Construction Materials Manual

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Preface

Books explaining the fundamentals of building materials have long since been standard reading for architects and engineers. They supply comprehensive information about materials for construction, explain their origins and production processes, outline the forms in which they are available and the potential applications, and hence provide an in-depth understanding of properties and processing options. The publications currently available also follow the traditional layout: an overview divided into sections devoted to the groups of materials, with comprehensive information on how they affect the performance of the building.

This established technical and business-like approach has been supplemented recently by other groups of publications. One group is the books – some of them in large format – of samples of materials which with their primarily visual means of communication would seem to represent the antithesis to the aforementioned standard works. They present extensive ranges of materials or provide an insight into the diversity of the possibilities of individual groups of materials. They display the available diversity as materials or in as-built contexts. This illustrates the increasing need to place the way we experience building materials on a sensual level at the very heart of our decisions regarding materials and hence improve the tangible qualities of the built environment in visual and sensual terms. The task of such books is to show us the surface of the material. The other group is those recent publications and sets of figures that primarily consider how building materials affect the environment and our health, also their durability and recyclability plus other sustainability criteria. These parameters were neglected for many years although the building industry consumes the largest share of all raw materials and energy and – despite the comparative longevity of this industry's products – also contributes the lion's share of the waste produced. The origins of the impact of building operations can be traced back to, above all, the choice of materials. Until now, their criteria and indicators have only been available to a specialist circle of readers.

The *Construction Materials Manual* combines the contents of these three formats. It brings together clearly the technical, sensual and, for the first time, also the ecological aspects in one work. Therefore, continuing in the tradition of the series of the *Construction Manuals*, it closes a sensitive gap. The reader gains access to a more comprehensive treatment of building materials. Based on this approach, the choice of material can be made with more circumspection and care, will also permit more sound reasoning than was possible in the past. The carefully prepared, comprehensive parameters now enable verifiable statements instead of vague claims, especially in the categories of efficiency and sustainability in the building sector. This also means we can say farewell to global prejudices regarding building materials; there is actually no building material that can be unanimously recommended or rejected without any riders.

Does this mean that "anything goes" where building is concerned? No, it always depends on the structural, building performance, functional and environmental contexts and the extent to which the material is used. The *Construction Materials Manual* can be used to check the intended application, to establish whether the planned material should be considered as suitable or critical. Unfavourable results need not necessarily lead to the exclusion of a material preferred for economic or design reasons. Increasingly, we find that material properties can be influenced, in the sense of "custom-made". In the future architects, designers and engineers – also with the help of the knowledge gathered together in this book – will be able to specify desired properties and assist in the development of new, highly efficient materials. At the same time, they can therefore make a significant contribution to improving the quality of building and to extending the design repertoire.

The choice of material has a very decisive effect on the appearance and perception of buildings, and not only their surfaces. For hundreds of years the materials available for buildings were very limited. Knowledge about materials was acquired over generations and handed down. Today, the expanding world of materials puts a broad selection of materials at our disposal for creating architecture. The risks of using new materials are high because long-term experience is not available. Nevertheless, the playful use of and pleasure in experimenting with materials are increasingly evident in our architecture. Material diversification, material alienation, conscious misuse of materials or materials "borrowed" from other industries have become acknowledged styling tools. Besides the primary edict of architectural form, the rhetoric of the materials is increasingly becoming the focal point of the culture of our built environment. Diverse innovations are creating an incredible need for information among architects and engineers.

The *Construction Materials Manual* cannot present every material, track every trend. Nevertheless, the authors have tried to take into account the diverse options available to architects today by covering a wide range of groups of materials, by describing their use in various practical contexts and by direct comparisons of their properties. For unconventional groups of materials, the various levels of consideration can perhaps to some degree compensate for the features that characterise our traditional building materials: dependable awareness of their properties, familiarity with their treatment and use.

The layout of the book follows the procedure for choosing building materials and then integrating them into the draft and detail designs.

Part A "Material and architecture" approaches the current and fundamental aspects of choice of materials. The articles show how choice of material influences contemporary architecture and trace the associated selection processes. They present the importance of sustainability criteria in the choice of material and describe the dynamics in the development of innovative building materials. Furthermore, the enormous part played by the surfaces of materials as the interface between building and occupants, not only in design, is clarified. This aspect is still much underestimated in architecture.

Part B "Properties of building materials" is dedicated to the overall consideration of the materials themselves. Here, the materials are sorted into groups according to their origins and production, methods of processing, but also their chemical composition, physical properties plus their impact and appearance. This section reviews the fundamentals for using the building materials covered and mentions the risks of those materials. The properties in terms of building performance are mainly shown in the form of tables. Wherever possible, the text is backed up with drawings, photographs and diagrams. Environmental parameters for the materials are described at the end of this section and are summarised in practical terms for the main building materials. Common reference units such as m^2 or kg are employed for easy comparison and ease of understanding.

Just considering the material alone is always an abstract exercise for planning and design when materials have a wide range of potential applications. This is true for the majority of building materials. For example: metals are just as useful as structural components as they are as cladding to external walls or linings to soffits, or pipework, or facade members. The authors therefore also saw it as part of their task to show the unison between material and design in addition to the wide range of potential materials. This context made it necessary to formulate the different possibilities and relationships that result from specific applications.

Accordingly, Part C "Applications of building materials" describes assemblies of components with respect to the use of the material. Besides functional and constructional aspects, building performance criteria such as fire protection, thermal insulation and sound insulation are considered specifically for the particular application (e.g. building envelope, intermediate floors). The multitude of design options and their framework conditions is derived directly from this. This also applies to the sustainability criteria. Various typical, layer-type constructions, presented in tabular form, are compared at the end of each section. From this, environmental effects and durability aspects related to particular components can be read off directly, which enable designers to estimate the overall impact on the environment of components and the complete structure at an early planning stage. Again in this section, the form of presentation is based on the need to provide the information in a compact format, and therefore uses the preferred method of conveying information for architects, i.e. photographs, drawings and graphics.

The prime aim of the selection of buildings in Part D "Case studies in detail" was to present the relationship between architectural expression and the materials used. The majority of buildings represent recent projects that are notable for their use of surface textures limited to just a few materials. The presentation of the projects features the materials and shows typical details for the use of such materials. The intention is to illustrate the architectural strengths that can evolve from an economic and skilful choice of materials.

Finally, I should like to thank all the staff of my department and all the institutions and people who contributed to this publication, and those who so generously provided material for inclusion.

Damstadt, August 2005
Manfred Hegger

Part A Materials and architecture

Fig. A Limestone stairs worn by thousands of feet over hundreds of years, Chapter House, Wells Cathedral, UK, commenced c. 1180 (stairs date from c. 1255), Adam Lock et al.

The surface in contemporary architecture

Christian Schittich

The increasing overabundance of stimuli, sensual impressions and colourful images has embraced architecture as well, even though the reaction to this is mixed. Some architects adapt to the circumstances and respond with similarly colourful images silk-screen-printed on brittle glass. Or with multi-coloured patterns over large areas, flickering media facades and illuminated screens. But others contemplate the quality of tried-and-tested building materials – solid, jointed natural stone, fair-face concrete, untreated timber or clay brickwork – in order to demonstrate the physical presence of a structure in an increasingly virtual world, or as a deliberate contrast to shrill surroundings. Whatever approach the architect chooses, the surface always plays a dominant role. It is essentially through the surfaces we see and touch that we perceive architecture. Their colours, textures and auras dominate the characters of interiors and facades.
Since time immemorial, people in all cultures have paid special attention to the surfaces of their houses and rooms, have fashioned them and decorated them. We see this in the colourful tapestries hanging in the tents of nomads, the colourful paintings in churches and palaces, and the tiles and stucco work of Islamic architecture (fig. A 1.1). In contemporary architecture we witness an alternation between schools that place form in the foreground, and others that emphasise the building envelope.

Emphasising the surface is currently "in". This goes hand in hand with the increasing separation between loadbearing structure and building envelope, but also with new technical options such as printing on glass and plastics, or the reproduction of patterns by means of computer techniques. And, of course, this trend is also linked to the growing significance of different media, which seem to imply that the image of a building is sometimes more important than the building itself! However, emphasising the surface directs our attention to the material itself, which more and more is being given the proper setting. The material becomes visible at its surface and its specific properties dominate its appearance, which depends quite decisively on whether a traditional or an industrially fabricated building material is being used, whether the material has been left untreated or covered or coated (to protect against corrosion), whether it is glossy or matt, textured or plain, or whether its appearance and its properties change over the course of time (intended or unintended). Like timber, which takes on a silvery grey colour, or metals, which oxidise and become dull, or untreated sandstone, which turns black over time.
In contrast to earlier times when everyday building projects could only make use of the materials available locally, we have at our disposal today an unprecedented diversity of building materials from the four corners of the globe to which industry is constantly adding new developments. This diversity brings with it

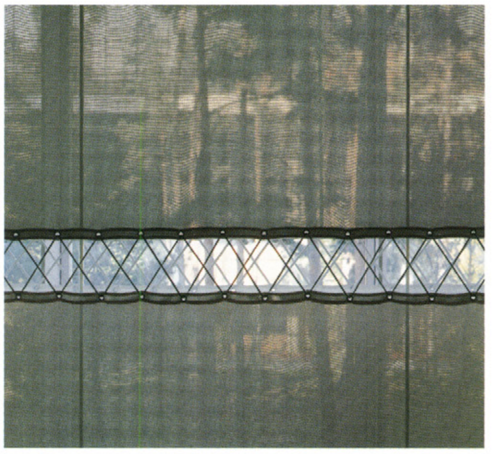
A 1.1

previously unforeseen opportunities, but also risks, at least in terms of the huge choice. Moreover, the growing "staging" of the material, which is not limited to traditional building materials, leads to more and more products from other sectors of industry – which hitherto found no use in building – being employed in architecture.

"Authentic" materials

The conscious treatment of materials is not a new concept confined to contemporary architecture. For more than 20 years, Tadao Ando has been using "authentic building materials with substance", such as untreated timber or (inspired by Le Corbusier and Louis Kahn) the raw power of fair-face concrete, in order to create rooms and moods. In his best designs the surfaces are not absolutely flat, but instead exhibit a minimal waviness within each formwork panel; the ensuing play of light and shadow lends the surface an adroit vigorousness (fig. A 1.4).
The buildings of Tadao Ando helped fair-face concrete to make a comeback. However, it was mostly the completely smooth surfaces divided into strict patterns by the formwork panels and punctuated by a regular network of real, sometimes even dummy, formwork tie holes on his ever larger works that found imitators worldwide.
Concrete in all its forms is currently popular. The use of rough formwork boards or subsequent furrowing or bush hammering gives it a striking, coarse character, the addition of coloured pigments or certain aggregates lend it a certain materiality. Jacques Herzog & Pierre de Meuron, for example, specified a concrete mix with gravel containing soil plus subsequent coarse pointing for the external walls of their so-called Schaulager in Basel (2003) in order to achieve a loam-type character (see p. 112, fig. C 1.27 c). On the other hand, the Basel-based architectural practice of Morger Degelo Kerez used a concrete mix with green and black basalt river aggregates plus extensive grinding and polishing on the art gallery in Lichtenstein (2000) to create the appearance of marble (see p. 112, fig. C 1.27 d).

A 1.1 Glazed ceramic tiles and stucco work, Alhambra, Granada, Spain, 14th century
A 1.2 National library of France, Paris, France, 1996, Dominique Perrault with Gaëlle Lauriot Prévost
A 1.3 Thermal baths, Vals, Switzerland, 1996, Peter Zumthor
A 1.4 Sunday school, Ibaraki, Japan, 1999, Tadao Ando



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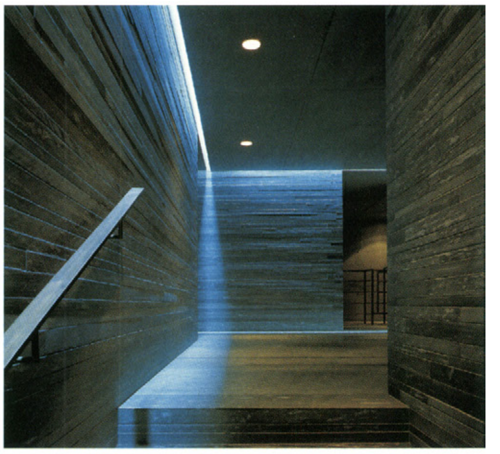


A 1.3

"Genuine" natural stone is used these days almost exclusively on the surface, in the form of thin cladding panels or even as "veneers" just a few millimetres thick bonded to an aluminium backing panel. Countless facades and foyers for banks and insurance companies bear witness to this.
But Peter Zumthor – like Tadao Ando a maestro in terms of the handling of materials – is not satisfied with such approaches. His structures draw their impressive strength from the conscious use of a limited number of primarily untreated materials such as stone, timber or concrete. Zumthor wants to expose the "actual nature of these materials, freed from all culturally mediated meaning", to allow the "materials to resound and radiate in the architecture". [1] In works like his stone-clad thermal baths in Vals (1996) or the chapel in Sumvitg covered in larch shingles (1988), his choice of materials reflects local traditions and helps to establish the structures in their surroundings. For example, the thermal baths in Vals takes on the appearance of a monolith growing out of the mountainous landscape, with the stone itself – in the form of solid walls made from local quartzite or as floor finishes and the linings to pools made from the same material – providing a multitude of aesthetic and haptic experiences both internally and externally.

