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The Big Picture

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The Big Picture

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Abstract. When considering sustainable construction consideration of the whole of the project is vital. This paper highlights how a focus on just one feature of a construction project can lead to a skewed outcome, that in the worst case can have a negative impact on sustainability. What is required is a change of mind-set; in particular to move away from short-term costs driving the design and construction process, to a more integrated design coupled with creative thinking. A sustainable approach can be achieved by considering the need to re-use existing infrastructure, reduce the materials used in new structures and designing for materials to be recycled at the end of a structure's life.

1. Introduction

To achieve truly sustainable construction requires careful consideration of all the impacts the finished project will have throughout its life, including what happens at the end of the structure's life. Decisions made today, will have long-lasting implications and should be made knowing as much as possible about the extent of the impacts over a wide variety of factors. It is very tempting to become fixated on a single issue, or a restricted group of issues, and then the decision-making process becomes skewed towards a particular outcome that often has unintended consequences. This is why it is important to look at the big picture. Figure 1 shows part of well-known structure, it is likely that very few people can identify it. Zooming out, as in Figure 2, means there is more chance the building will be recognised. However, if the whole building is shown (Figure 3), it is likely most people would be able to identify the iconic structure of the Petronas Towers.

The detail of the sphere at the base of the spike is an important part of the overall impact of the architecture of the Petronas Towers but it is only when viewed as part of the whole building that its contribution is fully appreciated.

The same can be said for sustainable design. It is essential to get the details correct. However, if the focus is only on a limited number of details, or they are considered in isolation, there is a risk that overall picture is not appreciated and the full benefits are not achieved. This paper will use some case studies to show how a focus on a particular issue can lead to unintended outcomes, whilst highlighting the need for a shift in mindset to develop truly sustainable infrastructure. It then proposes some approaches that can be adopted to improve the sustainability through good design. First, it is necessary to define what is considered to be sustainable construction.



Figure 1: Detail of a building structure.

Source: GetYourGuide (Copyright free)





Figure 2: Wider perspective of building.
Source: *GetYourGuide* (Copyright free)



Figure 3: View of Petronas Towers, Kuala Lumpur
Source: *Ghazzian Afif* (Copyright free)

2. What is sustainability?

A well-known definition of sustainable development is by Brundtland in The United Nation's 1987 report *Our Common Future*¹ "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This sets the vision, but more detail is necessary to be able to develop sustainably.

In 2005, the *World Summit on Social Development* identified what have become known as the "three pillars" of sustainable development: social development, Economic development and Environmental protection². This is an important evolution in our understanding of sustainability, as it identifies that environmental protection alone is not the primary route to sustainable development. A balance is also required with social and economic development. This is best illustrated with a Venn diagram (see Figure 4). Sustainability, is reached when the three pillars are in balance. This sets a challenge and perhaps the use of a Venn diagram is misleading; while the white zone in the overlapping area is small, it can lead to the assumption that sustainability is reasonably achievable. In practice, it is far more likely that achieving that goal will be more challenging.

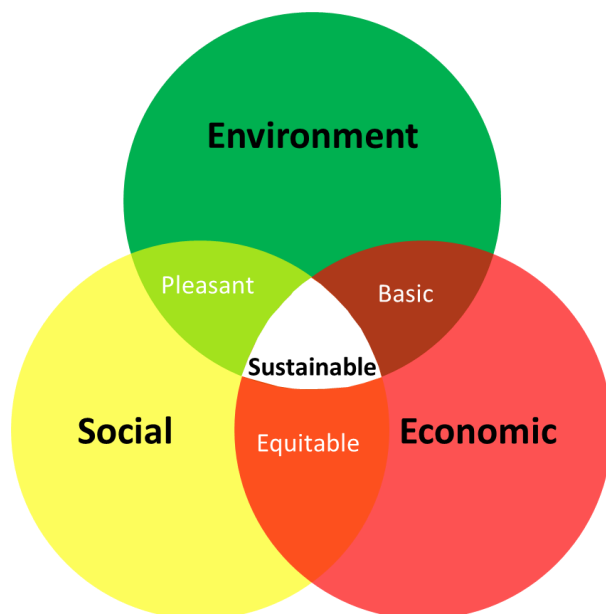


Figure 4: Three pillars of sustainable development.

