Chapter 3
Lightweight Materials and Environmental Quality Requirements

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Abstract This chapter introduces the theme of life cycle thinking design, underlining how the use of materials in buildings has to be cross-linked to their life span and desired performances. The challenge of using soft materials is mainly related to energy efficiency, thermal behaviour and recyclability.

3.1 Introduction

Wide-ranging theoretical consideration of landscape design, configuration of the urban context, seeking the right form, and indeed of building in general, necessarily requires thinking about questions concerning implementation techniques through a rigorous study of materials, techniques and building processes: architectural technology must be part of design from the earliest stages, and design must be associated with time. In Italy, contemporary design has the enormous responsibility of balancing the permanent temporal nature of an urbanized context, in the majority of cases historical, with the temporariness represented by new designed spaces. Here, the word "temporariness" is used to refer to the option of redefining and re-constructing; to a capacity for adaptation, rather than a brief period of use in time. The variable of "time", along with the variables "energy" and "weight" currently constitute a cultural and methodological basis for a contemporary approach to environmental design.

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3.2 Time – Environment – Life Cycle Thinking

An eco-compatible construction is the outcome of a design and construction process if the meta-design is guided by the concept of life cycle thinking. This entails considering the impact of the stages prior to building the property, including deciding what materials and technologies are suited to the project's context and end purpose, the property management stage, disassembly at the end of its life, and how waste is handled (Perricciol 2004). It is no longer sufficient merely to consider a property's energy load in order to deem it sustainable. We must look further: we must assess the consumption of non-renewable raw materials, quantify emissions of polluting substances and waste production during the production period, and forecast emissions during usage. The confines of the system that we must consider have become broader, entailing a change in paradigms and in our approach to design. Energy, the environment and time are becoming the new design variables for buildings that we simply cannot do without (Commoner 1972). Among the complexities of this new design path, environmental requirements for building sustainability entail further investigation of the "building/environment" relationship in terms of its life cycle and, on a scalable basis, between the building and its underlying elements (Monticelli 2006).

3.3 Form, Matter and Energy Efficiency – Search for Lightness

In design, attentiveness to optimizing a building's form and its elements with a view to deploying architecture that uses materials rationally and functionally, that is to say, more lightweight, means redressing the balance between nature and the "built". In turn, this means embarking on a search for lightness as a design paradigm, with its implicit double meaning of high formal and high material efficiency.

The affirmation of a new design ethic and new design paradigms is also leading to the emergence of new types and forms of built designs that are often determined by a necessary integration with new mechanisms and materials for eco-efficient buildings.

The search for lightness is research into materials. Research into lightweight materials is all about reducing the thickness, the section and the quantity of materials in a construction. Research into materials has overturned the relationship between designers and materials: if in the past materials suggested their own most appropriate use, today designers mould and define materials to cater to the project's requirements, no longer with any limits. From a life cycle design and eco-efficiency standpoint, designed materials such as polymers have a characteristic that traditional materials do not: reduced weight for the same volume (density) (Otto and Rasch 1996). This is paramount if the objective is to pursue savings in materials and energy, although it must also be assessed in terms of the other stages of the life cycle (Figs. 3.1 and 3.2).