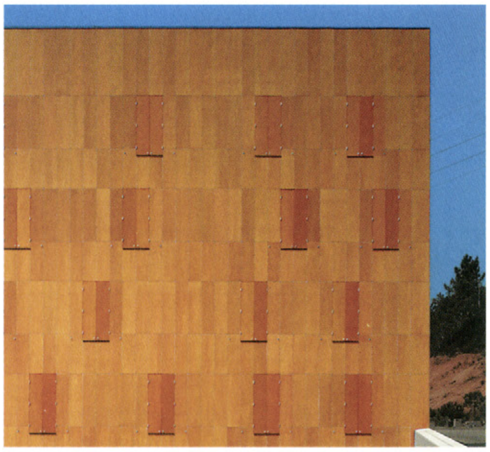
Industrially fabricated materials

Glass and transparent synthetic materials, but also metal meshes and fabrics, enable architects to play with the surface in a special way, to separate the physical and visual boundaries. In this respect, it is especially challenging to sound out the multifaceted zone between transparency and translucency. That can be achieved by covering the glass with louvres or perforated sheet metal, by printing, by acid-etching or the specific use of mirror effects and reflections.

The individual characters of and contrast between two very different materials – concrete and glass – was turned into an imposing theme by Peter Zumthor on his art gallery in Bregenz (1997). The monolithic core of in situ fair-face concrete walls and floors is enclosed in an overlapping cladding of acid-etched glass panes (see p. 86, fig. B 8.8), which thereby impressively reveals the physical presence of this "invisible" material. Translucent but not transparent, the consistent envelope changes its appearance depending on viewing angle, time of day and lighting conditions.
On their hospital pharmacy in Basel (1999), Jacques Herzog & Pierre de Meuron achieved a dematerialisation of the building fabric by using silk-screen-printed glass (see p. 117, fig. C 1.36c). In this example a completely regular pattern of green dots was applied to the glass cladding which encloses the entire building, even extending into the window reveals. The cladding therefore changes its appearance according to the observer's distance from the building. From far away the building takes on a uniform green appearance, but from closer the green dots become apparent. The spacing of the dots is such that the insulation behind and its fixings remain visible. As the observer changes his or her position, so he or she is treated to unceasing optical interference phenomena which animate the structure and break down its strict contours. The reflections of the surrounding trees merge with the facade. The Austrian architects Andreas Lichtblau and Susanna Wagner also used glass on their parish centre (2001) in Podersdorf on Neusiedler Lake, but this time for a subtle form of decoration. An enclosing and integrating glass wall

A 1.4


A 1.5


A 1.6

placed in front of the group of buildings was printed with passages of text written by local children mixed with quotes from the Bible (see p. 117, fig. C 1.36d). The result is not only interesting lighting effects on the buildings behind, but also a type of media facade conveying a message. Printing with texts or images – the primary objective of which is an aesthetic effect – still remains the customary form of media facade because active building envelopes with moving images and changing messages – with the exception of large advertising screens in city centres – have not yet become a familiar addition to the streetscape despite promising starts.
Matthias Sauerbruch and Louisa Hutton also exploited the possibilities of printed glass for their combined police and fire station in Berlin (see Example 24, pp. 258–60). In contrast to the two examples described above, however, transparency was less important than the concept of large-scale coloured patterns, with reflections in the glass surfaces providing additional charm.

Jacques Herzog & Pierre de Meuron managed to achieve a successful setting for synthetic materials, currently so popular in architecture, on the Laban Centre in south-east London (2003). The plastic four-wall panels are used so skilfully here that the result is a splendid, shimmering sculpture (fig. A 1.7). It emulates the straight lines of its surroundings, but at the same time its outlines become blurred with the sky, which leads to an almost unrealistic, seemingly intangible appearance. Colours are used very subtly here, with colour applied to the rear faces of only some of the plastic panels. This reinforces the shimmering, pastel-like effect. Depending on lighting conditions and viewing position, the material generates constantly changing colour effects. Inside the building, the interaction with the inner leaf of translucent glass results in a pleasant, softly coloured light which generates a positive atmosphere and suits the dance and practice rooms admirably.

Synthetic materials in the form of corrugated sheeting or multi-wall panels are inexpensive products that have been used in building for many decades, but usually for ancillary areas. In architecture they led a sort of shadowy existence – similarly to plywood, expanded metal or fibre-cement sheeting – until their aesthetic qualities were discovered and literally brought to the surface – to the visible sides of claddings and linings – in the course of the new awareness of materials.
Forming a contrast to this is the stainless steel fabric used by Dominique Perrault for the first time on the National Library of France in Paris (1995) – an example of the sensible transfer of a material from industry (where, for example, it is used for sieves) to architecture. Internally, in lecture theatres, staircases and other public areas, this semi-transparent material can be used as an acoustically effective soffit and wall lining, to conceal building services, as translucent partitions or as sunshading. This textured light- and air-permeable second skin lends the interior a special quality (fig. A 1.2).
Nowadays, the material appears in all sorts of places – from bank foyers to airport car parks. It is an effective treatment for facades too, as the curving skin of stainless steel fabric on the NOX arts centre in Lille demonstrates (see Example 15, pp. 234–36). The facade changes


A 1.7

its appearance depending on weather conditions and time of day – sometimes shining in the sunlight and concealing what lies behind it, at other times looking like a semi-transparent, fine veil draped in front of the building.

Variable surfaces

The effect and aura of a surface is essentially determined by the properties of the material, by the interaction of different building materials, by the alternation between closed and open zones, or even by movable elements. Variable building envelopes are not a new phenomenon. The window shutters of earlier times fall into this category of variability, likewise fabric sunblinds; in addition to being functional, they have always served as design features too. But hardly ever before has the aesthetic effect of the variable facade been given so much attention, the contrast between the closed and open conditions of hinged or sliding shutters placed in the settings conceived for them today. This applies to the student accommodation in Coimbra, Portugal, (1999) by Manuel and Francisco Rocha de Aires Mateus, where a completely flat, homogeneous surface of timber panels becomes an interestingly subdivided external wall by opening the shutters (figs A 1.5 and A 1.6). Another example is the straightforward, box-like stone house by MADA (see Example 5, pp. 212–13), whose hinged and sliding shutters do much to soften the building's severity.

That surfaces need not always be rigid was demonstrated by the Dutch pavilion at EXPO 2000 in Hannover, admittedly an extreme example. In this pavilion designed by the MVRDV team, the veil of water flowing across the outer skin was used to provide texture, its movement leading to a multitude of kaleidoscope-type patterns and a neverending alternation between transparency and translucency.

Interior surfaces

Besides the internal spaces themselves, the materials used internally for walls, floors, soffits, furnishings and fittings play a vital role. Their surfaces, textures and colours have a very decisive influence on the atmosphere. Unlike the facade, the building occupants have direct contact with the materials used internally; they can inspect them close-up, touch them, stroke them, perhaps even smell them. Natural and earthy materials such as timber, stone and concrete radiate warmth, exhibit a sensual materiality, whereas synthetic and coated materials can be readily used to express formal design concepts. For instance, in the minimalist interior of John Pawson (1999) it is wood with its reddish colouring and grain that dominates the character of the room, whereas in the fashion boutique by propeller z (2000) in Vienna it is the curving contours and the rich yellow colouring (figs A 1.8 and A 1.9).

Whether plastics, glass or wood, variable or minimalist, brightly coloured or plain, with its vast palette of possibilities the theme of the surface is probably more exciting now than it has ever been in the past. A tremendous delight in experimentation can be seen everywhere; boundaries are sounded out, traditional looks questioned, new materials and concepts tried out. But sometimes only a narrow dividing line

A 1.8

separates sensible innovation from hackneyed effects simply striving for attention. Focusing increasingly on the surface brings with it the risk of superficiality, which is particularly true for the applied ornamentation so popular at the moment, although it is true that the boundary between tastefully applied patterns and pure decoration is of course not fixed.

References:

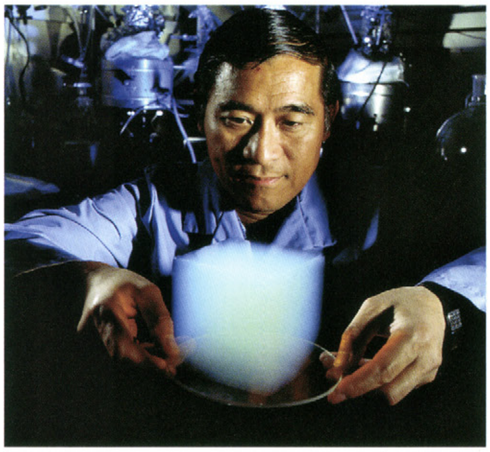
[1] Zumthor, Peter: Thinking Architecture. Basel/Boston/Berlin 2006

A 1.9

A 1.5–6 Student accommodation, Coimbra, Portugal, 2000, Manuel and Francisco Rocha de Aires Mateus
A 1.7 Laban Centre, London, UK, 2003, Jacques Herzog & Pierre de Meuron
A 1.8 Private house, London, UK, 1999, John Pawson
A 1.9 Fashion boutique, Vienna, Austria, 2000, propeller z

The architect as building materials scout

Christiane Sauer



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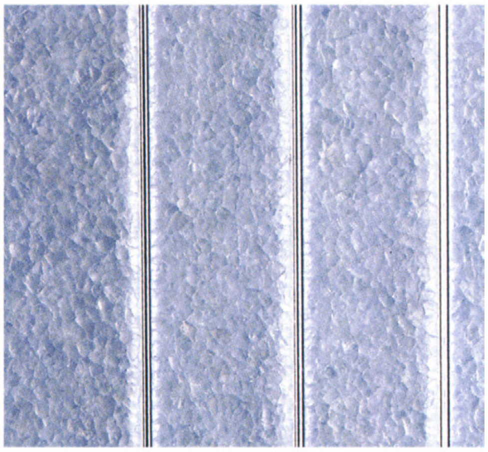


A 2.2

Architects have always tried to exploit the full design potential of the materials available to them. In the past, the architectural options were often limited to local materials and traditional methods of working. But over recent decades the globalisation of trade plus global communications and transport logistics networks have changed the situation drastically. For the architect, the search for the "perfect" material has become the search for the proverbial pin in the – now global – haystack. Research into innovative materials generally follows two principles: either the discovery of new technologies or the transfer of existing materials to other contexts. Another approach is the targeted new development of a material for a certain purpose or application, but this presumes an appropriate budget and a corresponding timeframe.

Materials and research

The laboratories and think-tanks of the automotive and aerospace industries are now the world leaders in the development of innovative materials. The ultra-tearproof, highly insulating, extra-lightweight materials and coatings developed by these centres of excellence also offer new opportunities for sophisticated building concepts. However, it is not unusual for many years to pass before the development of a highly specialised material in a high-tech industry is transformed into a marketable building product. This may be because the potential of the innovation transfer is not recognised immediately or because the funding for protracted, expensive approval procedures is not forthcoming. We therefore get the paradoxical situation of a solution being available before the problem has even materialised: industry already has a high-quality material waiting in the wings, but a use in construction has yet to be found.

One example of this dilemma is the nanomaterial aerogel, which was developed by NASA way back in the 1950s as an insulating material (fig. A 2.1). Aerogel, also called "solid smoke", has the lowest density of any solid material discovered or developed so far and exhibits excellent insulating properties. It consists of 99.8% air; the remaining 0.2% is ultra-fine silicone foam with pores just 0.2×10^{-6} mm in diameter. The pores are therefore smaller than the wavelength of solar radiation and smaller than the mean free path of air molecules, which means that the thermal conduction is less than that of stationary air. It was only just a few years ago – in other words nearly 50 years later – that the material was discovered for the building sector, and the first products are now appearing on the market in the form of translucent thermal insulation panels (fig. A 2.2).

