (CH), 1907, Otto Pfleghard and Max Haefli
A 13 Roof edge detail for a wood-cement roof
A 14 Layers of oil paper for a wood-cement roof
A 15 Residential district, Cité industrielle project, 1917, Tony Garnier



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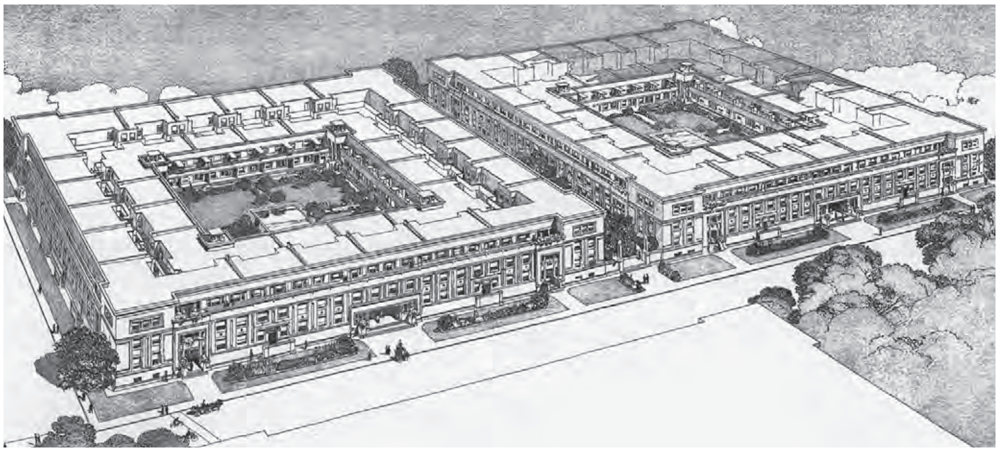

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Skyscrapers and bituminous felt: the flat roof asserts itself in Chicago

But the flat roofs mentioned above remained individual, exclusive examples. In the second half of the 19th century it was the USA, and principally Chicago, that took the lead in the use of flat roofs on a large scale.
After the devastating fire of 1871, in which about 18 000 buildings were destroyed, an unprecedented economic boom brought about a massive expansion of the city. Prices and a shortage of land resulted in a very dense urban layout characterised by building right up to the boundaries of the plots and taller and taller buildings. Most of the new buildings were purely utility structures which for financial reasons, but also because of the reduced fire load compared with pitched roofs with steel or timber supporting structures, were finished off with a flat "lid".
On the early skyscrapers with their facades still employing the language of classicism, this horizontal building termination was not only aesthetically desirable, but also offered space for the building services installations that were now starting to appear. The construction of flat roofs was made possible by the development of bituminous felt which employed bitumen as the waterproofing material. Bitumen is a waste product obtained during the distillation of crude oil and had been available in the USA since the mid-19th century.

The horizontal plate becomes a design element

A few decades later, Frank Lloyd Wright transferred the ideas of the Chicago School from the offices and department stores of the cities to the small buildings of the American suburbs. Right from his early designs, we see a diverse range of reasons for the use of flat roofs in his unparalleled output – from the accessible rooftop terrace to the reinforced concrete slab cantilevering for architectural reasons (Fig. 17) and the simple cubes of his "Usonian" houses (Wright himself remarked that pitched roofs had been avoided on those houses for financial reasons). The publication of his output by the Berlin-based Wasmuth publishing house in 1910 ensured his decisive influence on a whole generation of architects and artistic groups in Europe, from De Stijl to Walter Gropius and Mies van der Rohe. Wright designed the clearly structured blocks for the Lexington Terrace Apartments project in Chicago in 1901. With their stepped terraces around a central courtyard and access from each apartment, this design certainly anticipates the "stepped house", i.e. a house with terraces, even though the internal layouts paid little attention to orientation (Fig. 16).
Just over 10 years later, it was Adolf Loos who boasted that his Scheu House in Vienna (1912) represented the first stepped house built in Central Europe (Fig. 19). He had certainly collected ideas for this during his earlier travels around the Aegean and North Africa, even if he does deny this: "The Orient did not even enter my thoughts when I designed this house. All I meant was that it would be a great convenience to be able to stride out from the bedrooms,