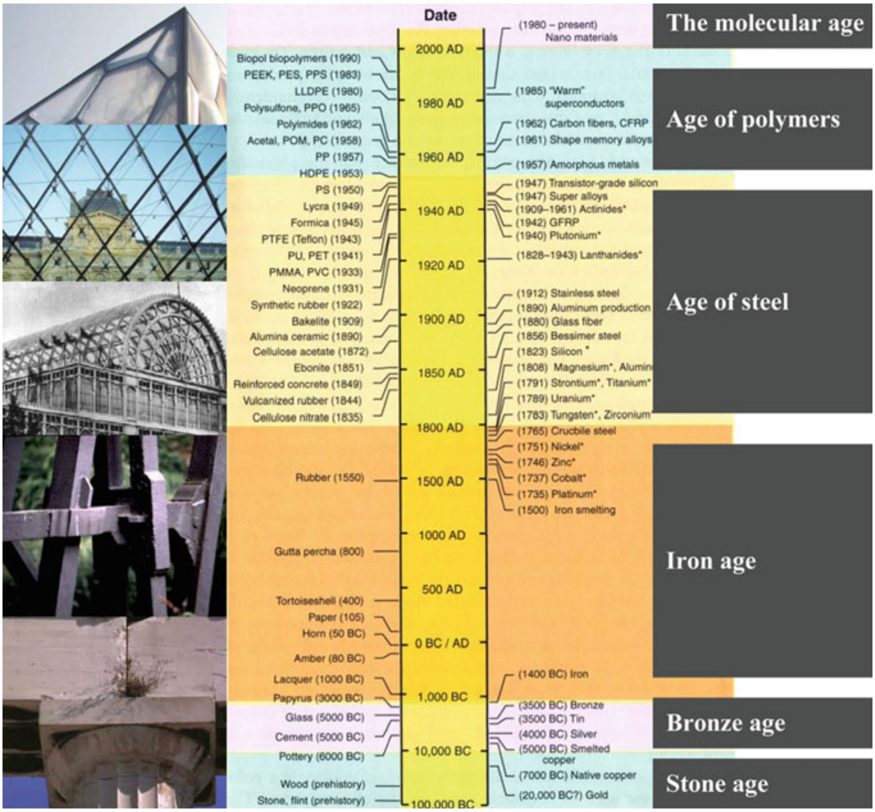

Fig. 3.1 The discovery and evolution of materials, seen in an historical time sheet, shows the search of lightness, from the age of stone to the actual molecular age: if in the past materials suggested their own most appropriate use, today designers mould and define materials to cater to the project's requirements (*Source* Ashby 2009 with elaboration of the author)

3.4 Verifying Indoor Comfort Using Lightweight Materials

In Italy, material culture has always approached building by using massive materials whose thermal inertia, combined with the thickness of strong walls, effectively caters to internal building comfort in both summer and winter conditions. If, in the same context, a building is designed using lightweight materials, whatever their thickness within the envelope, their mass, which ensures thermal inertia, is intrinsically lower. It is therefore necessary to consider the potential and limitations of these materials in relation to the function of the building where used. If the lightweight materials considered for a project include membranes, which are no longer just used for structural purposes but are far more often employed in

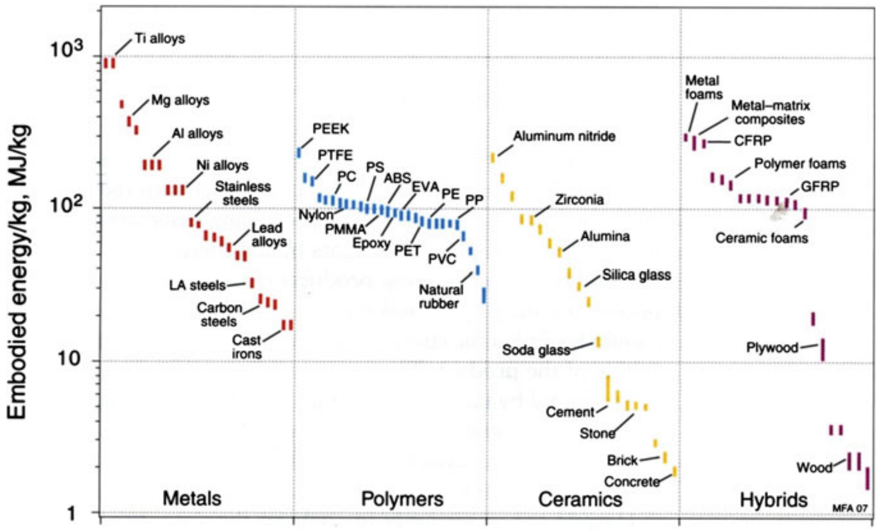

Fig. 3.2 Bar chart of embodied energy of basic materials by weight: by this measure polymers are more energy intensive than other "older" materials, but in the building systems they allow lightweight solutions and less involved quantities, with respect to the same functions of the other families of materials (*Source* Ashby 2009)

permanent building shells, ultra-light weight corresponds to polymer film-like ultra-thinness. Membranes offer undeniable advantages such as the translucent nature of textile membrane roofing and the option of retaining natural light; they also make it possible to achieve a good level of internal environmental quality if they are lower treated. On the other hand, owing to their thin section, membranes bring with them difficulties in maintaining optimal environmental conditions in differing external situations (Fig. 3.3).

Nonetheless, when used in projects, in terms of function and the degree of temporariness/permanence, membranes must ensure comfort through their mechanical, thermal-hygro, acoustic and visual performance (in the latter case, exploiting 10–15 % luminous transmittance and a reduction in artificial lighting), while respecting fire resistance, vulnerability to condensation, and environmental impact performance associated with material manufacturing processes and their lifetime.