Materials and architecture

The adaptation of materials for new applications is a theme for the architectural avant-garde, at least since the 1970s when Frank Gehry built and clad his house in Santa Monica with materials like wire mesh, corrugated sheet metal and plywood. Polycarbonate double- and multi-wall sheeting and neon tubes from the local DIY store were given a new honour by Rem Koolhaas in the design for the Rotterdam art gallery in 1992. Transferring the materials into an unusual programmatic context fascinated the architects because it tapped new aesthetic freedoms.

By the late 1990s design experiments had become more virtual: new computer software, the origins of which are also to be found in the high-tech laboratories of the aerospace industry, rendered possible the development of complex forms that were very difficult, indeed even impossible, to realise using traditional building materials. The amorphous "blob" became the symbol of a generation of architects: wall, roof and floor merged into one form and called for new, flexible properties in structure and surface. To date, the manufacturers of building materials have hardly reacted to these new trends. The architect must therefore devise individual solutions alone – and take the responsibility. This demands a high degree of personal commitment and idealism.

The architect as "building materials scout" can become a job in itself, like the post of "Materials Manager" at the Rotterdam offices of OMA; the manager's task is to handle all the developments in materials and the practice's contacts with manufacturers. Or the architect could "just

A 2.1 Aerogel – "Solid Smoke"
A 2.2 Light-permeable thermal insulation panel, filled with nanogel
A 2.3 "HeatSeats", Jürgen Mayer H.
A 2.4 Thermosensitive bed linen, Jürgen Mayer H.
A 2.5 "WOS 8" heat exchanger station, Utrecht, Netherlands, 1998, NL Architects

walk around with eyes wide open and gather information to be recalled as and when needed", which is how Berlin-based architect Jürgen Mayer H. describes his source of inspiration. "Magazines, books or DIY store, discussions with experts from specific fields such as shipbuilding – the boundaries are fluid."

Thermosensitive paint

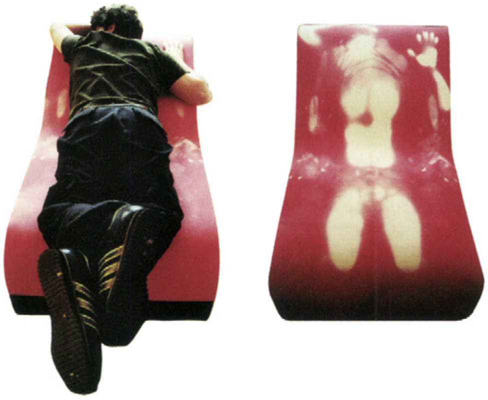
Jürgen Mayer H. works consciously with the transformation of surfaces into new contexts. His use of thermosensitive paint spans the boundaries between people, spaces and objects. He was still a student when he designed a facade that reacted to temperature fluctuations by changing colour. His "housewarming" exhibition in a New York gallery in 1994 gave him the opportunity to realise this concept. The paint – a technical product designed to reveal overheating on machine parts – originated in the laboratories of NASA. In his exhibition, this special paint – adjusted to react to body temperature – was applied to the walls and doors. Visitors to the exhibition left behind temporary white patches – imprints of those parts of the body that had made contact with the paint. He developed this interior surface treatment into a covering for chairs, the so-called HeatSeats, and also for bed linen (figs A 2.3 and A 2.4). The original idea of decorating facades with this paint had to be discarded owing to the material's insufficient resistance to ultraviolet radiation.

In the opinion of Jürgen Mayer H., innovations in materials are easier to implement internally than they are externally: "...because here the requirements in terms of liability and guarantees are not as high as for external applications. In the case of innovations, the clients' guarantee demands are disproportionately higher than for conventional materials, which calls for a huge amount of work to convince them. Graphic displays and reference samples represent important aids in this respect."

Jürgen Mayer H. knows what he is talking about. He is currently working on the transformation of a nutty chocolate spread into a design for the University of Karlsruhe. The structure of the cafeteria is based on the "Nutellagram": when a nutty chocolate spread (= Nutella) sandwich is pulled apart, thread-like connections ensue between the solid top and bottom parts (i.e. slices of bread). In the search for a surface material corresponding to the elasticity of this image, the architect hit upon the idea of a synthetic coating: liquid polyurethane is sprayed over an inexpensive timber backing to form a homogeneous, skin-like surface.

Seamless synthetic coatings

NL Architects used the principle of the plastic skin for the first time on the "WOS 8" heat exchanger station in Utrecht (fig. A 2.5). The material, which bridges over cracks and was originally developed as a material for waterproofing roofs, is used here on horizontal and vertical surfaces to cover the entire building. The underlying structure is a conventional assembly of calcium silicate bricks, precast concrete elements and cement render.



A 2.3

A 2.4

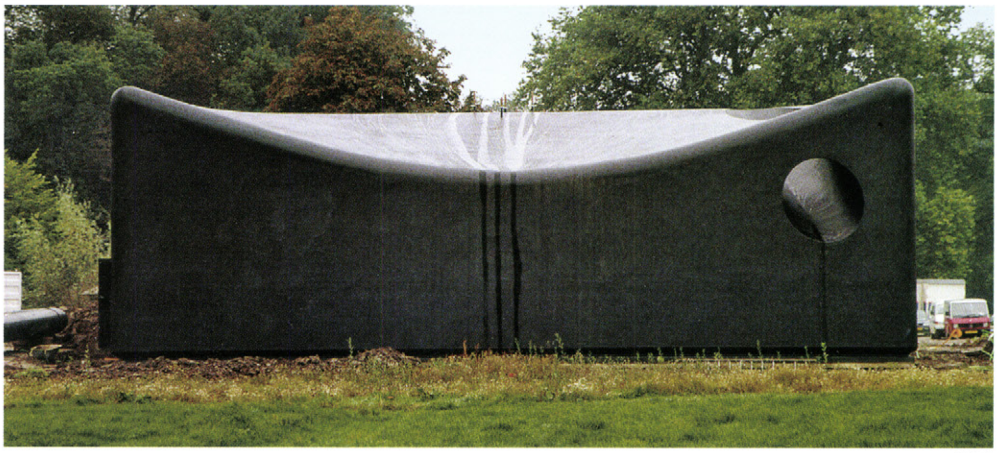
This utility building had to comply with strict stipulations: the external dimensions had to be kept as compact as possible and had to match exactly the sizes of the technical equipment inside. The opportunities for architectural expression were therefore restricted to the surfaces of the building. The polyurethane skin results in a seamless, monolithic appearance. Individual elements such as doors, which convey the scale, are lost in this large format. Normally, isolated buildings such as this are targets for vandalism. "WOS 8" does not attempt to defend itself, but instead invites utilisation: its sides embody various functions and therefore can be used as a vertical playing field for those forms of youth culture that are undesirable on other buildings. A basketball basket, a climbing wall, peepholes – the hardwearing skin amalgamates all these elements both architecturally and technologically.

The sprayed synthetic envelope makes traditional facade details such as flashings unnecessary. Rainwater is allowed to cascade down the building at random, creating an almost sculptural display on the days on which it rains in the Netherlands (average: 134 p.a.). "The material permits a differentiation in the facade, which still appears uniform," is how Kamiel Klaase, co-founder of NL Architects, describes the aesthetic advantages of the envelope.

It was in the 1990s that NL Architects began researching the possibilities of using rubber and synthetic materials for architectural applications. Inspiration for the black finish to "WOS 8" came from the immediate neighbourhood of the plot itself. The fields around the site are used for agriculture, and after harvesting, the bales of hay are wrapped in black plastic and weighted down with old car tyres. The building therefore fits in well with the prevailing colour and material language of the local scene. Kamiel Klaase explains the design process: "Naivety is the starting point. It begins with minor fantasies and brainstorming, and then you have to find the specialists who can realise the idea. ... Many of our elements are materials 'recycled' from another context. That is the simplest form of design: simply change the operating instructions!"

"Baroque high-tech" made from expanded polystyrene foam

Maurice Nio from Rotterdam goes one step further in the construction. In 2003 he designed the largest-ever building built entirely of plastic. His 50 m long bus terminal in Hoofddorp (see Example 11, page 224–25), lovingly christened by him as "the amazing whale jaw", consists of an expanded polystyrene foam core with a covering of glass fibre-reinforced polyester – not unlike the construction of a surfboard.



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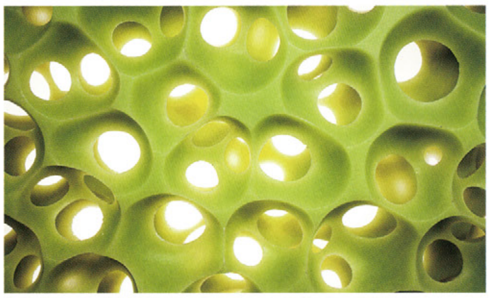
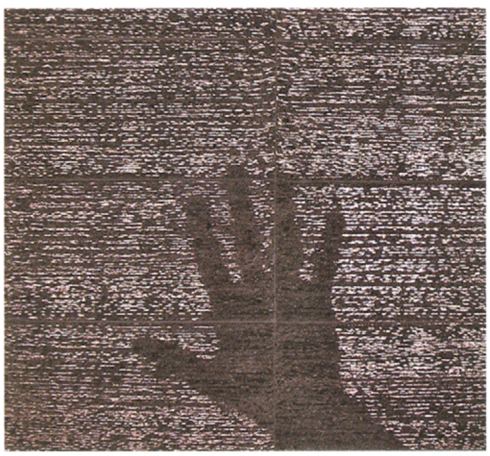
A 2.6


A 2.7


A 2.8


A 2.9

A 2.6 Bus terminal, Hoofddorp, NL, 2003, NIO
A 2.7 CNC milling of the expanded polystyrene foam for the Hoofddorp bus terminal
A 2.8 "Prada foam" product development: gypsum test
A 2.9 "Prada foam", scale 1:1
A 2.10 Translucent concrete
A 2.11 Prada Store, Los Angeles, USA, 2004, OMA


A 2.10

In terms of architecture, the structure is difficult to classify. "To me this is Baroque high-tech – the positive feeling of modernism à la Oskar Niemeyer coupled with a type of voodoo culture," is how Maurice Nio himself describes the building (fig. A 2.6). "When we develop a project, we start with an emblematic picture that drives the whole project forward. We immediately also think in terms of the materials that could fit this picture – the form as such is not so important; that simply happens at some stage."
The architects wanted to create a strong, dynamic image to counter the normal picture of a bus stop – a ubiquitous utility structure normally designed to be as neutral and inconspicuous as possible. The original plan was to use concrete, but the complex formwork requirements exceeded the budget considerably. On the lookout for alternatives, Maurice Nio was inspired by a LEGO building kit, and began to break down the structure into modules. The construction is almost completely open in all three dimensions, like a three-dimensional roof – there is only a small enclosed restroom for bus drivers.
A manufacturer of swimming pool articles and a boatbuilder provided Maurice Nio with the right material and the technology to produce the components. The loadbearing foam material is extremely lightweight and inexpensive, and can be machined with a five-axis CNC milling machine (fig. A 2.7) in order to produce the complex, partly undercut forms. More than 100 individual parts were worked out in a computer model and fed directly into the milling machine. All features such as recesses and benches were integrated into the prefabricated surface. On the building site, the parts were anchored to a timber plinth and glued together in situ. "The most important thing you need to carry out such a project is a good team of people who believe in the idea," says Maurice Nio. "The team is a close and sensitive network made up of client, contractor, subcontractors and architect – and all with the courage to take a risk. In the end, the building could not be built perfectly; there are several details that are not quite correct. But it is precisely this beauty in imperfection that I like – just like a wrinkled face tells us something about a person's life."

The transfer of an existing technology from boatbuilding to a building in this example brought about a new way of thinking about design and detailing. The working of the material was tailored to the needs of the project. But what happens when the surface itself becomes the object of the design? What happens when the architect is also the inventor of the material? Again, those involved need stamina, cooperative industrial partners and clients, and must be prepared to take risks. This was the case in the Rem Koolhaas project for Prada: two large stores in New York and Los Angeles required new concepts in order to redefine the Prada brand, to create exclusivity and a new identity. Virtual measures were added to the traditional interior design brief: research into shopping trends, the conception of the Prada website, even the development of new types of exclusive materials, e.g. shelving made from solid, cast synthetic resin, silicone mats with a bubble structure, and the so-called Prada foam, a light green polyurethane material whose structure oscillates between open and closed, positive and negative.

