1 INTRODUCTION

Our whole economy has become a waste economy, in which things must be almost as quickly devoured and discarded as they have appeared in the world, if the process itself is not to come to a sudden catastrophic end. (Hannah Arendt)

Today buildings are a graveyard for materials – once used they rarely have a further life. We hear that increasing percentages of demolition waste is ‘recycled’, but what value comes from this? Most recycling actually means crushing and use as road base or for other low value uses. Much of the usefulness and financial value is lost. Yet existing buildings and industrial waste streams are huge reservoirs of materials and components that can potentially be mined to provide much needed construction resources. There is increasing recognition that a building at the end of its life is an asset to be valued and that innovation and imaginative design can offer new opportunities for using discarded materials and components as valuable parts of buildings. In the developed world we can learn from ecological systems and from resource strategies in poorer parts of the world, where materials are more precious and salvaged items are more highly valued. This may help to create material systems for construction that replicate and integrate with the cyclical features of nature.

But what would our cities look like if our buildings were to be built from locally available, renewable and salvaged resources? What sort of new urban vernacular may emerge if we focus on previously used materials and components that come from the local area and do not need large amounts of energy and other primary resources? How does value in old materials get transformed and reconceptualized into new value? How can we transfer heritage value in components and not just whole buildings? Will the process of designing and constructing buildings need to change if it is based on a harvest of local, salvaged materials? What infrastructure is required to make this happen?

Today there is increasing interest in exploring how buildings are made and un-made, and in finding new business models that make use of discarded materials, components, and buildings (Figure 1.1). The above questions are addressed in this book,
Figure 1.1 The TAXI building in Denver, CO, was entirely modernized by tres birds workshop using reclaimed materials, including a thermal exterior wall system fabricated from 21,000 recycled PET plastic water bottles.
which draws on the experience of practitioners and case study projects to explore the potential for a new type of architecture that places a high economic, social and ecological value on existing materials and treats the urban environment as a transient store of resources that should be redeployed once their initial use is complete. The book focuses on the experience of designers who have started to explore ways to close resource loops, attempting to create systems where less is wasted. Materials destined for landfill are put back to use, with positive effects on the economy, society and the environment. As architect Jeanne Gang put it, they have begun to explore an ‘architecture originated in the material itself rather than in a formal language or design concept’.²

**Box 1.1 Venice Architecture Biennale 2016**

For the 2016 Venice Architecture Biennale, Chilean architect Alejandro Aravena created two introductory rooms using over 90 tonnes of waste generated by the previous year’s art biennale in Venice. Short lengths of previously used crumpled metal channelling were suspended vertically, creating a unique ceiling using waste. Also, the walls were covered by 10 000 m² (100 000 sq. ft.) of multicoloured leftover plasterboard (drywall) pieces which were stacked to create a moulded surface that included protruding display shelves.
1.1 BACKGROUND

Architecture in its traditional role is probably a dying profession. Today, architects must work with systems; they must design new ways of living and working in which buildings play a key role. We desperately need mediators between human need and the enduring cycles of nature. Architects can, and must inhabit this new role. (Paul Hawken3)

Architecture is created from a fusion of concept and matter, what Louis Kahn called ‘the measurable and the unmeasurable’, and throughout history architecture has been shaped by a dialogue between ideas and materials. Kieran and Timberlake in their book Refabricating Architecture state that ‘architecture requires control, deep control, not merely of the idea, but also of the stuff we use to give form to the idea’.4 Traditionally this has led to a fascination with the newest and most innovative materials, and the evolution in architectural history has a strong association with new technology. Today the vast majority of materials used to create the built environment are new and pristine, and our consumer culture leads us to assume that new is best. At the same time, most materials are unrelated to place, and predominantly come from all over the world – aluminium may come from South America, steel from Russia, glass from China, timber from Canada and so on.

Material and component selection is a vital part of architecture because it holds such potential to communicate meaning in our built environment. In the developed world today we do not normally conceive of buildings as being made from local, salvaged, pre-used materials. We are used to the off-the-shelf method of choosing materials (and technologies). But up until the twentieth century many building components were custom designed by architects. Windows, columns and so on were not standardized. More recently, architects have come to rely on a readily available architectural palette of standardized components from catalogues or web sites. Information such as specifications, dimensions, and standard details for globally produced building components are readily available and their use is facilitated by digital technologies. Design and construction for most buildings is organized as a process of integration of appropriate components. This has isolated designers from a better understanding of materials and their tectonic potential and has removed some creative possibilities and discovery from design.
Furthermore, the quantity of these materials that we use has grown hugely. In the last 50 years the world population has doubled yet our use of some engineering materials has grown by 4–15 times. This huge increase has enabled us to increase our living standards, creating and servicing a huge urban infrastructure connected by extensive transport networks. But, as architect Thomas Rau has pointed out, unlike energy, which is widely available from the sun (we just need to implement appropriate technologies for harvesting it), access to materials is effectively limited by what is available on earth, and for some materials we have consumed most of the easily obtainable supply.

In a world faced with climate change, increased resource scarcity, and other environmental, social and economic challenges, access to new material resources and disposal of waste are becoming far more costly and constrained. Growing concerns about the loss of useful resources and physical limits of the earth’s capacity to provide new resources and absorb the mountains of waste accumulating in landfills, as well as the increasing cost of disposal, are leading some to a rethink how we deal with resources. The United Nations Environment Programme (UNEP) has noted that ‘As global population continues to rise, and the demand for resources continues to grow, there is significant potential for conflicts over natural resources to intensify in the coming decades’.

The work of photographers such as Edward Burtynsky, Timo Lieber and Vik Muniz (Figure 1.2) brings to light the vastness of the process of dealing with materials throughout their linear life cycle and highlight some of the impacts this has on individuals, society and the natural world. As buildings gradually become less carbon intensive for operating energy use, the impact of extracting, processing and installing the materials used to create the built environment become increasingly important and the embodied energy and carbon that occurs from this becomes progressively more of a concern.