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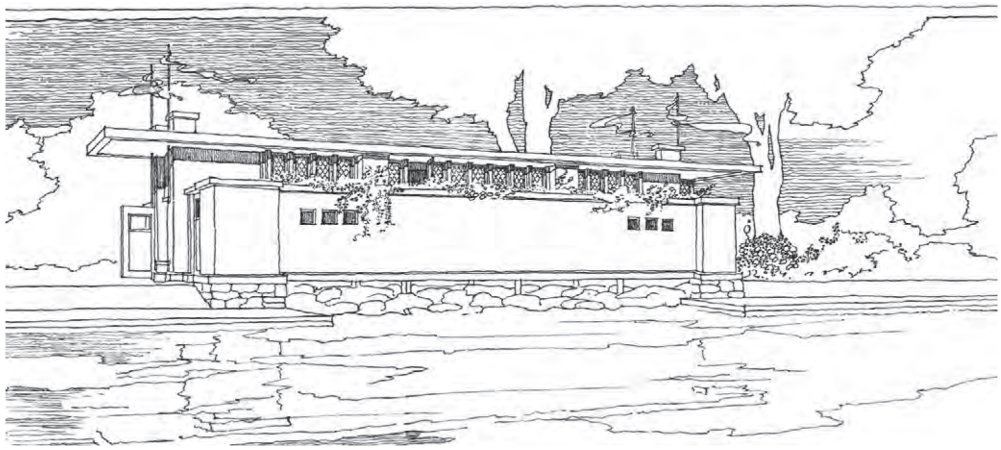
"One must ask oneself why terraces have been common for thousands of years in the Orient and why they have not been used in our climes. The answer is simple: The forms of building construction known hitherto could only realise the flat roof and the terraces in frost-free regions. Since the invention of the wood-cement roof (gravel roof) and since the use of asphalt, the flat roof and hence the terrace is also possible. The flat roof has been the dream of architects for four centuries. This dream became a reality in the middle of the 19th century. But most architects didn't know what to do with the flat roof."

Adolf Loos [6]



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which are on the first floor, onto a large, common terrace. Anywhere, whether in Algiers or Vienna." [6]
Furthermore, in this and other designs by Loos, the great purist, who throughout his life opposed the use of senseless ornamentation, aesthetic considerations of course also play a decisive role in the shaping of his strictly cubic building form. But this did not make him popular with his fellow citizens. The irritated public of Vienna, still ruled by the Kaiser at this time, missed the accustomed roof and complained in no uncertain terms about this architectural affront.
During that period the flat roof became more quickly established on industrial buildings, which were seen as utility structures where appearance counted less than economics. Just how wide the scope for interpretation was at the start of the 20th century, even among progressive architects, is impressively demonstrated by, on the one hand, Hans Poelzig's expressionistic, monumental Werder Mill (1906), with its massive walls, and, on the other, Walter Gropius' Fagus Factory (1911–14) in Alfeld an der Leine, which with its set-back loadbearing structure and softened corners already heralded the start of the modern movement (Fig. 20).

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A 20

A 16 Lexington Terrace Apartments project, 1901, Frank Lloyd Wright
A 17 Kaufmann Residence ("Fallingwater"), Mill Run (USA), 1937, Frank Lloyd Wright
A 18 Yahara Boat Club project, 1902, Frank Lloyd Wright
A 19 Scheu House, Vienna (A), 1912, Adolf Loos
A 20 Fagus Factory, Alfeld an der Leine (D), 1911, Walter Gropius, Adolf Meyer

"… reinforced concrete has a hostile enemy: expansion, the risk of cracking. In order to overcome the risk of cracking, it is advisable to plan hanging gardens on the roofs. Why? Because they retain a certain level of moisture and protect against expansion. Furthermore, it is incredibly pleasant for the human soul to rest among living greenery on the roof."