"Prada foam" made from light green polyurethane

The development began with one of the countless design models at scale 1:50 in which a model building foam was tested as a wall or display element. This foam – an open-pore, beige-yellow material – is normally used on urban planning models to represent areas of shrubbery and trees. The surface proved to be fascinating, especially when lit from behind, and that initiated a period of intensive research into how to transform this material into scale 1:1. In other words, the original belonging to the model had to be found, or rather developed. Countless tests were carried out on the most diverse materials and surfaces: air-filled balloons as voids in a gypsum structure (fig. A 2.8), soft silicone, chromium-plated metal, rubber, gloss, matt, opaque or translucent surfaces. Several companies were involved in the industrial realisation of the material. The prototypes were manufactured from plastic and finished by hand in the architects' Rotterdam offices. The aim was to check the shape and position of the holes once again according to aesthetic criteria and – where necessary – to regrind the material until the appropriate permeability and appearance was attained exactly. The 3.0 x 1.5 m panels were subsequently measured and fed into a computer as a 3D structure. This data served as the digital basis for producing the final CNC-milled negative moulds. The moulding compound for the "Prada foam" was a greenish translucent polyurethane compound specially developed for the project that met the necessary fire resistance requirements (fig. A 2.9).
After two years of preparatory work, the material was first revealed to the public in 2004 at the opening of the Prada store on Rodeo Drive in Los Angeles (fig. A 2.11). OMA and Prada share the rights to the new development; neither can use the material for further projects without the approval of the other. The exclusivity of the material is therefore guaranteed.

Translucent concrete

Following a spontaneous impulse and without the financial backing of a large organisation like Prada, a young architect from Hungary developed an idea for a new material almost out of nothing. In 2001 Áron Losonczi submitted his translucent concrete idea for a Swedish postgraduate scholarship promoting new approaches in art and architecture. He had been inspired by a work of art he had seen shortly before: fragments of glass cast into a

block of concrete, and with some of the fragments left protruding to catch the light. The concrete appeared to be perforated and therefore lost its massiveness.
Áron Losonczi was granted a scholarship to develop his idea at the Royal University College of Fine Arts in Stockholm. He studied the principle of directing light and built the first prototypes – about the size of a standard brick – using gypsum and glass fibre. Further prototypes followed, this time in concrete, and after two years of research he applied for a patent for his light-directing concrete.
Back in Hungary, the first large panel was made by hand: 1500 x 800 x 200 mm and weighing 600 kg. The fibres were laid manually in the fine concrete in layers perpendicular to the surface. The amazing thing about this material is that it appears incredibly delicate and transparent, although only about 4% of the concrete is replaced by glass, and therefore the loadbearing capacity of the concrete is hardly affected. The material is currently undergoing various trials – so far successful; it has a compressive strength of 48 N/mm^2. The principle is simple and fascinating at the same time: light is directed through the fine glass capillaries from one side of the concrete to the other. The concrete appears to be illuminated from within, shadows and silhouettes appear quite distinctly on the non-illuminated side (fig. A 2.10). The brand-name "LiTraCon" – an acronym of Light Transmitting Concrete – was invented for the industrial production and marketing of this new material.

Talking about the long way from the idea to the marketable product, Áron Losonczi says: "It was very difficult at first to convince the companies to work with me. The larger a company, the more difficult it is to get in touch with the right people. It was certainly important that I had built the samples as prototypes and my idea could therefore not be rejected out of hand as crazy. Nevertheless, up until the first major papers, the companies did not take the product seriously. In the final year there was then a boom in publications, and in December LiTraCon was presented as one of the 'Innovations of the year 2004' by *Time Magazine*." But the success story of Áron Losonczi's light-directing concrete is not yet over. In the meantime he has found a manufacturer who wishes to produce the concrete on an industrial scale. We await with excitement the first buildings with translucent concrete walls...

New materials – from the idea to the product

The story of the development of translucent concrete shows the stony road from the idea to the product: however much the idea of the material may fascinate the architect, the building materials industry works purely according to economic criteria governed by batch sizes, sales and profits. If the industry was to look beyond the direct costs–benefits calculation, it would often see the long-term gain in prestige that such experiments can bring. In this respect, the establishment of strategic partnerships is without doubt beneficial for both sides: the architect profits from the technical expertise of the company, and the company can tap new markets with the architect's ideas.
For a number of years we have been witnessing designers' tremendous fascination for surfaces and new materials. This is revealed not only in the numerous publications, symposia, trade fairs, research and consultancy offers on this subject, but also in the designs of the new generation of young architects. The surface often forms the starting point for a design, be it the external cladding to a facade or an internal lining. Materials have always been a central theme among architects, but the handling of this theme has become much more cosmopolitan and experimental.
Where did this materials "trend" originate? It is possible that new approaches were required to enrich the amorphous, arbitrary forms generated by computer designs by adding haptic qualities again. In our over-informed world there is without doubt a longing for the sensual, for the direct experience. In this respect, surfaces are the direct mediator between people and architecture; this is where we can touch the building.
At the same time, there is also the danger that the surface will become more and more superficial, reduced to just an eye-catcher, simply a gimmick. What might appear very decorative in high-gloss publications, could in reality be nothing more than cladding to trivial, trite architecture. On the other hand, good-quality architecture has always been distinguished by a close conceptual relationship between perception, space and materials which transcends all definitions of style or personal taste. An interesting material cannot create interesting architecture on its own. In this sense, the well-known slogan of the concrete industry can be extended to cover the entire spectrum of building materials: material – it depends what you do with it.

A 2.11

The critical path to sustainable construction

Peter Steiger

A 3.1 Tools and information systems for the work phases of the German scale of fees for architects and engineers (HOAI)
A 3.2 Loam structures (these examples are in Morocco) exhibit optimum conditions regarding comfort and durability, even from the modern viewpoint. At the same time, the environmental impact – from production to disposal of materials – is minimal.
A 3.3 Even with sustainable forms of construction, buildings still have to be maintained and cared for.
A 3.4 Deserted houses and settlements gradually disintegrate and return to the landscape.

The term "sustainability" was coined in 1987 by the World Commission on Environment and Development, the "Brundtland Commission". What this means is: "... to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." At the United Nations Earth Summit in Rio de Janeiro in 1992, sustainable development was defined as the improvement of the living conditions of people in economic and social terms but in harmony with the long-term safeguarding of the natural foundations for life. Today, the term sustainability awakens the hope of a trouble-free interaction between an efficient economy, a sound society and an intact environment. The global concept, which is formulated in Agenda 21, should be implemented on a local level with a responsibility towards the environment and future generations. As the forces of nature are sometimes experienced as a threat and generate a feeling of helplessness, the prospect of an intact environment awakens hidden longings in many people. However, this ideal state can no longer be produced through the realisation of the global concept of Agenda 21. But, looked at realistically, which goals can we pursue through sustainable development? What should we call them? Interestingly, there is no precise term for the "maximum utilisation of naturally occurring environmental energy", for the "lowest technically achievable value of environmental impact" (for unavoidable energy conversion processes), or for the "lowest possible consumption of resources for the maximum quality of a structure" (for sustainable methods of construction). But without such terms we are also lacking designations for a targeted way of thinking and acting and also information about those forces that can deliver results in this issue.

Where are we growing to?

Even the first report of the Club of Rome (1972) questioned the sense of everything technically feasible. However, it was not until the mid-1980s that we managed to shrug off the conviction that energy consumption went hand in hand with economic growth. Today, this recognition must be transferred to the consumption of all resources as a whole because if economic growth is only possible with a constant increase in the consumption of resources, then economic growth must be restricted.
From the point of view of ecological sustainability, the term "growth" must be replaced by words like retreat, sacrifice, limitation, avoidance or reinstatement in order to formulate an adequate ecological objective. However, all these terms have negative connotations in the general use of the language because success is harder to identify in the form of restraint than it is in the form of accomplishment. Consequently, such terms do not trigger any positively motivated actions.
Typically, there is also no word for the opposite of economic growth that in the same way promises hope of greater prosperity but without the growth associated with this in the past. The term "qualitative growth", which fills the void as a placeholder, at least points to the expectation that an increase in prosperity includes not only quantitative but also qualitative components. But terms that are not associated with values and imply benefits and success are not suitable for the advancement of science and culture. This is clearly shown by the word "sustainability", from which all sides currently derive their own particular interests. The tallest skyscrapers are given the "sustainable" award when their huge steel-and-glass facades include attributes for the passive or active use of solar energy. In this way, emphasising individual aspects while ignoring the overriding objective helps those terms that can only be measured in terms of benefits and success. The goal of present and future generations of architects must be to achieve maximum quality in the finished products with a maximum sparing of resources. Therefore, the motto for consumption of resources "less is more" coined by the architect Ludwig Mies van der Rohe will no longer be just the technically feasible, but instead the actually necessary. In the building sector in particular, the work required to achieve high quality consists not only of labour costs, but also the intelligent deployment of capital and suitable means of production. Quantitative and qualitative comparisons to ensure a thrifty consumption of resources should therefore be the focus of our construction ideas in order to create the foundations for measuring complete building works under sustainable and qualitative premises.

Developing tools for the selection of building materials

In order to be able to measure and evaluate the consumption of resources in building works, a method of assessment based on the primary energy input (PEI) of a building material was developed as long ago as 1982. The comparison of various building materials by means of the primary energy input represents an important basis for life cycle assessments (LCA). In order to assess buildings and structures as a whole and to enable the choice of those construction methods and forms with minimal environmental impact, a model was developed in Switzerland in 1995 (SIA Documentation D 0123) which comprises a scientific–quantitative part, the "index", and an assessment of the qualitative serviceability, the "profile". By converting the respective pollutant emissions from a construction into equivalent variables (CO_2, SO_2), the environmental effects (e.g. global warming, acidification of soil and water) can be compared.
Today, we increasingly need computer-assisted information systems to enable ecological and economic comparisons of individual forms of construction and overall concepts, and to meet the current thermal standards. As a further development of SIA D 0123, an online component computation system is currently

Tool	Building award				Computer tool							Reference work		
HOAI work phases	eco-bau	LEED	BREEAM	TOTAL QUALITY	Catalogue of comp.	LEGEP	OGIP	VITRUVIUS	SNARC	ECOBIS/WINGIS	WINGIS	SIA D 0123	BKP data sheets	ECO-DEVIS
1 Clarification of design brief									■					
2 Preliminary design	■	■	■	■	■	■	■	■	■	■		■		
3 Draft design	■	■	■	■	■	■	■	■		■		■	■	
4 Design for approval by authorities	■	■	■	■	■	■	■	■		■		■	■	
5 Detail design	■	■	■	■	■	■	■	■		■	■	■	■	■
6 Preparation/award of contract	■	■	■	■		■	■	■		■	■		■	■
7 Assistance/award of contract	■	■	■	■				■		■	■		■	■
8 Site supervision	■	■	■	■				■			■			
9 Project management/documentation								■			■			
Origin	CH	USA	GB	A	CH	D	CH	CH	CH	D	D	CH	CH	CH

A 3.1

being developed which in addition to calculating the U-value will also enable different methods of construction to be assessed by way of a life cycle assessment. The designer is given the opportunity to process information relating to energy and sustainability parallel with the economic optimisation of the project. The German equivalent of the Swiss system is the LEGEP program, which has an ecology module that provides an ecological assessment of the building to accompany the design work.

In the meantime, various awards and certificates are available for the assessment of a building as an overall system. The Swiss building award "eco-bau", which together with the MINERGIE award enables a comprehensive appraisal of a healthy, ecological and energy-efficient form of construction, is currently being introduced onto the Swiss building market. Other systems already established are the LEED system, which comes from the USA and has been adapted for other countries, the British award BREEAM, and the Austrian certificate TOTAL QUALITY. Of these systems, the LEED system, which is based on the international "Green Building Challenge", is the most widely used and accepted.