It is now commonly recognized that a linear economy, which focuses on maximizing ‘throughput’, is wasteful because it permanently disposes of valuable resources after their first use. There is an increasing awareness of the need to move towards a circular economy, based on cyclical systems as observed in nature, which aims to transform the value of existing resources that have come to the end of their usefulness in their current form. Many governments around the world are beginning to consider resource efficiency, resource productivity and waste reduction, in addition to climate change and other development issues in their policies. In 1999, John Prescott MP (then UK Deputy Prime Minister and Secretary of State for the
Environment, Transport and the Regions) stated that ‘In the past, focus has centred mainly on improving labour productivity. In the future, greater emphasis will be needed on resource efficiency. We need to break the link between continued economic growth and increasing use of resources and environmental impacts’. These factors will, in future, have significant repercussions for materials availability and, thus, architectural design and building construction. Supply of bulky, low value, construction materials may in future be far more dependent on local proximity and local availability. The need to design and build using local, readily available, renewable or reused resources, and to develop closed-loop systems for the life cycle of building materials are likely to become major drivers for the design of the future built environment. And this will create new design opportunities, but will also change the design and construction processes.

Figure 1.2 ‘Atlas (Carlão)’ is one of several amazing portraits created by photographer Vik Muniz and the catadores – self-designated pickers of recyclable materials, using waste from Jardim Gramacho waste dump located on the outskirts of Rio de Janeiro.
Some designers and building owners have begun to explore alternatives to the produce–use–dispose linear model of resource use in the built environment and to consider closed-loop approaches that aim to find use, value and inspiration in what was previously classified as waste (Figure 1.3). Materials destined for landfill can be put back to use, with positive effects on the economy, society and the environment. Such an approach has potential to alter the design and construction processes in ways that may lead to more place-based architectural solutions. It is also important to differentiate between reuse today, which has to deal with material that is already in use, and future reuse of materials that we can now ensure will be more readily reusable.

Although green building rating systems such as LEED and BREEAM encourage a move towards closed-loop systems through strategies such as choosing recycled materials and reused components, at present in the developed world the reused building material sector is fragmented. There is an absence of a clear system or infrastructure with recognized business models and processes aimed at reuse. There is a need to establish a supply chain and inform designers about the

Figure 1.3 The Mountain Equipment Coop explored the potential for material reuse in several of its stores such as this one in Winnipeg, Canada.
potential of such materials and components, and to create a
demand that will encourage demolition contractors to decon-
struct old buildings due to the value they can get from them.
Inventories are needed of salvaged products to enable designers
and their clients to have confidence in the availability of materi-
als. And certification processes for materials are needed to
facilitate their use without concern.

At present, such factors are preventing the construction industry
in most countries from embracing a more long-term view of the
value and potential of existing materials and components, and
this is hindering the establishment of mechanisms for their
widespread reuse. However, in future, when choosing materials,
it will be necessary to consider the social, ecological, and
technical relationships and the networks that materials are part
of. Identifying new business models that make such strategies
profitable, and using appropriate design approaches that
address consumer needs and create unique buildings, can
overcome industry hesitation to embrace new material ecologies.

Successful case studies of reuse of components and materials in
building projects discussed in this book are gradually becoming
accepted in the mainstream. Although the designers featured
are innovators and leaders in this field, they present a foretaste
of a potential future that recognizes the value of existing
resources, how they can be transformed and the resulting
environment that can be created. They also offer some ideas
about the infrastructure that will be necessary to establish reuse
as a common feature of the built environment.

---

**Box 1.2  Current Resource Use**

It is estimated that as much as 40% of the raw materials consumed in North America is for construction.

The European Union (EU) uses 8,566 million tonnes of material resources, of which 7,654 million tonnes (89%) are
non-renewable.

From 1980 to 2010 worldwide metals and minerals use increased 66% from 19 billion tonnes to 31.5 billion tonnes
(and is expected to grow to 53.7 billion tonnes by 2030).

Typically we still use materials on average only once.

People in rich countries consume up to 10 times more natural resources than those in the poorest countries.
On average an inhabitant of North America consumes around 90 kilograms (kg) of resources each day. In Europe,
consumption is around 45 kg per day, while in Africa people consume only around 10 kg per day.

Sixty percent of discarded materials is either put in a landfill or incinerated, while only 40% is recycled or reused,
but usually for low value uses.

Ninety-five percent of the value of material and energy is typically lost at the end of the first use. Material recycling
and waste-based energy recovery captures only 5% of the original raw material value.
1.2 SCARCITY OF RESOURCE

Scarcity appears to be a simple concept based on the notions of availability and shortage. However, it is a term that encompasses economic, political, social and ecological domains each with different associations to resource allocation and material use. Systems-theorists, such as Donella Meadows and others, suggest that scarcities occur when resource flows are in some way constrained or exhausted. Economic doctrine encourages us to dismiss such concerns, relying on the market to achieve optimal flows. In the 1970s, economist Georgescu-Roegen was the first to apply the thermodynamic law of entropy (which states that energy tends to be degraded to ever poorer qualities) to mineral resources, arguing that resources are irreversibly degraded and will eventually be exhausted when put to economic use.11 His work inspired the field of ecological economics and the study of natural resource flows in economic modelling and analysis. He claimed that the economic process irreversibly transforms low entropy (valuable natural resources) into high entropy (valueless waste and pollution), thereby providing a flow of natural resources for people to live on but at the same time degrading the value of these resources.

Others argue that scarcity is a socially and economically constructed condition – there is enough food in the world, it is just in the wrong place. There is enough housing in the developed world, just in the wrong ownership. In the developed world of seeming abundance it is difficult to comprehend the relevance of the concept of resource scarcity. Thus, in reality, scarcity is extremely complex and mutable, and fundamental to the essential question of whether we can really have continual growth on a bounded and limited planet.

There is growing consensus that material availability in the future will be significantly constrained compared to the recent past. This may be due to physical exhaustion of supply of some materials (such as rare metals or platinum) but in many cases scarcity is linked to ease of availability, energy intensity of processing, cost of extraction and processing, and transport. There may be a lot of iron ore or aluminium ore in the earth but it may not be realistic to extract such large amounts of it in future. Conversely, as we have seen with the recent advent of fracking and tar sands oil extraction, sources become more or less economically and politically viable due to price changes for a particular resource and government policies and ideologies.