Within each of the pillars there are range factors that should be considered, Table 1 lists some of the factors in each of the categories. It is important to realise that sustainable construction is more likely to be achieved when all of the appropriate factors are in balance.

Table 1: Some factors to be considered for sustainable design.

Social	Environmental	Economic
Fire resistance	Material use (including resource depletion)	Efficiency
Health and safety	Water use	Cost
Acoustics	Emissions to air and water	Quality
Robustness	Embodied energy and energy in use	Durability
Aesthetics	Waste disposal.	Residual value

3. Challenges to sustainable construction

One of the greatest challenges to the goal of sustainable development is that the economic development tends to become the priority for Governments, companies and individuals. This is well recognised and this topic will be addressed later in the paper. Perhaps less obvious is that when interventions are put in place, they can be focused on a single outcome; which has the result of unintended consequences. The following case studies highlight how a single issue can become dominant, leading to a unsustainable outcome, even when the reasons for the decisions taken were laudable.

3.1. Juxon House

The area north of St Paul's Cathedral in London was bombed during World War II and for many years lay undeveloped, proposals were put forward for the development of the area, known as Paternoster Square. The Prince of Wales, Prince Charles was highly critical of the proposed designs in a speech to the Corporation of London Planning and Communication Committee's annual dinner at Mansion House.

Eventually, this led to buildings on the site being designed by a classical Architect, William Whitfield. One of those buildings was known as Juxon House (see Figure 5) for which the façade was required to be Portland stone.

In the past a building of this design would have used the Portland stone as a load-bearing material to support the structure. However, for this new development it was considered that the fastest, and therefore lowest cost option, was to construct a steel frame with the façade fixed to the steelwork for lateral support.

From a sustainability perspective



Figure 5: Juxon House, City of London.

Source: Sidell Gibson Architects

there were some unintended consequences:

- Portland stone, a limited resource, was quarried in the south of England, and transported to the north of England to be pre-fixed to large concrete panels.
- The Portland stone, a viable structural material served no more than a decorative purpose.
- The completed panels were then transported back down to London in the south of England to be fixed to a steel frame.
- The concrete panels, a viable load-bearing material was used only to support the weight of the façade up to fourth floor level.

The outcome was a considerable volume of viable structural materials were used but they did not serve a structural purpose. This building was designed and built in the 1990s, around the time of the Kyoto Protocol in 1997, and therefore the environmental impact of the chosen construction method was not given much consideration. However, it does show how the over-emphasis on one aspect – in this case aesthetics can have a large environmental cost.

3.2. Environmental impact of cars

To use an example outside of construction, in the UK there is a significant debate about the emission of nitrogen oxide (NO_x) from diesel car engines. It is now considered that nitrogen oxide has a significant impact on the health of humans and can shorten the lives of those affected. During the 1990's successive European Governments and the car industry were keen to promote fuel efficiency for environmental reasons and diesel engines were seen as the best way to increase energy efficiency in cars, as their fuel consumption was lower. The primary focus was on reducing carbon dioxide emissions to minimise the impact on climate change, in doing so other environmental considerations appear to have been ignored. The outcome is that diesel cars were promoted as they were considered to be emit less carbon dioxide, but it is now known that the nitrogen oxides produced by diesel engines have caused pollution (an environmental issue) and negatively impacted on the health of humans (a social impact).

It is quite possible that a similar error will be made with the push to introduce electric cars. Figure 6 shows that over the life-time of an electric vehicle, it will produce less carbon dioxide emissions than an average European car. However, an electric vehicle used in Norway will be significantly better from an environmental perspective than an electric vehicle used in Germany. This is due to the variance in power generation between those countries; Norway uses hydroelectric power, whereas Germany's power generation mix produces far more carbon dioxide. Again, the focus is on carbon dioxide emissions particularly those from the tailpipe, and consideration of the overall impact on sustainability appears to be small.

3.3. Sustainability assessment schemes

Perhaps a little more controversially, sustainable structure assessments schemes can lead to poor choices being made in design and specification. These schemes are intended to objectively assess the sustainable credential of a new structural design, based on a large range of measures. The schemes usually intend to encompass a wide range of environmental and social impacts and to act as a tool to enable designers to consider the sustainability of their designs. Structures are awarded grades based on the outcome of the assessment. The intentions are good, and they have had a positive contribution to improving the quality of design. However, there are examples where designs are skewed towards inappropriate choices merely to obtain some additional credits in the assessment scheme.