Le Corbusier [8]

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A 22

The early days of the modern movement

In the years before World War I it was only a few avant-garde architects who experimented with the new rational cubist language. And we certainly cannot speak of a uniform style – partly due to the continued presence of strong movements such as historicism, traditionalism and Art Nouveau. But in the immediate post-war years the collapse of the old order resulted in a fertile breeding ground for new ideas. And more than just a few architects and clients were now of the opinion that a new architecture was needed to reflect the new political and social structures. Painting, too, provided decisive momentum and contributed crucially to the establishment of the International Style.
For example, the members of the Dutch group De Stijl, a circle of artists and architects formed in 1917, transformed the abstract geometry of the painters Piet Mondrian and Theo van Doesburg into three-dimensional, neo-plastic concepts. Gerrit Rietveld's Schröder House in Utrecht (1924), with its space-forming plates intersecting at right-angles, can be regarded as the most rigorous example of this interpretation (Fig. 21). But eight years prior to that, Robert van't Hoff, another member of the group, had designed Henny Villa in Huis ter Heide (Fig. 22) – a profoundly modern piece of architecture for the Europe of that period. In terms of both its interior layout and its reinforced concrete outer shell, which is dominated by the overhanging flat roof, it takes its themes from the designs of Frank Lloyd Wright, whom Van't Hoff had met during a trip to the USA.
In the Soviet Union it was the Constructivists Malevich, Tatlin and Chernikhov who employed this new architectural language in their bold Utopian designs. In France, besides Le Corbusier it was primarily Robert Mallet-Stevens and André Lurçat, pupils of Josef Hoffmann, who helped the modern movement to achieve a breakthrough. And in Italy Giuseppe Terragni, with his Novocomum apartment block and the Casa del Fascio in Como. In the case of all these architects, whose common stylistic feature is a cubist architecture devoid of ornamentation, architectural considerations were among the main reasons for choosing the flat roof. But there were other, equally important, reasons that led to the spread of the flat roof in the early days of the modern movement, e.g. new construction techniques that required the new forms, illustrated in exemplary fashion by Mies van der Rohe's design for a reinforced concrete office block dating from 1922. New interior layouts also played a role. Wright's idea of the unconstrained interior layout quickly found favour in Europe and was developed further by Mies van der Rohe to create the flowing space, the most rigorous realisation of which was his Barcelona Pavilion (Fig. 23). It is the cantilevering roof plate that emphasizes the continual transition from interior to exterior in the layout below.

Prefabrication und the "roofs dispute"

Other architects, in addition to Adolf Loos and Le Corbusier, focused on the utilisation of the roofs. Richard Döcker published his book *Terrassentyp* (terrace type) in 1929, the prime aim of which was to illustrate the necessity for sun terraces in hospitals and also the pleasantness of rooftop gardens on private buildings, using his own buildings and projects as examples. For many architects the firm belief in technical progress and rapid developments in industrialisation were important reasons for choosing the flat roof. It was precisely the urgent need for housing for the masses that convinced the avant-garde that roofs – in keeping with the

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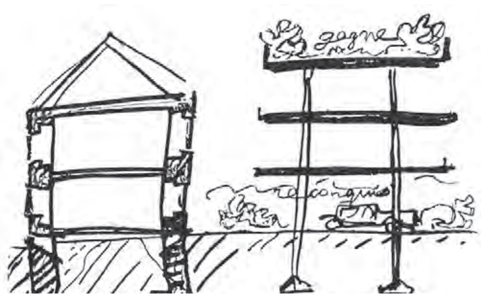
"… one must come to a totally different solution. It is necessary for the roof to slope inwards, for it to carry the snow over the entire winter, and for the meltwater that arises as a result of the central heating to drain away via a downpipe which is no longer external to the building, but rather internal, is possibly located in the middle, i.e. where it is warmest. And that this downpipe extends from the inward-sloping roof surface to a drain at the base of the building, where there is no risk of freezing, and into which, incidentally, pipes from bathrooms and elsewhere discharge."

Le Corbusier [10]



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state of the art – in all developed regions of the world had to be flat and could only be waterproofed with industrially manufactured materials such as sheet metal, asphalt or bituminous felt. The traditional craft-like methods of working were rejected as obsolete and old-fashioned. On this theme, Franz Schuster wrote the following in 1927 in the magazine *Das Neue Frankfurt*: "It would contradict all labour economics and the technical spirit of our age, which again and again entice us to build our houses from large-format elements, if we were to place the old hand-crafted pitched roof, with its posts, ties, rafters, battens, tiles and many, many nails, on top of the house walls set up with the few turns of a crane." [9] The euphoria for the prefabricated building was enormous. Many experiments were carried out, but the great breakthrough eluded the experimenters.