Nevertheless, there is mounting evidence for all the major resources – energy, water, food and materials – that our existing global industrial models are leading to a series of persistent shortages and/or uncertainties. The Stockholm Resilience Centre has shown that using the concept of planetary boundaries, of the nine boundaries that the Centre has identified, by 2015 four have already been breached and several others are close to the
In 2007 the New Scientist magazine looked at the availability of many key minerals and calculated how many years these minerals would last based on various use scenarios. They speculated that material scarcity will call into doubt the aim that the planet might one day provide all its citizens with the sort of lifestyle now enjoyed in the west. Researchers at Yale University suggest that ‘virgin stocks of several metals appear inadequate to sustain the modern “developed world” quality of life for all of Earth’s people under contemporary technology’. The Worldwatch Institute has estimated that by the year 2030 the world will have run out of many raw building materials and we will be reliant on recycling and mining landfills. Increasingly, questions are being asked about whether we have the resources to deliver?

Consequently, consideration of building materials scarcity goes beyond simple availability and cost, to include engagement in the whole supply process from extraction, through processing, delivery, technologies used, skills required, assembly on site, use, maintenance and end‐of‐life disposal methods. It requires consideration of all the tangled social, economic, environmental and technical networks that are necessary to make a resource useful, and their consequent impacts. As Till and Schneider suggest, scarcity in an architectural context is much more than just an actual lack of material, space or energy. Rather, scarcity is revealed as socially, economically and politically constructed and requires a discussion of patterns of creation, consumption and behaviour. They also suggest that scarcity presents a radical challenge to the architectural community as the most appropriate solution to a spatial problem under conditions of scarcity may often be the avoidance of new building.

A changed approach to materials, or a ‘new materialism’ based on ecological principles and recognizing limits, demands a rethinking of the nature of material processes in architecture, leading to a

---

**Box 1.3 Resource Use In Construction**

*In England, the Construction Resources Roadmap states that around 380 million tonnes of resources are consumed by the construction industry each year. The table below provides estimates of global use of five principal construction materials.*

<table>
<thead>
<tr>
<th>Material</th>
<th>Global production (Mt/yr)</th>
<th>Use per person – based on world average (tonnes person/yr)</th>
<th>Carbon intensity (kgCO₂e/kg)</th>
<th>Approximate % used in building construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>1400</td>
<td>0.2</td>
<td>1.5</td>
<td>42</td>
</tr>
<tr>
<td>Cement</td>
<td>4000</td>
<td>0.57</td>
<td>0.7</td>
<td>75</td>
</tr>
<tr>
<td>Aluminium</td>
<td>70</td>
<td>0.01</td>
<td>9.2</td>
<td>24</td>
</tr>
<tr>
<td>Plastic</td>
<td>299</td>
<td>0.04</td>
<td>3.3</td>
<td>20</td>
</tr>
<tr>
<td>Timber</td>
<td>534</td>
<td>0.075</td>
<td>0.31</td>
<td>40</td>
</tr>
</tbody>
</table>

Note – these data are a best estimate based on a variety of sources.
fundamental revision of both the way we create our built environment and what the urban environment will be like in the future. This may lead to new forms of architectural practice and new procurement processes, some of which are explored in this book.

1.3 WASTE AND OBsolescence
The way we see it, waste is what you call something when you have no idea what to do with it. The fact that waste exists anywhere is more a testament to our lack of imagination than it is to the inherent value of any material. If you have a purpose for it, it’s no longer waste. (Omar Freilla17)

The increase in waste generation is inextricably linked to urbanization and economic development. As countries urbanize and standards of living increase, consumption of goods and services increases, so waste generation typically increases. In recent years there have been increasing concerns about the vast garbage dumps that are necessary to service urban areas, and the huge amounts of waste (particularly plastics) that accumulate in the world’s oceans, endangering humans and wildlife and taking hundreds of years to degrade.

Waste has become a significant concern, having major impacts on people’s health, the environment and national economies. Waste disposal has significant costs to municipal governments, pollutes the local and global environment and contributes to climate change in the form of greenhouse gas emissions from transport and processing. Yet, much of this discarded material has significant potential value and usefulness. Discarding it is therefore negligent. In developed countries, construction and demolition waste typically contributes about 35–40% of the total waste stream. It is estimated that about 75% of this demolition waste (by weight) has residual value that can be utilized by reintroducing it into the urban fabric through reuse or recycling.

The problem of waste as a concept is reflected in the difficulty of defining waste and the assumption that it is a burden that requires discarding. Often definitions are not useful and reflect the current linear attitude to resource use. In many countries complex rules define different types of waste and how they can be treated, with legal implications. Sometimes these can prevent legitimate reuse of potentially useful materials. The UK government rules for defining waste state that ‘A material is considered to be waste when the producer or holder discards it, intends to discard it, or is required to discard it’.18 This ignores any useful value the material may have. Zero Waste America defines waste as ‘a resource that is
not safely recycled back into the environment or the marketplace. A new and evolving ecology of material sees waste streams not as a burden but rather as a valuable resource. In the book Wasting Away, Kevin Lynch suggested that ‘Architects must begin to think about holes in the ground and about flows of materials’. A new type of infrastructure of valuing, recovering, sorting, processing, managing and using is beginning to evolve to exploit discarded materials. A new aspirational target of ‘zero waste’ (along with zero energy and zero carbon) has been proposed for new and existing buildings and urban areas which will require the redesign of urban systems and material flows. As with zero carbon buildings, a discussion is needed about the appropriate scale and strategy for achieving zero waste – should we address waste at the level of the component, building, district or city? Most likely all should be considered.

Although in recent years waste management and recycling schemes in some countries have reduced the volume of waste going to landfill, to achieve fundamental change in our approach to waste we need to rethink our approach to design, component life cycles and building life cycles. This requires reconsideration of the concepts of obsolescence and decay. Since the built environment uses a lot of materials and lasts a long time, there is a need to carefully reconsider how a material, component, or building decays and when it becomes obsolete. Extending the life of resources (not necessarily buildings) should be an essential aspect of design and management of the built environment.