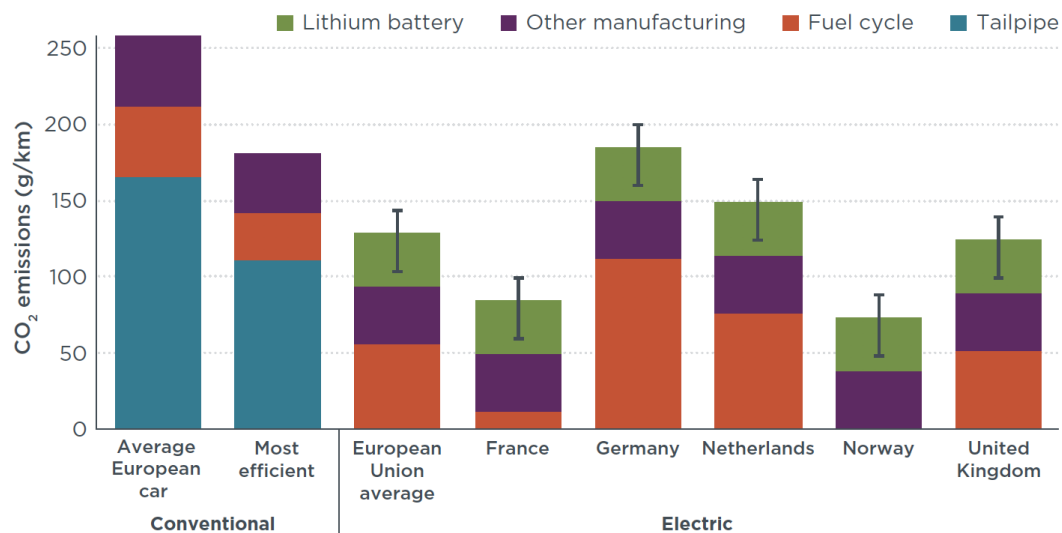


Figure 6: Life-cycle emission (over 150,000 km) of electric and conventional vehicles in Europe in 2015. Source: *International Council on Clean Transportation*.

A good example is where schemes reward the use of recycled materials. There have been projects where the structural engineer has specified recycled concrete aggregates in the structural concrete. It is perfectly possible to use recycled concrete aggregates but used inappropriately the sustainable benefits are questionable for a number of reasons. Firstly, it is necessary to identify a source of material that is consistent and can be tested, that means it is usually necessary to use crushed concrete from a large project being demolished. If that project is geographically close to the new project it can make sense, but what if the recycled aggregates have to be transported large distances?

Secondly, since most recycled crushed concrete is angular in nature it is often necessary to increase the cement content in the concrete to achieve the desired strength. Thirdly, recycled concrete aggregate is often referred to as being “down-cycled”, i.e. the crushed concrete is of lower worth than the original material and it also requires significant energy to crush the concrete. The concrete waste from the demolition of a concrete building is used in a wide variety of applications such as hardcore, and this is likely to require less crushing and transportation than for use in structural concrete. If the crushed concrete aggregate is not available, then new aggregates may be quarried for these other uses, which may defeat the object of using recycled materials. This does not mean that it is never right to use recycled crushed concrete in structural concrete, but clearly merely maximising the use of recycled materials in a project does not ensure that the outcome is sustainable overall.

The UK Institution of Structural Engineers has produced a briefing note³, which reaches the following conclusions for this particular example:

- RCA should only be used if it is locally available (within roughly 30 miles) or would otherwise go to landfill. Long distance road transport of RCA is to be discouraged.
- The deployment of RCA to replace primary aggregates in situations where both fine and coarse portions can be used (e.g. as fill) should be given preference to deployment in structural concrete.

It is therefore necessary to ensure that design choices lead to a genuinely sustainable design rather than artificially fulfilling the criteria of an assessment scheme. This can give the impression of a project being sustainable, without actually be any more sustainable than it would have been. This is not the intention of those who have prepared the schemes, but can be the outcome if the scheme is applied merely as an exercise to obtain a particular classification.

4. A change of mindset

To achieve sustainable construction a change in mindset is required as it is necessary to think about the issues from a new perspective. As engineers we should be challenging the prominence of economic consideration and using our technical skills to provide solutions that get the balance of environmental, economic and social requirements. There are perhaps four areas where a change of approach is required to make significant improvement in the construction industry; costs, creative thinking, design integration and early collaboration.