Another tool for life cycle assessments is the Swiss computer program OGIP, which expresses the environmental impact of a building in key figures. OGIP can be used to analyse details (components, forms of assembly, design variations) and also as an element within the scope of environmental compatibility assessments to analyse a complete structure and its effects on the environment.
Energy and environmental audits can also be produced by VITRUVIUS, a Swiss system for facility management and maintenance planning. A corresponding module for the ecological and energy-related assessment in the realm of cost planning renders possible complex life cycle appraisals.
In order to be able to deploy the ecology aspects as assessment criteria equivalent to design, functionality and economy even at a very early stage of planning (competition, preliminary design), a "System for the assessment of sustainability in architectural competitions and studies" (SNARC, SIA Documentation D 0200) was developed in 2003. This software enables comparative statements on aspects of resources consumption (land, water), the resources required for provision and operation, and the functional suitability of planning tasks.
A comprehensive database for the entire planning process is available in the form of ECOBIS. The ECOlogical Building materials Information System was set up by the German Federal Ministry of Transport, Building and Urban Development together with partners from industry. It contains data on groups of building products which is relevant to environmental and health issues in all phases of the life cycle (production, processing, use, disposal). However, it must be remembered when using the system that the information was gathered in the year 2000 and current developments have not been taken into account.
There is a direct link between ECOBIS and WINGIS, the hazardous substances information system of the employers' liability insurance association for the building industry (GISBAU). WINGIS provides comprehensive information on the health effects related to the spread of building products or building product groups.
A comprehensive aid for ecological planning (and revised at the start of 2005) is now available in the form of "data sheets according to the building costs plan for tenders" (BKP). These are published by "eco-bau" in conjunction with an amalgamation of the building authorities of many Swiss cantons and towns. They contain information on choice of materials and processes, and the evaluation of various alternative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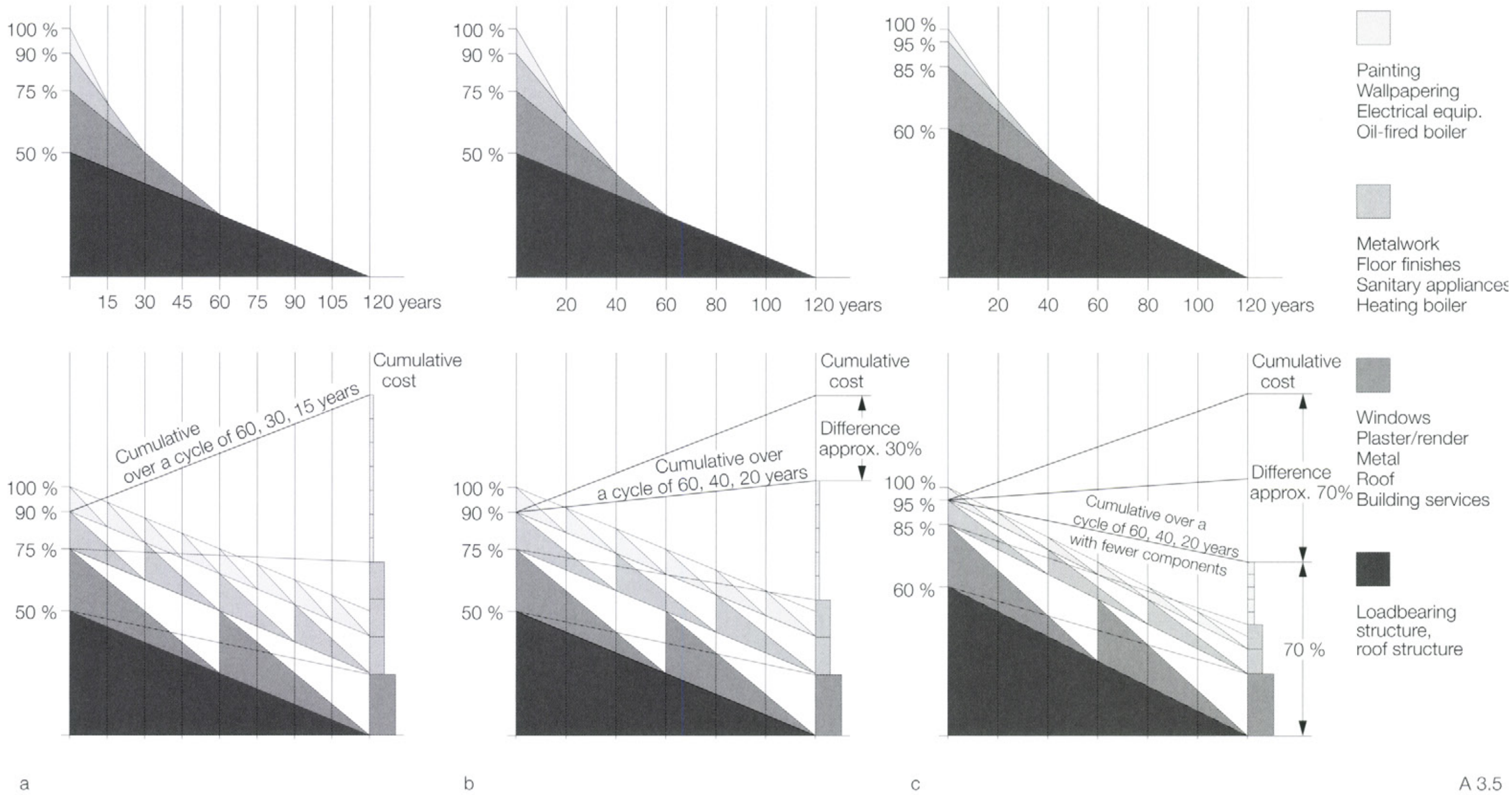
A 3.4



A 3.5

approaches. Specific recommendations help to achieve an optimisation by avoiding and/or reducing emissions or consumption of materials. The ecological specifications of "eco-devis", also published by "eco-bau", were drawn up for tenders. These provide advice and recommendations concerning the use of materials and forms of construction that reduce consumption of resources to a minimum. It is noticeable that each of these tools covers only some of the architect's services (fig. A 3.1).

Lifetime of building materials

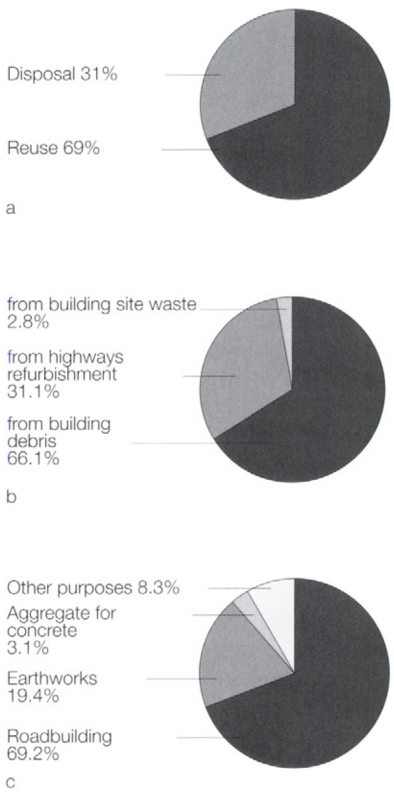
Besides the number one priorities of using a material sparingly and reducing the quantity to the necessary minimum, the choice of material, the combinations and their proper interconnection determine the overall ecological outcome. For every building component, the respective lifetime can be calculated from the durability of the material and the connections to form a type of construction. Immovable, massive structural components can last 100 years or even longer. Parts subjected to mechanical actions may have to be replaced after 10 or 20 years depending on their use.
In order to sustain the value of a building at the residual value of the basic fabric, maintenance and repairs must be carried out on all components corresponding to their specific renewal cycles. The more long-lasting parts a building contains, the better will be the ratio between the materials and initial capital outlay and the cost of the continual renewal of the structure (fig. A 3.5). Basically, it can be said that all building components with shorter renewal cycles should be integrated into the structure in such a way that they can be renewed or replaced without affecting longer-lasting components. The unnecessary demolition and subsequent rebuilding of intact components merely to gain access to areas requiring refurbishment results in unnecessary consumption of materials (and money), and contradicts the principle of the careful husbandry of resources. Limiting the design to just a few materials generally results in a longer lifetime for a structure because it is easier to coordinate the maintenance and repair cycles. The use of many different building materials in one construction leads to higher maintenance costs and in some situations the premature replacement of certain parts.
However, more attention must be given to the upkeep of ecologically oriented building materials, which varies with the actual material. Untreated timber or limewashed facades, for instance, require more inspections and care than those that achieve their weathering and pest resistance through the use of chemicals.

The time factor

In order to shorten the work processes and to reduce the cost of building and maintenance, the time factor often plays a decisive role in the choice of materials and methods. The preferred building materials are those that give the building process independence from the weather and allow the work on site to continue through the winter, also those that shorten the waiting times between different trades, and finally also those that minimise (or at least promise to minimise) the cost of subsequent cleaning, care and upkeep. The ecological and toxicological issues are not usually given sufficient attention in this economics-oriented appraisal.
A "modern" timetable and plan therefore considers – right from the start – not only the cost of the provision and operation of the structure, but also the work and social costs sparked off indirectly by the choice of building materials and methods that impact on the environment. These days, environmentally friendly materials and methods of processing are available for the majority of applications – without any noteworthy increase in the cost. There is no longer any reason to burden the environment indirectly through production residues.
So far, the estimate of the specific lifetime of each component has been based on economic criteria and interests. However, in many cases the lifetimes assumed do not coincide with the actual lifetimes of components or materials, quite apart from the fact that no figures are yet available for many of the new materials. The "Sustainable Building" guidelines published by Germany's Federal Ministry of Transport, Building and Urban Development provide a starting point. The guidelines contain a comprehensive overview of the lifetimes to be expected from all customary building materials and forms of construction – based on the current state of knowledge. And the Swiss publication "SIA 480 – Economic analysis for investments in building" provides an up-to-date summary of the lifetimes to be expected for building components and building services.

From "pollutor pays" to "precautionary" principle

The world consists of material, energy and information. The building industry uses energy to turn raw materials into commodities and processed building materials. Every stage of this transformation process from raw material to



A 3.6

processed material to waste product requires energy. Some of this is stored in the product, some is released again, depending on the transformation stage.

The erection of buildings has consumed an enormous amount of materials over recent decades. After the lifetimes of the materials used for new work and conversions have expired, there remains a correspondingly large quantity of waste products. The transformation processes of industrial materials have an impact on water, soils and the air. The desire to limit the damage to the environment gave rise to the notion of a life cycle. Whereas this undoubtedly applies to natural processes, in the case of industrial processes it is an appeasing analogy to nature. The "recycling" of building materials is currently limited to a few components and materials and is also only advisable when a later reuse can be allowed for in the first use (fig. A 3.6).

Owing to the chemical substances used in the production of building materials, the disposal of building debris is reaching its capacity limits. Some demolition waste contains substances that are extremely problematic in terms of disposal or reuse. What that means is more and more hazardous building debris which must be classed as special (i.e. toxic) waste. However, the "pollutor pays" principle does not apply to the elimination of existing pollution because the time between production and disposal is too long. Therefore, the precautionary principle should be applied to future structures, i.e. taking into account the later dismantling of the building in the initial planning and choosing the materials and forms of construction accordingly. As far as possible, resources should be deployed in such a way that there is no enforced "recycling" and, in the end, no enforced disposal of environmentally incompatible substances.

Limit, target or minimum values

Not only in building are limit and target values stipulated according to the maximum permissible load and reasonableness and not according to the technically feasible minimum values. For instance, the term "environmentally compatible" suggests that acceptable effects for humans and ecosystems can still be achieved with maximum values for emissions and the limiting of contamination. The stipulation of limit and target values, maximum or minimum figures is not the result of scientific experimentation, even when it is presented as such in the publications. Basically, such definitions are merely attempts to estimate triggering mechanisms and effects about which we know very little. Looked at in this way, the upper limit for a level of contamination in no way represents the optimisation of an environmental state or the minimisation of an intervention in the ecosystem, but rather at best the standardised definition of acceptability and risks for an apparently irrevocable state. We accept risks as intrinsic to life, but in most cases they can be defined and therefore avoided. In the "precautionary principle" hygiene and safety measures are desirable to achieve maximum prevention. But the "pollutor pays" principle is based on the apparently unavoidable risks and consequences of causes and countermeasures.

Elements of risk expectations can be found in every building code, every standard and in countless specifications. The rapid increase in synthetic building materials and additives has resulted in a tremendous increase in the precautions-based recommendations and the specifications placing a burden on the pollutor. At the same time, the willingness to take risks with unproven materials and daring forms of construction has increased, which has resulted in a rise in insurance premiums for the residual risks. A flourishing economic factor has in the meantime developed around this willingness to take risks, which means higher building costs, higher overheads.

Foreign substances or hazardous substances

If a material is regarded as harmless, then we assume that the material contains or gives off no hazardous substances or compounds. Chemical substances need not necessarily be unsafe as such, but can become hazardous substances under certain conditions (see "Hazardous substances", p. 268).