Obsolescence is defined as when something becomes no longer useful, is outmoded, out of date, or falls into disuse. In construction, a component or building is regarded as obsolete at the point when it is discarded for whatever reason. Conversely, decay is the process of rotting or decomposition and is closely related to physical effects. It has been noted that obsolescence occurs for many reasons and is strongly connected with economic value, regulations and market forces, and less with physical decay; thus, architectural design has a limited impact on building obsolescence. A study by the Athena Institute into the reasons for the demolition of 227 buildings in Minnesota, USA, showed that only one-third of the buildings were demolished due to decay and, thus, their physical condition. The study highlighted urban issues and site planning as well as aspects of building construction and maintenance as ways to increase building longevity and avoid obsolescence. Various researchers have presented obsolescence as the divergence over time between declining performance and rising expectations. For building stocks, Thomsen and van der Flier have defined obsolescence as a process of declining performance resulting in the end of the service life. But the reasons for this can be many and are often not technical. They claim that ‘obsolescence of building stocks is only partly a physical phenomenon. It is
essentially a function of human action or disregard. Therefore a distinction should be made between actual and potential performance’. A variety of causes have been suggested for obsolete buildings, including: physical, economic, financial, functional, location, environmental, political, market and fashion. Figure 1.4 shows a conceptual model for building obsolescence as proposed by Thomsen and van der Flier.

Abramson has explored architectural obsolescence and the idea that buildings and cities can suddenly lose their value and utility. He claims that our current concept of architectural obsolescence evolved out of early-twentieth-century US capitalist real estate development and spread globally in the mid-century urban and social realms before impacting architecture directly. He states that ‘a building’s value was represented in time and money, inextricably declining and rendering demolition inevitable’. Abramson also identifies obsolescence related to urban renewal and the resulting removal of many technically usable buildings, and related to the corporate strategy of planned obsolescence and the general infusion of a culture of short term-ism. In this context, issues of physical or technical obsolescence become less important as financial concerns dominate.

Some designers have embraced obsolescence’s liberating promise of expendability and short-life buildings. Others object

---

Figure 1.4 Conceptual model of obsolescence redrawn based on Thomsen and van der Flier.
to its implications of transience and waste, and have sought to reverse obsolescence through tactics of preservation, postmodernism and ecological design. Abramson proposes obsolescence as the forerunner for today’s dominant paradigm of sustainability as a way of comprehending and managing architectural change.

Box 1.4  Waste In Construction

The World Bank estimates that urban waste generation worldwide will increase from about 1.3 billion tonnes of solid waste per year in 2012 to 2.2 billion tonnes by 2025.

Construction and demolition waste typically constitutes about 25–30% of the total solid waste stream in developed countries.

Construction and demolition waste (CDW) consists of numerous materials, including concrete, bricks, gypsum, wood, gypsum drywall asphalt roofing glass, metals, plastic, cardboard solvents and excavated soil, many of which can be recycled or reused.

In the United States, annual construction and demolition (C&D) debris from buildings (not including roads and bridges) was estimated to be around 162 million tons in 2013 – or about 0.5 t/person/yr.

In the European Union, construction and demolition waste from buildings is estimated 180 million tonnes/yr or about 0.5 t/person/yr.

The Construction Resources and Waste Roadmap in the United Kingdom estimates that total construction and demolition waste in England, including road building, was at 120 million tonnes.

The US Green Building Council (USGBC) estimates that only about 10% of construction waste is diverted from landfills in North America. The European Union has a target of 70% diversion.

Researchers in the United States estimate that the ‘typical’ North American home generates about 1600 kg (3500 pounds) of wood waste during its construction.

Repair and remodelling tends to generate more waste than new construction because many repair and remodelling projects involve both demolition and construction activities, both of which generate waste.

Many countries have established recycling strategies that prevent much C&D waste going to landfill but much is downcycled as low grade road fill products.

Note – these data are a best estimate based on a variety of sources.

1.4 PERMANENCE AND REPAIR

Permanence is not a matter of the materials you use. Permanence is whether people love your building. (Shigeru Ban23)
than expected. The concept of permanence in architecture is contrary to obsolescence and relates to attitudes about durability and maintenance—and also perception. Most architects hope that their creations will last and become permanent and unaltered. In traditional societies the large investment required to create a major building was justified by the conviction that important buildings should be permanent. But the concept of permanence can mean very different things. For example, in Europe permanence in architecture is traditionally equated with stability, mass and solidity. Stone monuments and their durability of construction are often used as examples of permanence. Yet as Ford has pointed out ‘Much of Renaissance Venice is a 19th-century reconstruction; the Venice Campanile dates from 1910. The Vienna Opera and Milan’s La Scala date from the late 1940s. All the members of the Eiffel Tower have been replaced at least once. The Lincoln Bedroom….. dates from the Truman administration’. So what about these buildings is permanent? Ford also argues that although the Parthenon still consists of its original stones (and indeed they are treated almost as religious relics), much of the original content of the architecture—the colour, detailing, context—no longer exists. So permanence of the physical matter has not conserved all the original content and ideas. An alternative view of permanence is represented by the Ise shrine in Japan, which, although originally constructed in the seventh century has been reconstructed in an elaborate ritual approximately every twenty years. So, is it 1300 years old or 20 years old? As Ford and others have pointed out, in Japanese culture, where architecture was typically created from timber and so easily destroyed by fire and other natural forces, value was embedded in the ideas and not the material reality. In this case it is the style and ideas enshrined in the building that are preserved, although the physical matter is constantly renewed. Many vernacular buildings such as earth buildings have an extended life because of the willingness of the community to regularly spend time renewing and maintaining the buildings in order for them to endure in their original form. This highlights the link between permanence and maintenance—most buildings can last a long time with appropriate maintenance, and become obsolete for other reasons.