4.1. Costs

Many decisions are made on the grounds of costs, and affordability will always be primary consideration. However, decisions made solely on cost are usually short-sighted. The biggest challenge in this area is that it is often the decision-makers that are driven purely by cost, encouragingly there are signs that this is starting to change.

Cost has not always been the main driver in decision making and there are numerous examples where society has benefitted from decision makers having a longer-term vision. Just one example is the Natural History Museum (see Figure 7) in west London, built in 1873 it clearly required considerable skill and workmanship to build. It is a spectacular building that has stood the test of time. The funders had the vision to create and pay for a landmark building, and it is continuing to perform its intended function well beyond the normal design life of a building.

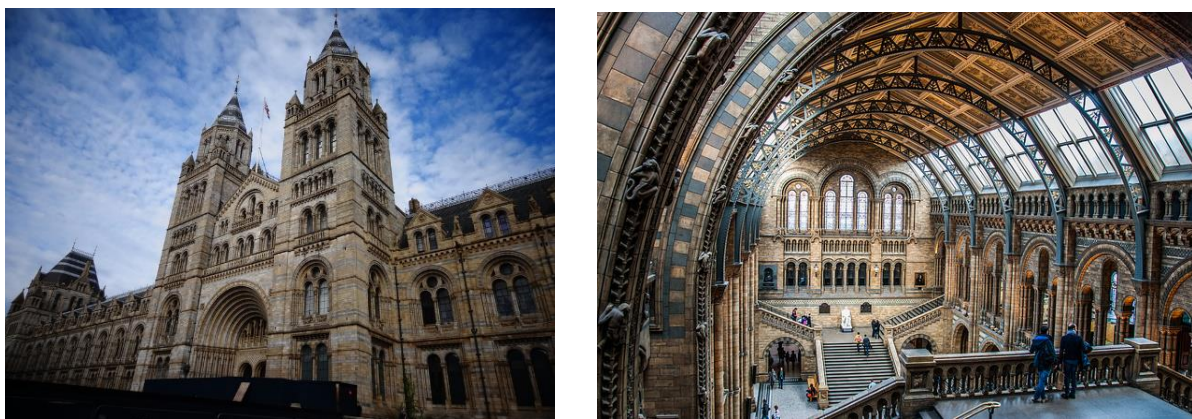


Figure 7: Natural History Museum, west London.

Sources: Pixabay & Creator Unknown (Free to distribute)

Nowadays, a particular problem is that funders or developers can be focused on constructing a building or infrastructure and then selling it to generate a profit as quickly as possible. Even from a purely economic point-of-view this will not necessarily be the most cost-effective strategy of a building over its life-time. Consider Figure 8a, which shows initial costs, with ongoing usage costs and regular maintenance costs. It is easy to envisage that a small additional capital cost can reduce the long-term

cost of a project (scenario 2), but it may also be the case the even greater capital outlay could make a greater impact to the life-time cost (scenario 3). A further consideration is to consider the cost of disposal (see Figure 8b), does the structure have any recovery value at the point of disposal, or will there be further costs incurred in demolition and waste processing. If the structure is designed to be re-used or re-cycled, it can have a positive economic as well as sustainable impact.