The "roofs dispute", which had been smouldering for some time, finally burst into flame with the Weißenhof Estate in Stuttgart, which was built in 1927 to demonstrate the new way of building. Architects were divided into two camps. The question "Flat roof or pitched roof?" became a question of attitude. Whereas one group regarded the flat roof as the symbol of the new age, the new technology, and regarded it as indispensable, the more traditions-oriented group regarded the pitched roof as the expression of the indigenous roots of building and polemicised vehemently against the cubist constructions in Stuttgart.

Le Corbusier's pair of semi-detached houses for the Deutscher Werkbund exhibition in Stuttgart proved to be a convincing declaration of his architectural philosophy, which he summarised in his famous book *Five Points of a New Architecture* (Fig. 25). Hardly any architect of the modern movement propagated the design and use of flat roofs as decisively as he. Le Corbusier was convinced that "it is human instinct to climb up to the roof of a house" [11], and asked: "Does it not truly offend all logic when a whole urban surface … remains unused?" [12] Rooftop gardens, one essential demand in his *Five Points*, were ascribed not only functional, economic and architectural attributes, but purely technical and constructional ones as well.

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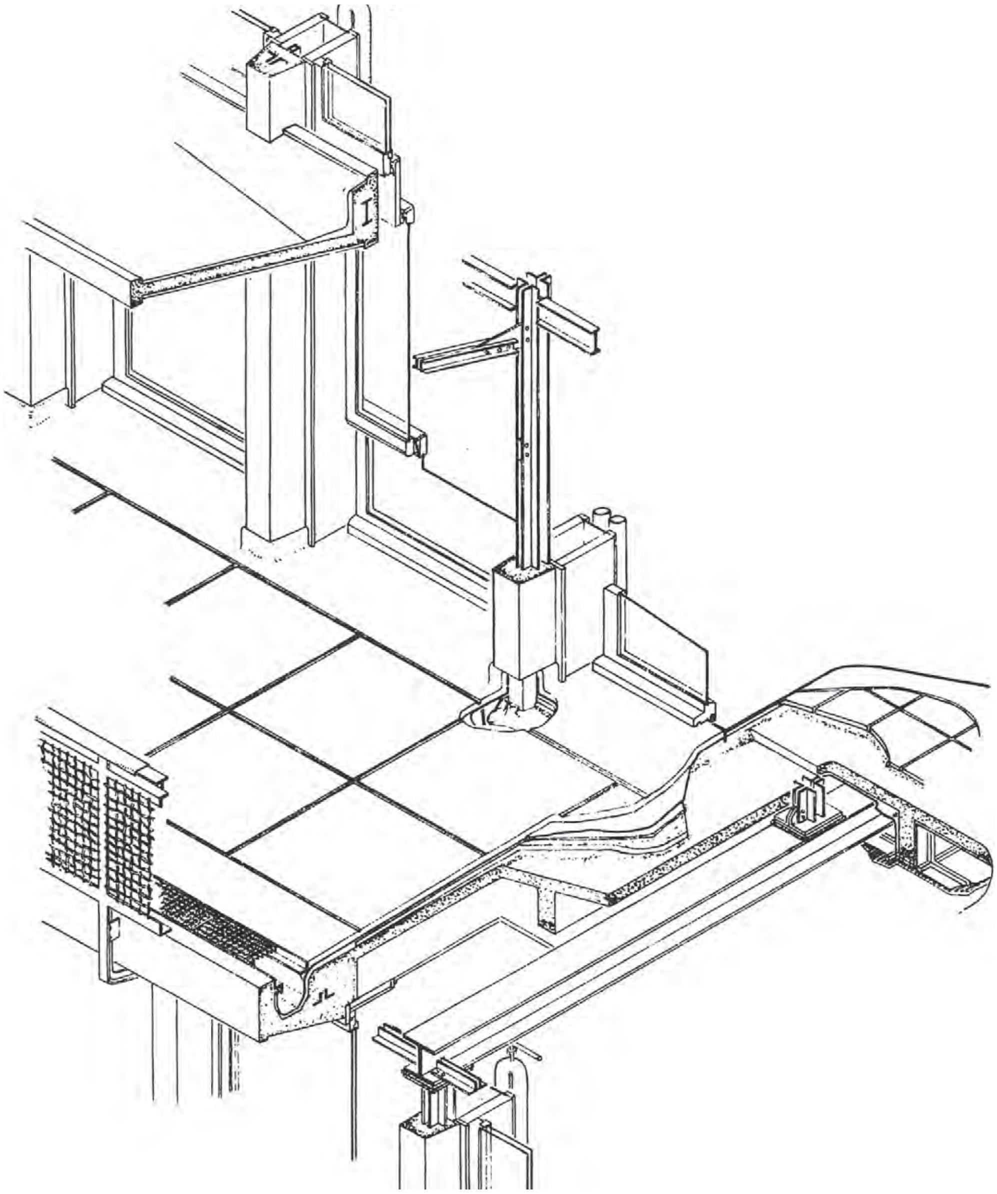
A 21 Schröder House, Utrecht (NL), 1924, Gerrit Rietvelt
A 22 Henny Villa, Huis ter Heide (NL), 1919, Robert van't Hoff
A 23 German Pavilion, Barcelona (E), 1929, Ludwig Mies van der Rohe (reconstructed 1983–86)
A 24 Sketches for comparing new and conventional forms of construction, 1929, Le Corbusier
A 25 Rooftop terrace, semi-detached houses, Weißenhof Estate, Stuttgart (D), 1927, Le Corbusier