Since the industrial revolution architects have been more willing to reject the traditional view of permanence of buildings and recognize that the fast changing nature of modern life may require more transient built environments. Le Corbusier’s call to treat a house as a machine suggested that both maintenance and durability for houses should be similar to the way machines are maintained. Machines are generally seen as more transient but at the same time require more maintenance. Furthermore, technical advances and the introduction of codes have changed expectations for building performance in a way that has undermined permanence in buildings, and questioned how we should treat even some historical buildings. For example discussions
about whether, and how, to improve the performance of historic parliament buildings in England and Canada highlight the friction between permanence, heritage value and thermal performance. Groak argues that it is meaningless to speak of building lifetimes, since different parts of the building have very different lifetimes. He asserts that ‘buildings have to be understood in terms of several different time scales over which they change in terms of moving images and ideas in flux’.25 Nevertheless, most new buildings are designed with the often unrealistic assumption that they will not substantially change (typically for a 50–60 year life), so whether measured in money or carbon this can lead to considerable waste.

In the book How Buildings Learn, Stewart Brand discusses how buildings adapt to changing requirements over long periods. He challenges the proposition that architecture is permanent and that buildings cannot evolve, and proposes that buildings adapt best when constantly refined and reshaped by their occupants (Figure 1.5). This raises the question of the role of architects and Brand is in favour of an evolutionary approach where owners can change a building over time to meet their needs, and the architect's role is to facilitate this process. He proposes that rather than being artists of space architects need to becoming artists of

Figure 1.5 This Victorian industrial building in London has been regularly transformed to a new use throughout its life. It has been used for industrial, commercial, retail and catering uses in the last 40 years.
time, using the conceptual model of layers of a building – site, structure, skin, services, space plan and stuff (Figure 1.6), each of which has a different timescale and can be maintained and replaced to suite its individual needs (see also Chapter 2.6).

Groak notes that buildings are only ever sustained as coherent artefacts by incessant microrenewals (small repair and improvements). Historian David Edgerton claims that ‘although central to our relationship with things maintenance and repair are matters we would rather not think about’. Consumer culture has developed a prejudice against repair (as a sign of poverty) and permanence as a way of increasing economic activity. Edgerton states that until the mid-twentieth century more expensive and complex equipment was kept working by a constant interaction with repair regimes. Repair was the means by which they were kept functioning. Early automobiles, for instance, required constant attention to keep them running. Complex contemporary buildings have some similar characteristics, as without knowledgeable operators capable of appropriate control and repair they do not function optimally. Thus, Cairns and Jacobs conclude that durability is not an intrinsic attribute of architecture but rather a feature of how the world views architecture.

But the idea of permanence can also be applied to materials and components, even when the building is no longer treated as permanent. Current consumer culture encourages a disposable approach to everything, and permanence expressed in the value of components and materials challenges this (Figure 1.7). Can we design ways of assembling buildings that creates permanence at a subbuilding level and avoid obsolescence for the components and
1 INTRODUCTION

materials? And what type of infrastructure and industry would this require? Long-life construction materials, components and buildings require effective decision tools that can be applied at the critical early stages of design. The effects of longer product/building life on life cycle costs, revenues and environmental impacts need to be better understood to inform design strategies.

1.5 MATERIAL EFFICIENCY

“Buckminster Fuller was keen to know how much a building weighed. A better question would now be, how much material resides in the building plus how much material was displaced and energy consumed in the making of the building.” (John Fernandez.28)

Energy efficiency entails providing energy services with less primary energy and has become accepted as a requirement for a sustainable future. In the same way the concept of material efficiency suggests providing material services to humanity while
reducing demand for primary materials (using less material, for longer, to achieve the same function), and is also seen as essential to a sustainable future that is compatible with ecological systems. The importance of this concept was highlighted by analysis at the University of Cambridge of the worldwide manufacturing sector that found it very unlikely that manufacturing could meet the 2050 IPCC greenhouse gas (ghg) reduction targets by a strategy of energy efficiency alone. But combining energy efficiency with material efficiency has a reasonable chance of meeting ghg and energy reduction goals for the manufacturing sector.

Key elements of material efficiency are products with longer life cycles, finding ways to return products and materials into service after the end of their current or initial use (reuse, recycling) and designing components that use materials efficiently (reduce). In this way the same level of material services can be provided with reduced extraction of primary materials and less waste generated. Unfortunately, this is inconsistent with many current practices, as construction materials are often relatively cheap but labour is expensive. Thus, many of our buildings use materials such as concrete and timber wastefully, as a more resource efficient proposal requires more labour and design effort.

Some other industries are more advanced with the process of rethinking how products are put together to increase material efficiency. This is partly due to EU legislation that is increasingly putting the responsibility for disposal of products at the end of their useful life onto the producer. Features such as reversible joints, upgradeable components and materials that can be separated are now gradually being incorporated into new products and appliances. Car manufacturers increasingly consider the end‐of‐life disposal of their products, designing cars to enable recovery of components on ‘unassembly lines’ and for easier replacement and reuse of worn parts. Simpler designs and assembly processed using less materials and components can lead to cost savings and are often more applicable for disassembly. Although the nature of construction and the timescales involved are very different to most other industries, there is a need to consider how to apply similar principles and approaches in the built environment. This may necessitate producers of goods taking them back at the end of their life for reuse, recycling or disposal. Ideas such as leasing materials and components are being explored, and ‘materials passports’ (see Chapter 2.7) can provide information necessary to facilitate reuse. In the United Kingdom, the British Standards Institute has recently issued a new British Standard, BS 8895: Designing for Material Efficiency in Building Projects, which is intended to help design teams to consider the materials that they use, factoring in high recyclability, designing out waste and considering circular strategies before any work is undertaken.

**Box 1.5 Energy Savings from Reuse and Recycling**

The US EPA undertook a study to calculate the energy benefits of improved material management throughout a material’s life cycle. The study developed net energy factors for a selection of materials analysed for four waste management options: source reduction, recycling, combustion, and landfill. The study showed that recycling and reuse generates energy savings for all the materials studied but reuse can reduce greenhouse gas emissions over 60% compared to recycling for materials such as steel and glass. The savings vary depending on the material and are driven largely by the difference between manufacturing inputs.
Our current age is defined by the imperative to address climate change, which requires reducing carbon emissions from human activity. As operational energy performance in buildings improves, with more demanding codes and standards pushing building performance towards net zero energy (and carbon), focus is gradually shifting towards energy and carbon emissions related to the processes of supplying and incorporating materials into buildings (embodied). The embodied energy and carbon of a typical new building represents a significant proportion of its impact, possibly as much as 30–70% of its lifetime carbon emissions.