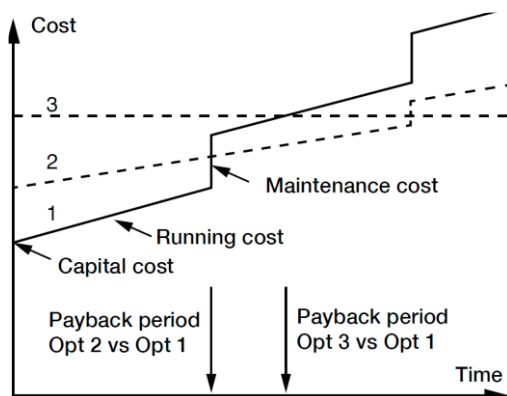


Figure 8a: Different life-cycle cost strategies

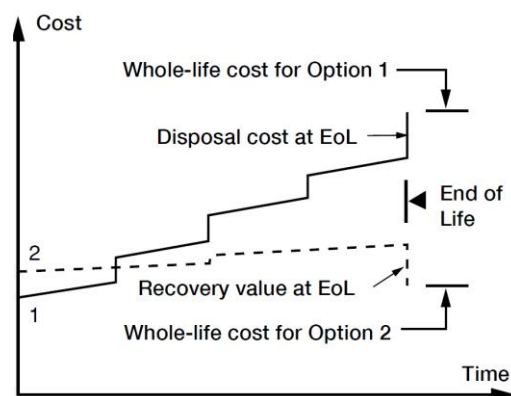


Figure 8b: Consideration of end of life value⁴

As has been noted many decisions are made on short-term costs only, but there are signs that this is beginning to change. In 2006 the *Stern Review on the Economics of Climate Change*⁵ concluded: “the benefits of strong, early action considerably outweigh the costs.” The full report explains the economics behind this statement, which makes it clear that economic considerations are not a reason to dismiss sustainability and in fact failure to consider sustainability in the long-term is a poor economic choice.

More recently, Mark Carney, the Governor of the Bank of England and Chairman of the Financial Stability Board, spoke, in 2015⁶ and 2018⁷ of the need to consider the risks to financial stability of climate change. He identified 3 key risks:

- Physical risks – from weather events
- Liability risks – from parties seeking compensation for damages
- Transition risks – from a sudden and disorderly change to low-carbon economy

He spoke of the importance of considering these risks in our financial systems.

In the UK, the Task Force on Climate-related Financial Disclosures (TCFD) prepared a report⁸ which aims to develop voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers and other stakeholders. Once developers and funders begin to take on board these requirements, as seems likely, changes in the approach to funding of structures will be seen.

4.2. Creative thinking

The example given above of specifying recycled concrete aggregates for structural concrete purely to meet a requirement for increasing the recycled content of a structure, shows how it is important not to be restricted in thinking by well-meaning external expectations. Creative thinking is required to enable innovation and development of structures that are sustainable, using the most appropriate materials in the most efficient way. The use of creative thinking is a specialist subject area, which cannot be covered

in detailed in this paper, however there are some straightforward methods to employ to challenge the preconceptions:

- Lateral thinking. An example of this would be breaking down the steps taken in a process and asking 'why' at each step to see if a better process can be created.
- Brainstorming. This involves a group of people looking at an opportunity with fresh eyes. The aim is to generate as many alternatives as possible in an ideas generation session and where, initially, nothing is discounted.

4.3. Design integration

Structures are rarely the work of one designer and require collaboration between disciplines, but detailed integration often does not occur. The pursuit of sustainable construction, particularly for buildings will increasingly require integration of services, structure and architecture.

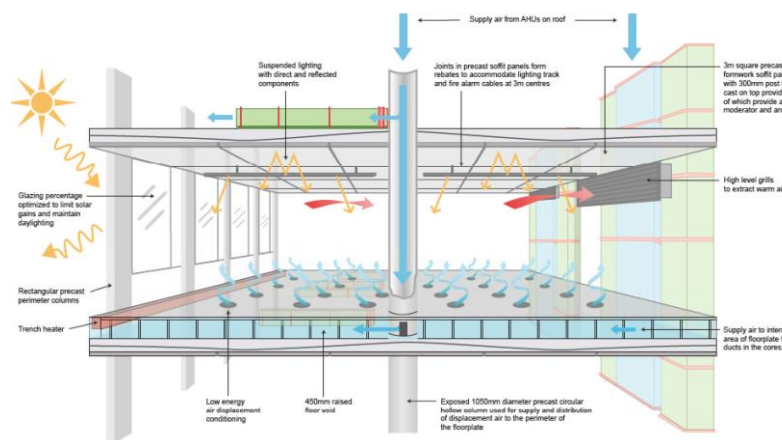


Figure 9: Integrated architecture, services and structure

Source: Nic Crawley, Allford Hall Monaghan Morris

A project in Tooley Street in London is a good example of a fully integrated building (see Figure 9). In this building the supply of air into a space above the floor void was through a void through the centre of the structural columns. The fresh air being introduced through the floor meant that the soffit of the concrete slab could be exposed – thus reducing the architectural finishes inside the building. The external structural support was provided by precast concrete panels, which included the external finishes. This project is an early example of minimizing the use of materials by maximizing the functions served by each element.