Forms of construction in the early modern movement

In the early years of the modern movement, when the flat roof was already a permanent feature of the language of progressive architects, there was still a deep rift between the architectural desires of the planners on the one hand and the constructional and technical possibilities on the other. Many new waterproofing materials and patents appeared on the market, but reliable experience was lacking at that time. So at the start of the 1920s the wood-cement roof continued to prevail, although reinforced concrete was gradually taking over from timber sheathing on timber joists as the loadbearing structure. From the building physics viewpoint in particular, there were still major problems to overcome. Thermal insulation was generally minimal and often attached inside, and the problem of thermal bridges was only scantily addressed. In order to avoid condensation, an additional air space beneath the loadbearing structure was frequently provided in the form of a suspended "Rabitz" ceiling (iron wire mesh embedded in gypsum). As external waterproofing, the wood-cement finishes were joined by asphalt and, ever more frequently, roofing felts too.
Flat roof drainage up until the early 1920s was still essentially to the outside, the perimeter, which required a minimal fall in one direction. But larger roof surfaces with internal drainage were already being built, e.g. the Schatzalp Sanatorium in Davos (c. 1900). Extremely enlightening with respect to the state of the art during the 1920s are the results of a poll that Walter Gropius carried out in 1926 among leading international architects for the journal *Bauwelt*. With only a few exceptions, all believed that they had the constructional problems under control. However, the many different views regarding the sequence of layers and the design of various junction details clearly reveal the great uncertainty still prevailing at that time. Otto Haesler and Peter Behrens were still firmly committed to the wood-cement roof, which had been rejected by others because the poor ventilation frequently resulted in rotting of the wood. Josef Hoffmann criticised the "inadequate durability of the layers of felt and shortcomings in detecting flaws". [13] Heavyweight roof structures with 30–40 mm cork or "Torfoleum" (compressed, impregnated peat boards) as thermal insulation plus two or three layers of roofing felt as waterproofing was the recommendation. The brothers Bruno and Max Taut swore by a special asphalt-saturated roof canvas together with asphalt board or mastic asphalt. There were also many different opinions regarding edge details and junctions with rising masonry.
The purist details of Mies van der Rohe, designed for their aesthetic effect only, with only a minimal upstand along the edge of the roof, certainly occupy a special position in this dispute (Fig. 29).