The embodied energy concept refers to all the energy resources spent in the extraction, manufacture, transportation and assembly of a material or component. It is directly related to the ‘emergy’ concept as proposed by ecologist Howard Odum to account for the variations of energy quality. Emergy (sometimes referred to as energy memory) is a measure of energy used in the past life cycle of a material/product and represents an alternative measure of value based on natural systems. It provides an environmental accounting system that considers the historical energy needs from the life cycle of the material/product and of every system participating in its past: its energy memory. When used in the context of buildings, embodied energy and embodied carbon are usually calculated using life cycle analysis principles and practices as defined by ISO standards. Embodied energy/carbon is also related to the concept of the ‘ecological rucksack’, which comprises all resources necessary to produce and transport a product all the way to the consumer.

Further emphasizing the importance of embodied impacts is emerging literature suggesting the importance of the cumulative carbon affect. The carbon cycle has reached saturation and excessive carbon emissions are not being recycled, so carbon is accumulating in the atmosphere. Due to the long time frames involved, the date at which carbon is released into the atmosphere affects the climate change impact it will have during this century. For example, one tonne of carbon emitted today will have ten years more impact by the end of the century than one tonne emitted in ten years. This implies that a greater weight should be placed on reducing current emissions as opposed to future emissions as the impact will be immediate. Thus, a greater focus on embodied carbon emissions is implied, which mainly
occurs during the material manufacturing stage. Greater focus on embodied carbon is also likely to promote local sourcing, manufacturing innovation and job creation.

Reducing embodied carbon can complement initiatives already being taken to reduce operational carbon. Already today organizations, such as Skanska UK PLC and Sainsbury’s, are actively measuring and reducing the embodied carbon of their construction projects and looking at whole life carbon impacts. Conceptually, for a building achieving net zero operating energy (or carbon), all emissions are due to construction or renovation. The Green Building Council Australia state that ‘buildings need to have zero emissions in their construction, operation and embodied energy to be truly carbon neutral’.33 Research in the United States34 suggests that embodied carbon emissions can be reduced by around 30% by selecting appropriate existing materials and technologies, by using lower‐carbon materials and by employing

---

**Box 1.6 Embodied Energy (and Carbon) of Materials**

It has been estimated that embodied emissions (from the extraction, processing, manufacturing, transport of materials and construction of the built environment) amounts to 63 MtCO₂e in 2007 or 9.5% of the United Kingdom’s 2007 reported domestically produced emissions of 666.1 MtCO₂e emissions.35

The production of five key materials: steel, cement, aluminium, plastics and paper, account for about 20% of world greenhouse gas (ghg) emissions.36 So even if some people feel that material stocks are not a concern, the production process for these and many other construction materials is a challenge at a time when climate change is seen as a age defining problem.

By 2050 the total embodied carbon from building construction that will be emitted in the United Kingdom is estimated to be about 3100 MtCO₂e, equivalent to over 5.5 years of current annual UK total emissions.31

In the United States, the embodied emissions from the construction of 500 million m² (5.7 billion sq. ft.) of new buildings per year are estimated to be about 300 MtCO₂e tons per year,34 and the embodied emissions from those new buildings are expected to outweigh the operating emissions from those buildings over the next 20 years.

**Contribution to UK CO₂ emissions made by the construction sector in 2008**37

<table>
<thead>
<tr>
<th>Subsector</th>
<th>CO₂ (Mt)</th>
<th>% of total</th>
<th>% of Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Design</td>
<td>1.3</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>• Manufacture</td>
<td>45.2</td>
<td>8.6</td>
<td>15.1</td>
</tr>
<tr>
<td>• Distribution</td>
<td>2.8</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>• Operations on-site</td>
<td>2.6</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>• In Use</td>
<td>246.4</td>
<td>46.9</td>
<td>82.6</td>
</tr>
<tr>
<td>Demolition</td>
<td>1.3</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Total Construction</td>
<td>298.4</td>
<td>56.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Other Sectors</td>
<td>226.6</td>
<td>43.2</td>
<td></td>
</tr>
<tr>
<td>Total UK</td>
<td>525</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>
more efficient design and construction processes. But an even more effective way to reduce embodied carbon emissions is to reuse existing buildings, components and materials. Building renovation and component reuse usually generates significantly less emissions than new construction and creates an opportunity to reduce operating emissions from existing buildings.

In future, it is likely that whole life cycle carbon budgets for buildings will be assessed and regulated, and it may be necessary to evaluate the initial embodied carbon investment against the carbon savings generated in operation. For example, a UK Green Construction Board report on creating a more sustainable construction industry sets out a route map for a 21% reduction of embodied carbon by 2022 and a 39% reduction by 2050 (compared with a 2010 baseline). The report suggests that all future projects will require analysis of how much carbon was invested and how long it will take the savings from increased efficiency to offset that investment. In such an analysis reused material choices can have a big impact, as studies indicate that impacts are significantly reduced when materials are reclaimed and reused (rather than recycled or discarded).

1.7 THE CIRCULAR ECONOMY
A circular economy... aims for the elimination of waste through the superior design of materials, products, systems and business models. (Ellen MacArthur Foundation)

The world’s current economic model is largely based on linear ‘take-make-dispose’ processes that rely on large quantities of cheap, easily accessible materials and energy, and create large volumes of waste. In the building industry this has taken the form of linear material flows: raw materials extraction, transport, materials processing, assembly, use, demolition and disposal. In recent years, the green building agenda has managed to increase recycling for some materials but the underlying processes are still largely linear. Gradually governments, policy makers, and some companies are realizing the physical limitations and consequences of this model, and the need for a circular economic system that operates within planetary boundaries.