When we speak of hazardous substances, we initially think of the harmful effects of a material. Our thoughts range from a neutral foreign substance that is unlikely to exert a dangerous effect to a substance that is only tolerable in limited amounts, limited concentrations. There exists a social consensus that says the intake of pollutants or hazardous substances should generally be prevented.

Therefore, in choosing our materials we should concentrate on low-emissions building products, materials and chemicals. Product designations, quality marks and environmental awards can be used to assess materials and products with respect to their potential risks. Furthermore, technical specifications or safety information provide data on contents and possible hazards.

The strategy for the choice of products based on toxicological criteria is based on the minimisation principle, i.e. a comparison of alternatives in order to select the product with the lowest undesirable contents based on the information available.

A 3.5 The course of evaluation of the building in relation to the durability of the individual components:
- a As a building is no longer usable after – at the most – 60 years if no maintenance is carried out, it is worthwhile carrying out maintenance on the residual value of the basic fabric and the retention of value according to the specific renewal cycles of its parts. However, it has been established that the cumulative value of this renewal work over a period of 120 years adds up to almost 1.5 times the original cost of providing the building.
- b If the components are selected in such a way that the renewal cycles can be extended to 20 or 40 years, the cumulative renewal cost drops by about 30%.
- c If, in addition, the diversity of components is limited in such a way that short-lived components or components with a high renewal requirement are avoided, the cumulative renewal cost compared to the value-retention cycle of 15 or 30 years is reduced by about 70%.

A 3.6 In the period 1999–2000 about 89 million tonnes of building waste and debris (excluding spoil) accumulated in Germany alone. Of this figure, about 69% could be reused, primarily in roadbuilding.
- a Occurrence and disposal of building debris
- b Occurrence of recycled building materials
- c Use of recycled building materials

Criteria for the selection of building materials

Alexander Rudolphi

For the building industry, the principle of sustainability means striving for a minimal consumption of energy and resources, a minimal burden on the natural household and a high degree of safety and comfort for building occupants in all phases of the life cycle of a building – from planning and construction to use and renewal and finally dismantling or demolition. These planning targets require a specific concept or sub-concepts with different potential solutions, alternatives and measures for every individual project depending on location, size and purpose. This is therefore an optimisation process with the aim of uniting the requirements of the environment with the intended use of the structure in an economic cost framework.

The aims of sustainable development in the building industry

The protection goals of sustainability can be summarised in a number of primary categories:

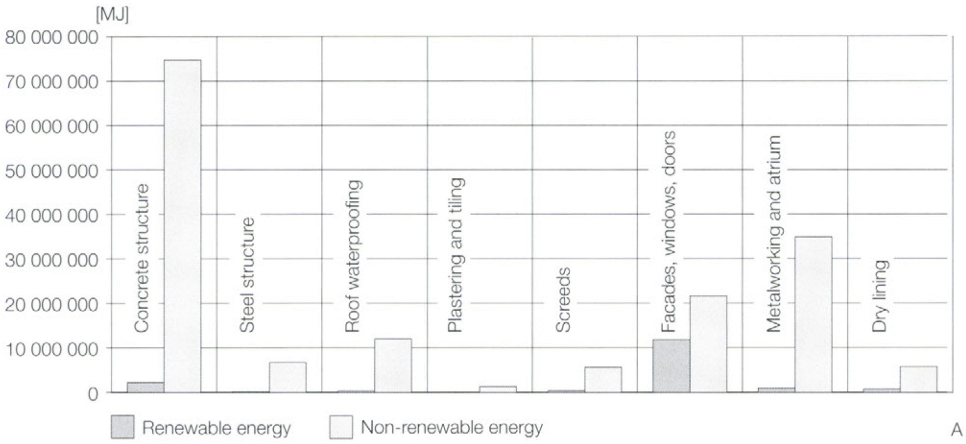
- Protection of the ecosystem and the natural environment, e.g. against damage to the atmospheric system by the greenhouse effect, against the destruction of the ozone layer, or the destruction of the variety of species by the overexploitation of ores or overfelling and deforestation by fire in the tropical rainforests of the Earth.
- Protection of natural resources, e.g. against the consumption of finite resources by the excessive use of non-renewable raw materials, against the uncontrolled consumption of energy from fossil fuels or through short-lived structures requiring intensive power supplies and repairs.
- Protection of health, e.g. against harmful effects caused by poor climatic and hygiene conditions inside buildings, or against harmful effects during the extraction of raw materials or the manufacture of products.
- Protection of social values and public property, e.g. against excessive development of areas of water and land.
- Safeguarding and retention of capital and values. Every premature or avoidable destruction of economic values and assets by defective, less durable structures inevitably leads to a corresponding consumption of capital and resources and further burdens on the environment.

The formulation of protection goals is the prerequisite for the recognition of a need for action, but by itself is not enough for definite, practical steps in the building industry. That requires a knowledge of the respective cause-and-effect relationships, a description of the effects by way of indicators and the stipulation of assessment benchmarks. In this respect, environmental research in the building industry comprises the following steps:

- The stipulation of indicators for describing environmental effects, e.g. the definition of a global warming potential or an ozone depletion potential as quantifiable, calculable variables, the description of comfort indicators for interior climates, or standardised measurements for the effects of pollutants.
- The description of the causal relationships between environmental effects and building technology actions, e.g. insulating measures, heating systems and regulating the rate of air change influence the annual energy requirement. The formulations and vapour diffusion properties of materials relevant to surfaces and storage of heat and moisture have an influence on the interior climate and the cleanliness of the interior air. The geometry of the building, the arrangement of the layout and the plan shape influence the consumption of materials.
- The provision of verifiable acquisition, quantifying and evaluating variables, e.g. uniform methods of computing total energy, area and volume requirements, methods for recording the function-related material consumption, or computational and simulation methods for interior climates.
- Evaluation, selection and description of definite, practical action goals, e.g. a maximum desirable annual energy requirement, an acceptable area and volume requirement in relation to the usage, maximum permissible summer thermal peaks and times, moisture and air change rates or an acceptable TVOC load [1] in time stages.

Principal prerequisites for describing the effects on people, the environment and the natural household, or the definition of impact categories and indicators, are a thorough knowledge of the extraction, production and processing methods for building products and materials, a knowledge of their formulations and compositions, plus their functional, physical and chemical behaviour over a long period of use.
This means that ecological optimisation potential is mainly based on a comprehensive information structure or a multitude of measurements and analyses of both the building product and the finished building component. Current efforts take this requirement into account by attempting to establish far-reaching declarations for building products, providing information databases available to a wide public, and developing standardised methods of measurement for the physical and chemical properties of building products and building components. All the steps mentioned above represent indispensable conditions for reproducible, sound, ecologically oriented decisions. They are also realistic. Only an accurate analysis of production, building and utilisation processes offers the chance to escape from the realm of speculative assumptions and random information.

A 4.1 Energy audit for a four-storey office building



A 4.1

Development of planning and evaluation tools

Numerous optimisation and evaluation tools for the goals of design and construction in building have been devised over recent decades; target and limit values have been defined and continually updated. A well-known tool already available is the building energy audit, which was introduced to help reduce the consumption of fossil fuels and the associated carbon dioxide emissions. Target values can only be defined with the help of corresponding methods of calculation, e.g. the energy requirement of 15 kWh/m^{2}a for heating, electricity consumption and ventilation as a criterion for "passive-energy houses". But in this field as well, further research is still necessary despite the precise knowledge of the physical relationships, and this is revealed time and again when the true total energy requirements of buildings are found to exceed the forecasts. In future the aim will be to specify buildings in terms of a total primary energy factor measured in MJ/m^2 which includes all the forms of operating energy consumption plus the energy requirement for the production/construction of the building and all the materials consumed – the so-called grey energy.
Fig. A 4.1 shows the estimate of the grey energy for a new four-storey office building with approx. 16000 m^2 usable floor space (foundations, floors and columns in reinforced concrete, facades and windows in timber). The total energy requirement for the building is approx. 160000 GJ, or 44000 MWh. If we spread this consumption over an operational lifetime of 50 years, the result is approx. 55 kWh/m^{2}a.

The indicators and methods of calculation for the "life cycle assessment" (LCA) were developed and standardised internationally in the DIN ISO 14040–14043 standards. The aim of the method is to evaluate primarily global and regional environmental impacts resulting from the extraction, production and disposal of building products. However, this quantitative method must be restricted to the recording of known processes and their consequences; unknown or secondary cause-and-effect relationships cannot be covered by a life cycle assessment.

It was not until recently that methods of calculation became available with which complex relationships such as the level of comfort in interiors and its effect on the occupants could be described and optimised. For the first time, these took account of the individual perceptions of people statistically by way of a so-called PMV (predicted mean vote) index and used methods of calculation to develop these into planning parameters for technical standards and codes. Olfactory effects due to emissions in interiors were approached in a similar way. Again, these effects are often not measurable, and therefore they are assessed using factors derived from the subjective perceptions of volunteers.
The description and evaluation of hygiene aspects has proved to be even more complex. For this purpose, about 150 volatile substances from building and home products were first defined and classified according to their volatility (very volatile, volatile and semi-volatile), a project that was initiated in 1989 by the European Commission. [2] Firstly, as no toxicity studies were available for the majority of the individual substances, the total of all the substances contained in the interior air (TVOC) was measured and evaluated. This approach proved to be unsatisfactory because there was no differentiation between highly toxic and less problematic substances. For this reason, work on evaluations of individual substances on several levels is currently being undertaken to establish guidelines for internal loads, and some of these have already found their way into new methods of assessment for building products through environmental agencies and regulatory bodies
The object of current research is the applicable and interdisciplinary methods for the environmental goals of easy reparability and durability of forms of construction. In future the new standards 21930–21932 "Sustainability in building construction" will attempt to bring together terminology, indicators, the necessary underlying data and product declarations plus methods of evaluation for sustainable building. Common to all these assessment and optimisation tools is the fact that each covers only a specific area of effects, a single planning and construction objective. Of course, in the light of the complexity and the amount of work required it is neither possible nor advisable to consider and use the tools available to evaluate all environmental targets simultaneously for every practical decision. For example, when deciding on a loadbearing material, e.g. concrete, timber, steel or aluminium, the question of the cleanliness of the interior air is hardly relevant. The main issue here is the environmental impact connected with the provision of such materials, which can be evaluated with a life cycle assessment. On the other hand, fitting-out and surface materials have a considerable effect on the interior hygiene and so the environmental effects of the manufacturing processes retreat into the background.

Criteria and indicators for sustainable construction

From a practical viewpoint it is therefore important to transfer the aforementioned general protection goals affecting the choice of building materials and the optimisation of forms of construction into practical optimisation targets, and to allocate the respective descriptive and evaluation tools available to these targets. To supplement this, the optimisation targets can be assigned to the phases of construction corresponding to the respective associated decision-making and action stages.

Preliminary and draft design

Selecting products and processes to save materials and minimise environmental impact:
- Plan layout that saves materials and allows flexible utilisation.
- Optimisation of materials used with regard to their global and regional environmental impact caused by extraction, production and provision.
- Preference for materials and products available locally to avoid transport.
- Saving of resources, preference for renewable materials or those with long-term availability.
- Avoidance of materials whose production processes are associated with severe risks in the case of malfunctions or those in which hazardous substances are required for the production process.
- Recommending materials that can be recycled with minimal loss of properties and without being linked to a particular function, plus composite products and elements that can be reverse-engineered locally.
- Recommending materials whose manufacturing processes include the environmentally friendly use of recycled materials.

Hygiene and health, interior climate:
- Safeguarding natural lighting when designing the plan layout.
- Insulation to prevent overheating in summer and heat dissipation by specifying storage masses.

Whereas the need for plan layouts and forms of construction that save materials and permit flexible utilisation is a well-known part of the planning process which can be evaluated by way of specifying floor areas and standardised, large grids, a realistic assessment of the environmental relevance of materials is much harder. In the context of the draft design, the selection of the main materials or deciding between possible construction alternatives – e.g. for facade, roof construction or ground slab – requires an analysis and relative evaluation of the environmental effects with respect to the materials chosen, or rather their extraction, production and provision processes.