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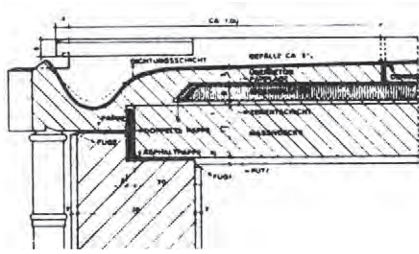

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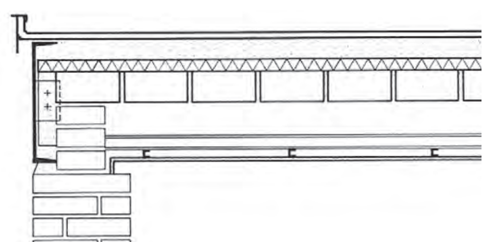

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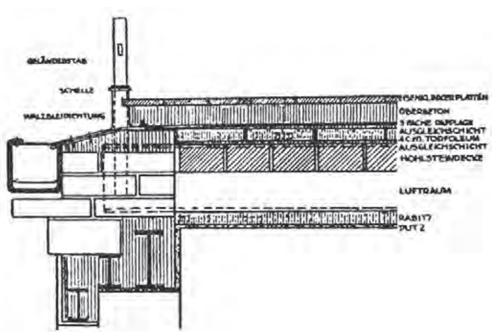

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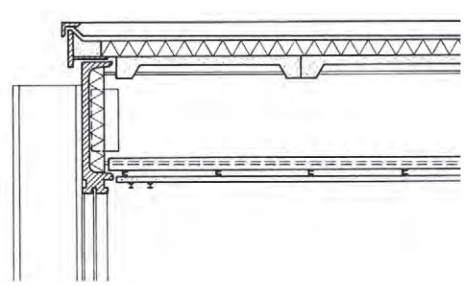

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The Frankfurt standard for small dwellings was published in 1927. It dealt in detail with flat roof constructions and can be regarded as one of the first guidelines for such roofs (Fig. 27).

The global spread of the flat roof through the International Style

In the years following World War II, as the International Style was enjoying its triumphal procession around the world, the flat roof associated with this architecture suddenly became the norm. But the technical problems had by no means been fully eradicated. In Germany and many other countries the years of reconstruction and economic prosperity resulted in huge numbers of quickly erected buildings for the masses whose aesthetic and technical shortcomings would do permanent damage to the reputation of the flat roof.
On the other hand, many dedicated architects exploited the architectural and functional options of the flat roof to the full. For example, Ludwig Mies van der Rohe used the idea of the external loadbearing structure for his Crown Hall (1956) on the IIT Campus in Chicago (Fig. 34). The flat roof of the building seems to float, suspended from four welded solid-web steel girders, above the space below, which has no intervening columns and therefore remains fully flexible and universal in its usage. He managed to create the apparently completely detached floating roof in his design for the National Gallery in Berlin (1968), which is in the form of a steel grillage. During the same period, the architects of the modular systems, large structures and stepped buildings so typical of the 1960s and 1970s made systematic use of the opportunities presented by the flat roof because its horizontal form was essential to achieving flexible, additive systems or the private open area in front of every dwelling. Good examples of this are the Metastadt System of Richard J. Dietrich (1965 onwards; Fig. 31) and the Olympic Village in Munich (1972), where owing to the separation of road traffic and pedestrians additional public thoroughfares and circulation zones are provided on vast flat roof structures (Fig. 32).
A few years later, architects with a technological bent, such as Lord Norman Foster with his Sainsbury Centre for Visual Arts in Norwich (1978), or Michael Hopkins with his Patera System (1984), attempted to resolve the constructional difference between roof and facade and construct the entire building envelope, including the roof covering, exclusively from industrially manufactured components. One purely concrete roof without any waterproofing at all was ventured by Heinz Isler on his own house (1964) in Burgdorf, Switzerland, which is protected by a dense, natural covering of plants and is still working well today (Fig. 33).

A 26 Isometric section through sun terrace, hospital in Waiblingen (D), 1928, Richard Döcker
A 27 Roof edge detail according to the Frankfurt standard for small dwellings, 1927
A 28 Proposal for roof edge detail for accessible flat roof, Erich Mendelsohn
A 29 Roof edge detail, Crown Hall, IIT, Chicago (USA), 1953, Ludwig Mies van der Rohe
A 30 Dachrand, Farnsworth House, Illinois (USA), 1950, Ludwig Mies van der Rohe
A 31 Model of Metastadt System, Wulfen (D), 1975, Richard J. Dietrich
A 32 Olympic Village, Munich (D), 1972, Heinle & Wischer
A 33 Isler's own house, Burgdorf (CH), 1964, Heinz Isler
A 34 Crown Hall, IIT, Chicago (USA),1956, Ludwig Mies van der Rohe