With global population continuing to grow and urbanize, and three billion new middle class consumers expected to enter the market by 2030, high material and component prices and volatility are predicted to be here to stay. Management consultant McKinsey & Company claims that rising commodity prices since 2000 have wiped out the decline in real prices that took
place over the whole twentieth century. At the same time, we are surrounded by a sea of discarded materials and McKinsey predicts that adopting circular economy principles could generate a net economic benefit of €1.8 trillion by 2030 in addition to environmental and social benefits.40

The circular economy is based on system thinking and was explored in the 1960s and 1970s in work such as EF Schumacher’s pioneering41 Small is Beautiful and the Club of Rome’s Limits to Growth report.42 Architect and industrial analyst Walter Stahel set out a vision of an economy in loops (or circular economy) and worked at developing a closed-loop approach to production processes.43 In 1982 he created the Product Life Institute in Geneva that pursues four main goals: product-life extension, long-life goods, reconditioning activities and waste prevention. It also focuses on the importance of selling services rather than products, embodied in the notion of a ‘performance economy’. Stahel argued that smaller closed loops, such as reuse and renovation, are more beneficial than recycling as they require less input of new resources.

More recently, the Ellen McArthur Foundation has pioneered initiatives that explore the policy implications of a circular economy and has published a variety of documents exploring its principles and applications. A circular economy is centred on closed loops of material flows and on a financial system that maximizes the value of materials and products at every stage of their life cycle. It challenges the concept of waste and assumes that every material and product contains useful technical or biological nutrients that, with the proper infrastructure and incentives, can have value and feed into established or new processes.

‘The circular economy is one that is restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption. It enables key policy objectives such as generating economic growth, creating jobs, and reducing environmental impacts, including carbon emissions’.44
The circular economy model for the built environment goes beyond individual strategies such as recycling, design for deconstruction, or extending building lives (Figure 1.8, Box 1.7). It implies full systemic change and requires innovations in technology, organization, finance methods and policies to create an integrated model that redefines concepts of value and ownership and connects the start and end of life, making recovery and repurposing the obvious financial choice. In a study for Denmark, the Ellen McArthur Foundation identified the built environment as one of the sectors with the highest potential for applying circular economy ideas, with several main opportunities:

- Industrial production processes, modularization and 3D printing.
• Reuse and high quality recycling of building components and materials by applying design for deconstruction techniques, material passports and so on.
• Sharing, multipurposing and repurposing of buildings, peer-to-peer renting, better urban planning.
• Substituting complex mixed compounds of materials that are difficult to reuse or recycle.

Denmark and The Netherlands have been front-runners in exploring the implications of circular principles, recognizing that products/buildings in such a system can require less energy, produce fewer ghg emissions and reduce the demand for raw materials. Now, other countries are also responding; in 2016 the European Commission adopted a Circular Economy Package, which includes revised legislative proposals on waste ‘which will boost global competitiveness, foster sustainable economic growth and generate new jobs’. In Canada, the Ontario Strategy for a Waste Free Ontario: Building the Circular Economy published in 2015 by the Ontario Provincial Government recognizes that ‘circular economy drives innovation. A shift to a circular economy encourages businesses to design long lasting, reusable and easily recyclable products. The reuse of products adds significant value to the economy by creating or expanding the reuse and remanufacturing sectors’. London’s Circular Economy Route Map was published in 2017, with the built environment being highlighted as offering the greatest net benefit. Initially such strategies have been motivated by waste reduction and are merely a start towards a full circular system, but they indicate a growing awareness of the importance of moving towards a circular model.

Box 1.7 Principles of Circular Economy

The Ellen MacArthur Foundation proposed five principles on which to base a circular economy:

1) **Design out waste.** Waste does not exist when the biological and technical components (or ‘materials’) of a product are designed by intention to fit within a biological or technical materials cycle, designed for disassembly and repurposing.

2) **Build resilience through diversity.** Modularity, versatility and adaptivity are prized features need to be prioritized in an uncertain and fast-evolving world.

3) **Work towards using energy from renewable sources.** Any circular story should start by looking into the energy involved in the production process.

4) **Think in ‘systems’**. The ability to understand how parts influence one another within a whole, and the relationship of the whole to the parts, is crucial.

5) **Think in cascades.** For biological materials, the essence of value creation lies in the opportunity to extract additional value from products and materials by cascading them through other applications. The complete biological entity should be considered.

See https://www.ellenmacarthurfoundation.org
In the built environment, moving towards a circular economy suggests that processes are re-examined at the material, product, building and urban scale, focusing on long-term value rather than just first costs. It suggests a fundamental shift in how the built environment is designed, constructed, maintained, owned and deconstructed. A circular economy challenges the significance of ownership, with value arising from service, performance and transformation rather than from ownership of a physical object. Rather than selling products, manufacturers would become providers of a guaranteed level of service (Box 1.8). Buildings would become adaptable and durable and be disassembled into components that could be reused or recycled. Underlying financial investment and insurance models will need to change if components are to be leased rather than owned and if buildings are to embed flexibility and be allowed to evolve to comply with circular economy principles (see section 3.1.1 for an example).

Two different types of circular systems can be expected:

1) Closed cycles – where companies take back their product after its lifespan expires to process it and integrate it into their own production. Examples include take-back of plasterboard (drywall) to make new plaster products and rental contracts for materials or services such as heating and cooling equipment.

2) Open cycles – where exchange is possible across different production processes and knowledge is shared about the materials that are cycling around. Examples include use of waste clothing as an insulation material (see Chapter 3.4.4) or use of waste tyres as a building product (see Chapter 3.4.1).

1.8 REUSE v RECYCLING

In recent years, recycling initiatives have become commonplace and many government policies aim to address waste by increasing recycling rates. Some European countries, such as The Netherlands, Belgium and Denmark, already claim to recycle around 90% of their construction and demolition waste, although mainly this is downcycled as road base. Some construction material suppliers have focused on recycling partly driven by the growing sustainable building agenda, as represented by green rating programmes such as BREEAM and LEED, and also from an increased awareness of potential economic benefits. Demolition protocols propose carrying out a pre-demolition audit to identify materials that can be recycled, and often the first activity of a demolition contractor is to identify materials that may have value.

However, recent research indicates that recycling in itself is insufficient for solving resource problems, as it does not deliver...
sufficient decoupling of economic development from the depletion of non-renewable raw materials. Grosse and others argue that ‘depletion of the natural resource of raw material is inevitable when its global consumption by the economy grows by more than 1% per annum’.\(^\text{46}\) They claim that recycling can only delay the depletion of virgin raw materials for a few decades at best, since growth in consumption is greater than the recycling rate. Their research shows that only maintaining annual growth below 1% and recycling rates above 80% would allow a significant slowdown of the depletion of natural resources.