As far as thermal-hygro comfort is concerned, in the case of massive walls, radiation and convection play a lesser role and are often neglected, with the focus instead being placed on conduction and associated parameters for thermal resistance, phase shift and attenuation of waves of heat. For membranes, where mass is irrelevant and thermal resistance is close to zero, convection and thermal radiation play a vital role and must be controlled. Heat exchange through thermal radiation depends on a membrane's thermal and optical properties and the surrounding space. Another aspect that should be considered with regard to membrane thermal-hygro

Fig. 3.3 The i.F.O.B.A. architects solved the problem of the lighting in this project (Aura House, Tokyo, 1998), choosing an entire curved envelope made of translucent textile membrane and using the textile as material for a permanent building (*Source* Nishizawa et al. 2000)

comfort is their thermal-light radiation properties, which are more representative of their thermal behavior with respect to the value of transmittance. Consequently, architects should take this information into account when comparing the energy and environmental performance of different textile products and when simulating micro-climatic conditions within tensile structures. This latter property depends on a number of factors such as solar absorption, and solar reflectance and emissivity, in addition to the type of textile and the coating from which they are made.

Two potential avenues may be pursued to obviate the ineffective thermal-hygro response of membrane lightness and thinness: (a) multi-layer membranes in which the number of layers is increased (with differing functions) using a variety of insulating, reflecting, water resistant materials etc., fibrous insulating materials, air chambers and foams; (b) insulated membranes featuring air blades, in which a layer of low density insulating material is inserted between the external structural skin and the internal lining (Fig. 3.4).

From a design point of view, the former solution ensures lowering the passage of heat and a reduced risk of condensation, as well as better control of thermal gain, light transmission and acoustic characteristics. The latter solution offers greater mechanical stability, greater thermal stability and humidity/condensation control, along with lower translucency or semi-transparency, in some cases reducing to zero transparency and diffused light (Fig. 3.5).

As well as other context-related issues, it is important to be aware of a project's climatic characteristics. If the project is part of a sustainability plan for a specific area in Milan, for example, as well as constructing an experimental setup of a

Fig. 3.4 Example of a multi-layer membrane installed into the Portuguese Pavilion, Expo 2000, Hannover, Germany: the number of layers is increased with differing functions (*Source* Zanelli 2007)

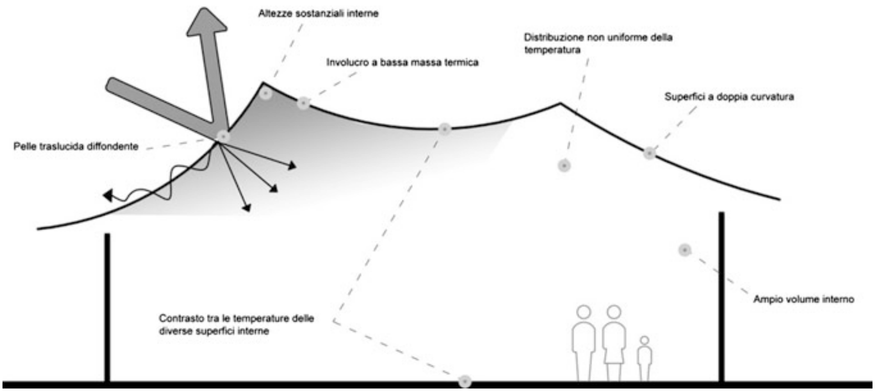

Fig. 3.5 Characteristics of a textile envelope in a building, which influence the environmental indoor behaviour (*Source* author drawing)

lightweight covering system, the climatic conditions in the city during the year must be known. For example, with regard to Milan's average winter temperature (January average temp. 1.4 °C, absolute minimum temp. −15.6 °C), building and health regulations require that a temperature of 20 °C must be catered to within enclosed spaces in order to guarantee adequate internal comfort; in summer

(July average temp. 23.1 °C, absolute maximum temp. 39.3 °C), the design must guarantee 23 °C indoors. In Milan, the annual average temperature is 12.5 °C (data sourced from the Weather Forecasting Station at Milan Linate).