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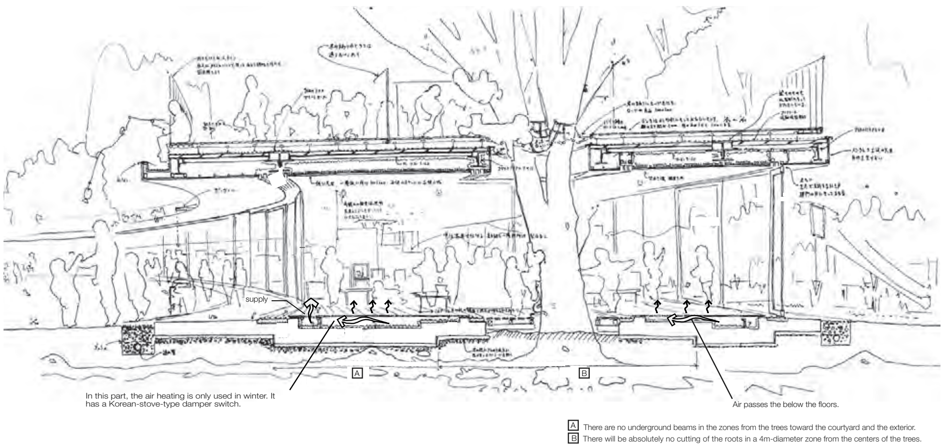

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The flat roof in contemporary architecture

Flat or pitched? Until well into the 1980s picking the right roof form represented virtually a confession of faith for architects. Only those who advocated the horizontal building termination were regarded as modern and hence up to date, whereas the proponents of the inclined variation saw themselves quickly forced into the corner of the "old school". Today, however, the "roofs dispute" is long since a thing of the past. Flat roofs and pitched roofs exist side by side on equal terms. At the same time, new materials and forms of construction are increasingly diluting the difference between the two forms. More and more, roof and walls merge into a uniform building envelope. However, wherever true flat roofs are used, their designers, especially in the case of prestigious structures, increasingly turn them into a fifth facade. Dominique Perrault, for example, covered the entire roof surface of Berlin's velodrome plus the areas of the facade defined by the loadbearing structure with what was at that time (1997) a new type of metal fabric for architectural applications. Besides the surprising visual unity, he also achieved interesting effects caused by the strong reflections of the incident light. For the MAXXI Museum in Rome (2010), the British-Iraqi architect Zaha Hadid used the elevation of the building in order to underscore the dynamic of the sculptural building form. She divided up the roof surfaces with glass ribbons that give the impression of movement and at the same time allow daylight to illuminate the interior of the museum below. In Lille the French architects Jean-Marc Ibos and Myrto Vitart created a flat roof of glass that lies like a reflective pond on the urban square in front of the Musée des Beaux-Arts (1997; Fig. 36). Massimiliano Fuksas, on the other hand, upgraded the roofs to his engineering centre (2004) in Maranello, northern Italy, with real water and therefore at the same time achieved a natural climatic effect for the adjacent offices.
Other designers have surprised us with unconventional uses of their roof surfaces. For example, Takaharu and Yui Tezuka used the entire oval roof to their kindergarten in Tokyo (2007) as a huge playground (see pp. 196–197). A similar

A 35 Kindergarten, Tokio (J), 2007, Tezuka Architects
A 36 Velodrome, Berlin (D), 1997, Dominique Perrault
A 37 Terminal, Yokohama (J), 2002, Foreign Office Architects
A 38 Musée des Beaux-Arts, Lille (F), 1997, Jean-Marc Ibos and Myrto Vitard
A 39 University campus, Saitama (J), 1999, Riken Yamamoto

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concept was pursued by the Berlin architects Armand Grüntuch and Almut Ernst with their grammar school in Dallgow-Döberitz (2005; see pp. 191–195). Although a less extrovert design, it offers a more diversified platform for experiences with numerous spatial references. Riken Yamamoto converted the entire horizontal termination to his university buildings in Saitama, Japan, into a huge maze-like garden (1999; Fig. 37). The nearby terminal in Yokohama, completed three years later, was also turned into an urban space for the public (Fig. 35). So the flat roof returns the land consumed by the building to the urban space and roofs coalesce into a morphological unity.

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