Quantitative life cycle assessment

The life cycle assessment (LCA) procedure developed over the last 20 years and standardised in ISO 14040–14043 – four evaluation parts necessary within the scope of a complete evaluation of the most important materials – can be used as a method of evaluation. According to these standards, the construction or material alternatives must first be analysed from the ecological viewpoint and quantified with respect to environmental impacts. In addition to this, ecological effects that can be estimated qualitatively – if applicable and known – must be specified and weighted according to their significance. Afterwards, the costs of the alternatives are investigated, and finally the socio-cultural aspects are listed. The latter includes such factors as strengthening the regional economy by restricting the invitation to tender to a certain region, the architectural requests of the users, or the integration into the neighbourhood. The final decision is based on bringing together all the individual results. Listed below – and based on DIN ISO 14042 "Impact assessment" – are the most important indicators or impact categories defined in the life cycle assessment which should be used in the quantitative evaluation depending on the data available:
- primary energy input (PEI)
- Aproportion of renewable (ER) and non-renewable energy (NER) in the energy consumption

Frequently, only the primary energy input necessary for the provision of materials is included in the comparative evaluation. However, this so-called grey energy should be further broken down into renewable and non-renewable forms of energy in order to distinguish environmentally friendly production methods.

In addition to this, the energy requirement during the entire life cycle, including any recycling potential if applicable, can be used as the "cumulative energy input" according to VDI 4600. The energy requirement during the period of use of the building is estimated by way of assumptions or scenarios.
In a comprehensive quantitative assessment, the primary energy input is included in the evaluation by way of the environmental effects caused by the energy generation:

- global warming potential (GWP)
- ozone depletion potential (ODP)
- acidification potential (AP)
- eutrophication potential (EP) or nutrification potential (NP)
- photochemical ozone creation potential (POCP)
- CO_2 storage (for regenerative raw materials)
- space requirements

Owing to the complex data, the indicators (also defined for the life cycle assessment) for the toxicity of the provision processes are mostly used only for significant individual evaluations. Examples of this are the heavy metals abraded from copper, zinc or lead oxides by rainfall and their toxic effects in the soil, or the use of particular poisons such as phosgene and isocyanate as by-products in the production of polyurethane. For this reason, the following indicators have also been defined:

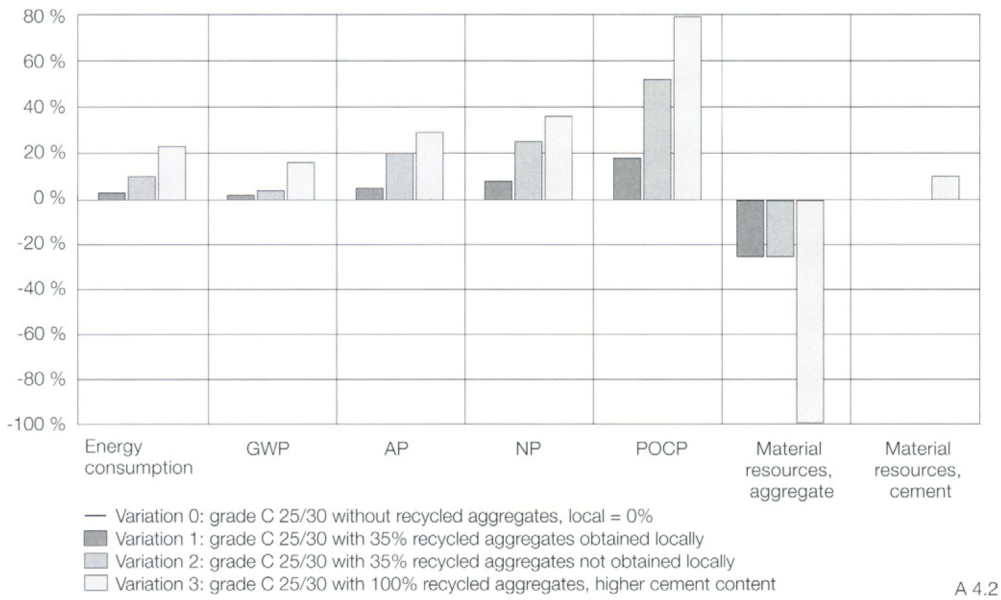
- aquatic ecotoxicity (ECA)
- terrestrial ecotoxicity (ECT)
- human toxicological classification (HT)

Expressed simply, all the individual steps of the necessary extraction and production processes – and wherever possible also the utilisation and disposal processes – are described within the scope of a quantitative life cycle assessment to ISO 14040. Product units to be compared must match exactly in terms of their functions (functional unit). The input–output analysis produced in this way is called a life cycle inventory analysis. Wherever possible, the individual values recorded for the aforementioned impact categories are grouped together (impact assessment). Different periods of use must be considered where applicable. The necessary respective renewal cycles for building components or individual building component layers for an assumed period of use of 80 or 100 years are calculated as a factor and multiplied by the result of the impact assessment.
The final evaluation of the indicators determined can be carried out – depending on the situation – based on the severity of the consequences (ecological risk), a relative comparison of variations, or the significance of the effects in relation to an existing environmental burden (distance to target). This latter evaluation principle is often anticipated by calculating the life cycle assessment on the basis of just a few indicators – those regarded as particularly important.

Qualitative environmental effects

In the second step of our overall evaluation, we consider the fact that numerous, essentially acknowledged but disadvantageous environmental effects cannot be covered by the quantifiable impact categories – partly because the relationships are not fully understood. These ecological effects must be specified in addition to the calculated life cycle assessment results mentioned above and considered in qualitative terms. These include:

- the irreversible impairment or destruction of ecosystems
- the infrastructure required for production and disposal



A 4.2 Life cycle assessment for concrete: variations with and without recycled aggregates

- the supervisory work required to safeguard the industrial processes and the scope of the industrial processing stages
- the potential risk of intermediate products
- the probability of reuse

A typical example of qualitative reasoning is the desirable avoidance of timber obtained from overfelling in tropical rainforests (fig. A 4.4). The effects in the form of the destruction of the ecosystems and the loss of diversity of flora and fauna species are hardly measurable. Appropriate bans or the demand for the certification of timber obtained from sustainable forests, i.e. a "Forest Stewardship Council" (FSC) certificate, are therefore environmental policy decisions based on qualitative assessments.

Until recently, the analysis of materials and forms of construction in a life cycle assessment was still very time-consuming and costly, and could not be integrated into a planning process. In addition, the life cycle assessment required extensive, generally accepted data on all the materials to be considered. Today, the situation with the data has improved to such an extent that a comparative appraisal on the basis of the life cycle assessment can be carried out alongside the planning work, provided we limit ourselves to the best-documented and most important impact categories. Furthermore, the auditing and calculation work has been eased considerably by the appearance of suitable computer programs.
Life cycle assessments are a suitable way of checking the reality of what appears to be – on the face of it – plausible, ecologically founded argumentation. We shall use the example of in situ concrete to illustrate this.
In principle, it is possible to produce in situ concrete with recycled mineral aggregates. In order to compensate for the risk to the strength that can occur when using these "scrap" materials, an increase in the cement content is prescribed for a recycled aggregate content > 35%. At first, the use of recycled materials appears to be sensible in principle. A number of variations are compared here for a practical design situation:

- normal-weight concrete, grade C 25/30, without recycled aggregates
- concrete, grade C 25/30, with 35% recycled aggregates obtained locally (< 100 km)
- concrete, grade C 25/30, with 35% recycled aggregates not obtained locally (> 100 km)
- concrete, grade C 25/30, with 100% recycled aggregates (can be approved for individual projects) obtained locally, plus higher cement content

As the recycled aggregates should be as uniform as possible and hence are best obtained from a single demolition site, the material may well have to be transported over long distances, which is why the distance parameter < 100 km/> 100 km is relevant. Fig A 4.2 shows the result: the zero line of the diagram represents normal-weight concrete without recycled aggregate; the vertical bars represent the improvement or worsening of the effects as percentages.
It can be seen that owing to the transportation required and the extra cement, in the most important impact categories the environmental impact rises as we increase the content of recycled material. Only the indicator for the consumption of materials decreases. So the use of recycled aggregates in concrete relieves the burden on the environment only when the aggregates are obtained from a nearby site (< 100 km) and if there is a scarcity of aggregates in the form of gravel or sand in the region of the batching plant, which it could also be due to limits placed on the quarrying of such materials.
This example clearly reveals that even after drawing up a comprehensive life cycle assessment, the results are not necessarily generally applicable to all projects or all regions. Each individual case must be checked to establish whether individual effects play a particular role.

Comparison of costs

Cost comparisons in building are generally performed by way of the well-known cost estimate, cost calculation and cost control. The crux of the problem in cost comparisons is the estimate of the cost of usage because this requires knowledge about the anticipated costs of maintenance and renewal. Several computer-assisted approaches based on the costs breakdown according to DIN 276 are available. [4] However, these do not permit any flexible treatment of the durability of building components or layers (in a sense of optimising sustainability). The costs including cost of usage and cost of disposal/demolition are known as the life cycle costs. In conjunction with efforts to harmonise the methods and to develop sustainability indicators for buildings, a dynamic, quality-related durability estimate for building components and products is currently undergoing development. [5]

Detail design

Selecting products and processes to save materials and minimise environmental impact:

- Planning of building services (electrics, hot/cold water, heating) to save materials through an optimised arrangement of sanitary and supply zones, service routes and supply lines.
- Water-saving systems.
- Reducing the conversion and renewal work during the period of use by choosing durable and reparable component forms that allow flexibility of usage.
- Building with recycling in mind by using splittable, mechanically detachable component layers or homogeneous material assemblies.

Hygiene and health, interior climate:

- Ventilation systems and ventilation rates.
- Optimisation of the interior climate conditions through the release of heat over a large area without convection.
- Safeguarding of a comfortable and healthy interior climate through optimised ventilation design, optimised supply and removal of heat, plus the provision of sufficient storage mass.
- Optimisation of sound insulation.

Quality assurance for detail design work

The optimisation targets of the long-term guarantees for the functions of building components, the ease of repair and the flexibility regarding change-of-use requirements can be grouped together under the heading of durability. This variable which has to be estimated is, of course, not a fixed value, but instead to a large extent dependent on the quality of design and workmanship. Depending on the quality assurance measures, it is not usual these days to replace wooden double-glazed windows until after 10, 20 or even 50 years. Likewise, in an entrance zone a floor covering with adjacent walk-off mats will last much longer than one without such mats. As already explained, it is vital to know the estimated durability of a building component when assuming renewal cycles and hence for the chronological part of the life cycle assessment and life cycle costing (LCC). The quality to be optimised here is commonly referred to as the experience of the architect, engineer or contractor involved. Unlike with the evaluation of the environmental effects of materials during extraction of raw materials, production and disposal, there is still no uniform tool for assessing the technical–constructional quality attained and the achievable useful life of a building component; however, research into this is ongoing, and this work allows us to discern a number of fundamentals.
One important criterion for optimising the durability is the more or less successful concurrence of properties and risks (sensitivities) of the material on the one hand, and the functional requirements and loads on the building component on the other. The result improves as the number of loads coinciding with sensitivities decreases, and the number of desirable functions coinciding with the typical properties of the material increases.
This leads to a second criterion: how the potential damage resulting from the convergence of particular loads and material-specific risks is compensated for in technical and constructional terms.
The third criterion concerns the question of the detachability of connections in a building component and hence the issue of reparability and partial renewal. The question regarding the respective main uses of the building component are important here. In the case of surfaces in particular, it is very likely that one of the main uses will be aesthetics, which can lead to a fashion-, taste- or identity-related replacement

of otherwise fully functional and trouble-free surfaces or products. A similar situation is found with components such as sanitary appliances, which are heavily influenced by culture. In such cases mechanical, easily detached connections should be chosen in order to minimise the consumption of materials in the event of replacement. In the case of concealed, purely technical components such as waste-water pipes, waterproofing systems or loadbearing components, it is the technical durability that must be given priority. Industrially manufactured composite elements may represent an improvement in quality, although they should always be checked for the separability of the different materials to aid recycling.

Comfort index

In recent years, the boundary conditions responsible for a healthy and agreeable interior climate have been standardised in the regulations with increasing precision, and have been fleshed out with target values. This concerns such important aspects as the airtightness of buildings (measured using the blower door technique to EN 13829), the minimum air change rate (0.6–0.7 times the volume of the room per hour for removing pollutants and carbon dioxide from the interior air), or the avoidance of cold bridges and mould growth (by using appropriate calculation methods to DIN EN ISO 10211.
Moreover, the perceived comfort in an interior depends on the air speed of the convection currents, the cold air radiated from walls and soffits, and the temperature stratification. The interaction of the individual influences plus their physical effects and individual, subjective perceptions cannot be solved with simple, physical relationships or algorithms. Therefore, the subjective perceptions of volunteers were included in DIN EN ISO 7730 for determining the thermal comfort conditions. The PMV (predicted mean vote) index represents an assessment of the thermal comfort and is formed by combining several physical boundary conditions. The PPD (predicted percentage of dissatisfied) index is a statistical function of the PMV and describes a forecasted figure for dissatisfied persons in per cent. We distinguish between three quality categories: A, B and C. These are the same as the climatic requirements of both DIN EN ISO 7730 and Swiss standard SIA 180, which should be used when planning climate-regulating forms of construction, e.g. for the design of thermal storage masses available in the interior, when conceiving the removal of heat in the summer, the ventilation systems, or the design and construction of thermally insulating components and their internal surfaces.