Thus, recycling is an important but not sufficient component of sustainability policies to address primary resource depletion and waste reduction. Recycling processes often still require significant amounts of energy and lead to emissions. For example, although it may be correct to claim that recycled aluminium has only 5% of the embodied energy of primary aluminium made from ore, Allwood and Cullen have noted that when considering a particular aluminium product like a drinks can, the difference is reduced and the recycled can requires about 25% of the energy to produce compared to a new can from primary material – still an improvement, but not as dramatic.\(^\text{5}\) Reuse, however, usually has much less reprocessing, so the benefits can be considerably greater. For example, when a glass bottle is reused many times, each subsequent use involves only cleaning, refilling and transport. As long as these are reasonably local and carried out in an efficient manner, energy and materials can be saved (Figure 1.9).

A report from the Institute for Local Self Reliance (ILSR) in the USA profiled nine private and four government reuse operations from an economic point of view.\(^\text{47}\) Based on these, ILSR estimates that on a per ton basis, reuse operations generate nine times more jobs than traditional recycling and thirty eight times more than land-filling and incineration. Another study concluded that seven jobs are created for every 1000 tonnes of waste diverted with an economic benefit four times greater than the net cost.\(^\text{48}\)

Reuse embraces three levels of preparation for secondary use:\(^\text{49, 50}\)

1) The first is direct reuse, where components are used as close as possible to their original state and for their original purpose, requiring almost no preparation.
2) The second is renewed reuse, where materials are slightly altered by cleaning, repairing, refurbishing, or mild remanufacturing to serve a new function.
Finally, the third is rethought reuse, where reclaimed materials are fused with other materials to create a secondary product with a new function.

From an architectural design perspective, using recycled materials usually requires little change. Whether the steel, aluminium or glass comes from a recycled or primary source does not greatly impact the design process of a building. However, reusing components can have a much more significant impact on the design and procurement process. For reuse to be effective, specific data need to be available about the component, its technical characteristics, available amounts, sources and so on. Currently, the supply chain does not readily provide this data. Also, a suitable supply infrastructure has not yet been established in most developed countries to facilitate reuse. The design and construction process of many of the projects shown in this book have been significantly affected due to reuse of components. This can be seen as both an opportunity and limitation, as will be discussed later.

Figure 1.9 The Bedzed project in south London featured reused steel components; BRE calculated that this had only 4% the environmental impact of new steel.
The motivations for reuse of building materials and components can be categorized as:

- **Aesthetic/Design opportunities** – What might a new materialism in architecture look like? How can limited availability of components be a source of inspiration for architects rather than a constraint?
- **Environmental** – Reducing climate change impacts and other emissions to air and water, and reducing waste disposal.
- **Resource conservation** – Reducing stress on the earth from extraction and creation of materials from primary resources.
- **Economic** – Local supply of resources leading to increased local employment and a strengthening of the local economy.
- **Social** – Development of skills within the community and a new approach of respect towards the built environment.

If we accept the premise that availability of materials is unlikely to continue as has been the case in recent years, and that environmental, economic and social pressures will constrain supply, architects will be forced to respond and develop alternative strategies. Future materials supply will likely focus on what is already in the system, and is currently in use but coming to the end of its useful life. As Till puts it ‘a shift under conditions of scarcity from the production of more stuff to the realignment of stuff that it is already there’. In such a system buildings should be seen as transient borrowers of matter rather than final destinations, and construction should be intrinsically reversible. Some materials may be able to go back into natural systems and be decomposed, etc, but others will return to industrial systems. Such materials are used in one form in their present use but may be employed in a different way in a future use, and it is important that their usefulness and value is maintained and not destroyed by their use or extraction. Our cities, our buildings and our infrastructure then become a store and a mine for future uses.

The present inherent difficulties with the incorporation of reclaimed materials into new buildings can discourage clients...
and designers from embracing reuse, unless it is for principled reasons. Although the cost of materials can be lower through reuse, these may be offset by higher labour costs and increased design fees resulting from more research required by the design team. There is also greater uncertainty over cost and schedule, as delays can occur if key components cannot be readily sourced or there are delays in the demolition process. A few architects have started to focus on the creative opportunities offered by reuse for new mainstream buildings and to develop a design language based on local waste streams and local renewable resources. As the exhibition Matiere Grise hypothesized, a new outlook on materials generates a new approach to architecture – less form based and more concerned with matter and the opportunities it provides. A new building design and production process and new know-how grounded in a new material reality is evolving founded on ingenuity, collaboration and the opportunity of working with what is already there, and drawing on the skills and knowledge of those most familiar with the materials. This book explores what this architecture may look like.

REFERENCES
6 Based on the research from FP7 CRM-Innonet, current linear economy approaches mean that the security of resources will become increasingly constrained, European Commission, Brussels, Belgium.
10 Sources for this box include: Friends of the Earth Europe (n.d.) OVERCONSUMPTION? Our use of the world’s natural resources, https://www.foe.co.uk/sites/default/files/downloads/overconsumption.pdf (last accessed 3 May 2017); McKinsey & Partners (2015) Growth
Building Regulations and Allowable Solutions, Embodied Industry Task Force.
46 Grosse, F. (2010) Is recycling part of the solution? The role of recycling in an expanding society and a world of finite resources. SAPIENS, 3 (1) [online].

**IMAGE CREDITS**
Figure 1.1 (a & b) Courtesy of Brooks Freehill/Mike Moore and tres birds workshop; figure 1.2 Courtesy of © Vik Muniz / SODRAC, Montréal / VAGA, New-York (2017); figures 1.3, 1.5, 1.7 & 1.9 By Author; figure 1.4 Redrawn based on work of Thomsen and van der Flier; figure 1.6 Courtesy of Adaptable Futures, Loughborough University; figure 1.8 Courtesy of the Ellen MacArthur Foundation, www.ellenmacarthurfoundation.org; Box 1.1 Courtesy of Saman Deilamani