3.5 The Right Membrane Technology for the Specific Context and Life Span

In designing lightweight architecture, the executive and definition phase of material construction techniques should commence with a heuristic phase. If the project is for open/openable spaces through the configuration of lightweight covering systems, it is important to choose one of the following possible scenarios depending on the project context:

– In the case of a permanent hyper-insulated enclosed building of a compact shape (i.e. cocoon-like) which ensures an efficient response to environmental requirements in winter, during the design stage it is vital to envisage how the high-temperature and radiative effects of sunlight in summer will be managed: it is necessary to thoroughly examine critical issues and implement a number of design strategies. With enclosed membranes, it is vital to ensure appropriate ventilation by adopting a number of strategies such as internal air layer mixing; in summer, natural ventilation must be ensured through features that are included during the design phase – for example, planning to position a number of openings into the covering; a continuous supply of air must be guaranteed from the outside in order to avoid areas of internal heat, whereas during the winter heat dispersion must be reduced to a minimum, along with the entrance of air from the outside, by mixing internal layers of air (through de-stratification fans or adjustable-sized waterproof openings).
– In the case of a permanent building open in the summer, it is necessary to envisage an option for enclosing the volume during the winter season, which means focusing on the paradigms of adaptability and transportability as well as form (this may also include an option of adding layers of covering in order to ensure greater comfort in a cold climate), all of which must be considered from the design concept stage onwards (Fig. 3.6).
– In the case of a seasonal building designed for the summer, which, for example, offers shade and shelter from heat radiation, there is no need to consider thermal insulation. However, if the building's function is to serve as a place for study or reading, what is more likely is the need to investigate acoustic insulation of the system to be designed; the prevailing choice would be to opt for extreme lightness and ease of assembly/disassembly by adopting a reversible structure in order to facilitate disassembly at the end of the summer season. In the case of open membranes whose function is to provide shade, it is possible to avert the radiative effect by employing sun-reflective materials (65–80 %) that avoid the generation of shade and overheating in the membrane; to create greater shade it

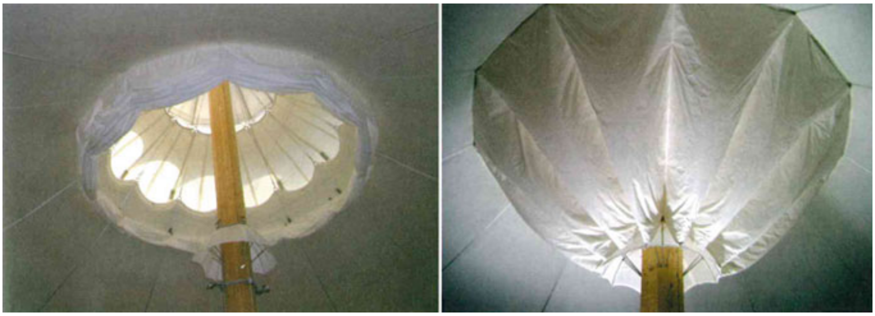

Fig. 3.6 Example of folding/re-folding membrane designed and installed with the strategy of reduction of the indoor volume during the winter time, Leonnberg, Germany (*Source* Zanelli 2007)

would be opportune to opt for colored coatings; adopting a grid-based tensile structure provides a cooling effect in addition to natural ventilation (Fig. 3.7).

– In the case of seasonal buildings designed for the winter, the prevailing environmental requirement is heat insulation and rendering the covering functional; owing to the thinness of lightweight materials, the envelope must be layered with multiple elements, each of which is functional to the various roles that envelopes must provide (impermeability to water, permeability to vapor, thermal and acoustic insulation, the internal/external visual relationship, etc.). To pursue the lightweight paradigm in any event despite this necessary layering it is vital not to increase the overall weight of the building, as at a later date it must be disassembled and reassembled.

Fig. 3.7 A case of a seasonal structure designed for the summer, which offers shade and shelter from heat radiation, El Cairo, Egypt (*Source* Zanelli 2007)

A number of important design strategies may be identified by considering a building's permanent or temporary nature from a lifestyle thinking approach:

- For "permanent" buildings, more attention must be paid to the operational phase (energy requirements for heating and cooling, maintenance), including the need for more envelope insulation, greater mass, more materials, and consequently a greater environmental impact during production processes; consideration of what material and technological solutions to choose and their environmental impacts takes place subsequently.
- For "temporary" buildings, the role of the impact of building components remains prominent, considering that in some situations energy heating and cooling plants and consumption during the usage phase are not required; at the design stage, the expected life span, which is almost always known and definable, is extremely important. One option is to use construction elements characterized by a high environmental impact, high embodied energy and good durability: their impact may be absorbed over forty, fifty or sixty years. A second option is for the materials chosen to provide low energy content if the lifetime is short, or else good durability despite their high environmental impact so that they may be reused/recycled: in this way the total impact is sub-divided into multiple life cycle loops (Monticelli 2009).

In the field of lightweight materials and membranes, materials used for temporary functions can become used for permanent functions. The building materials used in permanent functions are also used for temporary functions: at the design stage it is important to precisely define the building's function, be aware of its context and establish the expected life cycle of the building under design.

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