A 4.3

Tendering, award of contract and work on site

Selecting products and processes to save materials and minimise environmental impact:

- Safeguarding of the long-term retention of value and sustainable functionality of forms of construction and building components through inviting tenders for quality-controlled building materials, products or components and through a detailed functional description of the building works desired.
- Selection of solvent-free chemical products.
- Avoidance of products with environmental and health risks in the extraction and production processes.
- Low-waste building, recovery of residues.
- Ensuring a low-noise and low-dust building site, avoidance of groundwater contamination, pollution and dangerous methods of working.

Hygiene and health, interior climate:

- Selection of non-hazardous and low-emissions surface materials.
- Avoidance of materials with higher fire risks caused by high smoke densities or corrosive and, in addition, toxic fumes.
- Prevention of radon loads in the building from the subsoil through corresponding sealing measures to the ground slab and the basement walls.
- Avoidance of electrostatic fields and surface charges during usage through the specification of conductive products for floor coverings or office fittings in the tender.

As a rule, it is the tender documentation that first specifies details to the extent that specific products, connections and assemblies can be distinguished for the internal fitting-out trades. In the case of public-sector building projects especially, the nomination of specific products is only permissible in exceptional cases, and they are mostly not known until the bid is received – provided the requirements for naming products were correctly specified in the tender documents. The ecology and hygiene requirements the products should meet must be known and specified in full during this stage

A 4.4

of the project at the latest.
The interior air generally contains a broad spectrum of organic materials as well as dust and fibres. The source of these is people themselves (breathing, body odour) and the activities people are apt to perform indoors, e.g. smoking, cooking, etc., but also building materials and internal finishes and fittings, which may give off chemical compounds. Depending on their concentration and composition, the internal air can become overloaded, which may impair the comfort or even the health of the occupants, and in this respect poor climatic conditions reinforce such negative influences. Such impurities are becoming a problem as buildings become more airtight and the air change rates decrease.

Airborne pollution from organic substances

Emissions from surface coverings and coatings on buildings, assemblies, furnishings and fittings can give rise to organic contamination. Building components made from organic materials in particular, e.g. plastics, paints or adhesives, contribute significantly to airborne pollution. In order to develop an evaluation tool for this, a list of approx. 150 volatile substances (volatile organic compounds – VOC) [6] frequently encountered was drawn up. These are divided into the following classes (based on boiling point):

- very volatile organic compounds (VVOC), boiling point < 0–50 to 100°C
- volatile organic compounds (VOC), boiling point 50–100 to 240–260°C
- semi-volatile organic compounds (SVOC), boiling point 240–260 to 380–400°C

The sum of all these substances is known as the total VOC (TVOC). As toxicological studies are lacking for the majority of these substances, and therefore there are no useful limit values available for interiors, the German Environmental Agency has set target values for TVOC measurements which are applicable in Germany:

- short-term (1–2 months): approx. 1500–2500 μg/m²
- long-term (1–2 years): approx. 200–300 μg/m²

Owing to the highly disparate toxicities of the individual substances, evaluations of individual substances are currently being carried out one by one within the scope of the initiative "European Collaborative Action: Indoor air quality and its impact on man". According to this, two guide values for indoor air quality – RW I (desirable value) and RW II (intervention value with clean-up recommendation) – are specified for the individual substances. To date, substances such as styrene, benzene, naphthalene and formaldehyde have been assessed.
The VOC measurements are the final results of evaluations and are not suitable as planning values. To help choose individual materials relevant to surfaces in a tender, a method of evaluation was developed recently in which the products themselves can be classified and certified on the basis of VOC test chamber measurements (prEN 13419) over a period of 28 days. According to this, building products must exhibit the property "suitable for use in interiors" corresponding to an evaluation scheme specified by the German Institute of Building Technology (DIBt). This property must be verified for products requiring approval using test chamber measurements provided by the manufacturers and must be declared in the product specifications.
The boundary conditions for the measurements are to be stipulated and recorded by the laboratory appointed to do the work based on the DIBt criteria. This method of evaluation can be specified for primary and surface materials such as floor coverings, door leaves, faces of built-in items, and wallpapers.
Using the product specification, the final emission values reached in interiors cannot be simulated with adequate reliability, which contrasts with the building performance planning of the interior climate. The design of internal surfaces is therefore carried out primarily according to the principle of avoidance, i.e. by concentrating on low-emissions and zero-emissions materials (e.g. all mineral surfaces), and where low emissions are acceptable, by choosing certified products. Numerous certification systems are already in place, usually in the form of trade organisation awards, e.g. the Emissions Code for floor coverings and adhesives (EC-1), the certification for wall paints with zero emissions and zero solvents (ELF), or the RAL environment symbol for paints issued by Germany's Environmental Agency ("low emissions and low pollutants" RAL UZ 12).
Besides the organic impurities in the interior air, man-made mineral fibres or organic fibres represent another possible hazard. Since 1995 the formulations of mineral insulating fibres, for instance, have been changed in such a way that the so-called bio-persistence (presence of ultra-fine fibres in the lungs or pulmonary fluid) and hence the carcinogenic potential was able to be reduced in accordance with the size definition of the World Health Organisation (WHO). [7] Of course, even coarser fibres represent a potential risk for human respiratory tracts. Fibre insulating materials are used internally mainly in lightweight partitions, suspended ceilings, floor insulation and window junctions. These assemblies and details must be designed to prevent the fibres getting into the interior air, i.e. sealed. As a relative scale for the contamination in a room, the background contamination of the exterior air – which varies considerably from region to region – can be used (e.g. in Berlin approx. 300–500 WHO-definition fibres/m^3). Owing to the passage of air through joints and junctions, this background contamination usually exists inside buildings as well and should not be worsened by adding fibres from building components and materials.

Application of optimisation tools

The information structure required for the application of the aforementioned optimisation tools is being constantly improved by the growing declaration requirements for building products. The introduction of additional certification systems by the manufacturers, the provision by trade organisations of data records for life cycle assessment calculations and the development of standardised methods of measurement have led to the methods of evaluation being included in the design and construction phases of building projects without any significant time and cost disadvantages. However, owing to the information that must be gathered, the appointment of appropriate experts as consultants for drawing up comparative life cycle assessments for important components or for the ecological quality control of tenders and workmanship is recommended for larger construction projects.
Besides the ecologically optimised selection of main materials and components, another focus of the optimisation work is the writing of the tender documents, the product declarations of the suppliers and the constant inspection of workmanship. The finished structure can comply with the sustainability requirements only if these have been stated in detail in the tender documents without reference to any products. In numerous projects it has proved beneficial to demand – at the latest after opting for a certain bid – a binding declaration for the products and by-products to be used with the help of a list of products (including the safety and certification information), and to make this a component of the contract award and contract documents. Only after target values regarding primary energy input, comfort or hygiene have become part of the contract can they be checked upon completion of the structure and, if applicable, be demanded as an agreed property within the scope of the warranty. In future, defects in the environmental quality of buildings will increasingly represent a verifiable design error.

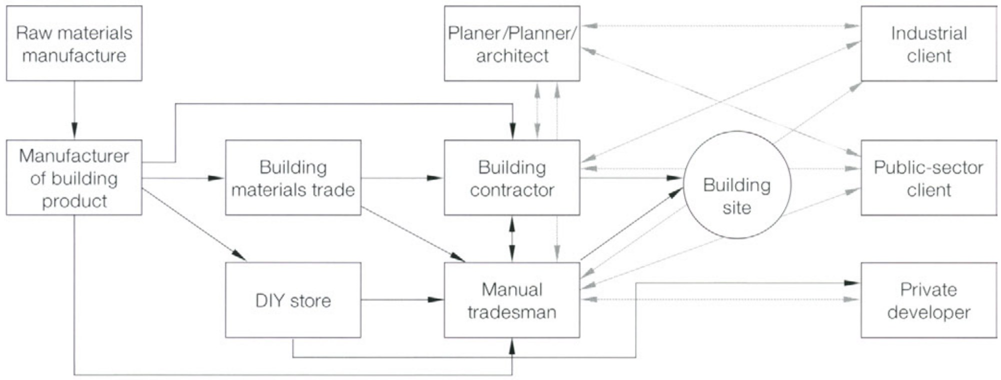
References:

[1] Total Volatile Organic Compounds
[2] European Collaborative Action: Indoor Air Quality and its Impact on Man (ECA)
[3] The FSC certificate regulates the sustainable management of forests. It is often demanded by public-sector clients in Europe in conjunction with the "Chain of Custody" trade certificate.
[4] GEFMA 2000: Kostenrechnung im Facility Management; PLAKODA, Planungs- und Kostendaten; Schmitz, Heinz, et al.: Baukosten 2004 – Instandsetzung, Sanierung, Modernisierung, Umnutzung, Essen, 2003
[5] ISO/TC/59: Item Buildings and Constructed Assets – Sustainability in Building construction – Sustainability indicators
[6] A list of the TVOC groups can be found in the glossary, p. 269
[7] Corresponding rock wool fibres are declared as having "reduced bio-persistence". Glass wool fibres are characterised by the "carcinogenicity index" (Ki), which may not be less than 40: Ki ≥ 40.

A 4.3 Transport distances should also be considered when selecting building materials.
A 4.4 Destruction of the environment in the tropics

The development of innovative materials

Dirk Funhoff



Physical materials flow – to building site
Influence on choice of material – for building

A 5.1

The building industry is not regarded as an innovative sector. According to a survey of Swiss companies carried out in 1999, the proportion of sales of innovative products in the building sector is just 10.7%, which does not compare favourably with the average figure of 37.1% for all sectors of industry. Just 24% of the companies polled carry out R&D work, compared to 49% for industry as a whole. [1]
High growth rates in the building industry are a thing of the past. In Germany low demand has resulted in many years of stagnation. Extensive regulations, standards and approval procedures make changes difficult; increasing complexity puts up the costs. At the same time, people are still looking for high-quality facilities for work and play. New findings in the field of housing physiology demand modified products; high demands need to be satisfied without excessive price rises. In the light of all this, the need for innovations is rising.
This chapter attempts to illustrate the development of innovative materials for homes and building, and to foster the mutual understanding of those involved in this process.

What is innovation?

The term "innovation" is frequently used simply as a synonym for "new" or "novel". But newness, i.e. the invention of a new material or new effect, is not enough by itself. Innovation is the establishment in the marketplace of a new technical or organisational idea, not just the invention of such. [2] This economic aspect explains why innovations offer great chances; innovators enjoy a better reputation in the market (also for their standard products) and they are attributed greater competence, which in turn is reflected in a higher acceptance of their products.
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Marketing success is vital to innovation. It is therefore not sufficient merely to describe which new materials or technologies exist. [4] Their development takes place within certain boundary conditions, which restrict the use and availability of the new materials. Placing these products in a fresh context is "new", but the desirability triggered is often neither sensible nor satisfying in the long-term. And if the marketing success is not realised, then we have no innovation. If those involved in innovation processes and the value-creation network of the building industry could learn to understand each other better and improve the coordination of their processes, it would open up a major chance for innovation.

Boundary conditions

Innovation on the material side is advanced by researchers or developers in the laboratories of the raw materials and building materials industries, even if there are impulses from other branches such as architecture or design. From the scientist's viewpoint, material in the more precise definition means "substance, raw material or medium". [5] From this they (also) create materials whose shape, colour, etc. are adapted to various applications. Architects and designers deploy these materials in order to create a desirable environment in which to build and live. In order to modify the products to match their ideas, they contact the suppliers. However, the suppliers do not always have the abilities to influence the underlying "fabric" of the materials because the value-creation network is so complex (fig. A 5.1).
Which materials are actually used in building work is decided by those by those working on the building site. The manufacturers of building products or the raw materials suppliers do not play an active role and are seldom called in to answer questions regarding choice of materials.
The story is different in the automotive and aviation industries. In these industries the manufacturers of the end products hold discussions with components and raw materials suppliers

A 5.1 Simplified diagram of the value-creation network in the building industry
A 5.2 Thermal conductivities of various materials