4.4. Early Collaboration

Closely aligned to the integration of the functional requirements of a structure is the requirement for early collaboration between disciplines. The graph in Figure 10 demonstrates that as the project moves through its development phases, the opportunity to influence the cost diminishes disproportionately. The greatest opportunity to influence the cost of the project occurs in the very early stages, so it is vital to ensure that all the cost influences are considered at the early stages. For many this might appear obvious and be a well understood concept, however, in practice it does not always occur and “value engineering” takes place at later stages in the project.

The same principle applies to sustainable construction. The greatest opportunity to maximise the sustainability of a project is to consider it from the outset. This significantly increases the opportunity for a fully integrated design and allows greater opportunities for creative thinking. The later in a project that sustainability is considered the less likely that an optimum solution is achieved. Sustainable construction cannot be achieved as an add-on at the end of project.

5. A sustainable approach

A popular phrase in use is “Reduce, Reuse, Recycle” – the 3Rs. This is a simple and yet effective way to approach any form of sustainable living, not just sustainable design. From a construction perspective it would be better to re-order the phrase to it to Reuse, Reduce, Recycle.

5.1. Reuse

Before embarking on any new project, particularly a building, serious consideration should be given to re-using an existing structure. There can be challenges in that floor-to-floor heights may be too low, spans too small or floor capacities too low, but the starting point should be to investigate the existing structure, to understand how it works, consider how to maximise the existing capacity and use creative thinking to establish how it can be reused.

Buildings that can be adapted are far easier to re-use for other purposes, looking back to the nineteenth century provides an example of a form of construction that has proved to be remarkable durable and flexible. This is the Victorian terrace house (see Figure 11). These can be found in nearly every major town and city in the UK. They are now over 100 years old, and yet they are still in everyday use, most are still used for residential accommodation, but many have been adapted into flats, shops or offices. The main vertical elements are the masonry walls, which serve the following purposes:

- Main vertical load-bearing element
- Main member resisting wind loads
- Main member providing stability to the structure.
- Environmental protection

They have been extended upwards (loft conversions), downwards (basement extensions) and rearwards. Internally, walls have been removed, large properties have been subdivided into flats, smaller properties have been knocked into one. So, they have proved to be very long-life and meet many of the sustainable criteria. The main reason for the adaptability is that the masonry walls have considerable redundancy for vertical loading, but are working closer to capacity for lateral wind loads.

From a truly sustainable perspective a large drawback is that the walls have poor heat insulation, so they consume above average energy to

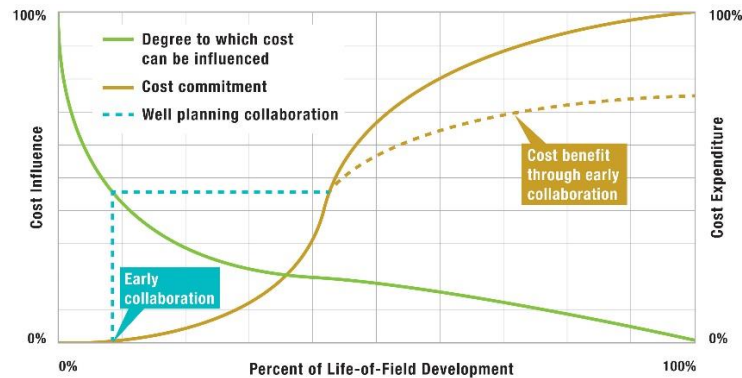


Figure 10: Benefits of early collaboration

Source: *Drilling Contractor*



Figure 11: Typical Victorian Terrace House

Source: *Manchesterphotos* (Copyright free)

keep warm in winter. When they were constructed it would have been normal to only heat the one room actually being used. Modern occupiers tend to heat the whole house. This is currently being addressed by considering how to increase the insulation and other measures to bring them up to more sustainable standards.

Looking back at what have made buildings adaptable and which buildings have proved difficult to re-use enables consideration to be given as to how new structures can be designed to make them simpler to re-use. Moffatt and Russell⁹ have identified some simple strategies to provide adaptable structures:

- Flexibility – to enable minor shifts in space planning
- Convertibility – to allow for changes in use within the building
- Expandability – to facilitate additions to the quantity of space in a building
- Durability – to reduce the maintenance and increase the lifespan of the structural elements.

In addition, for a building to be adaptable it is necessary to take care not to encapsulate short lifespan components within those having a longer lifespan. For example, building services often have a shorter lifespan than structural elements, and therefore they should not be embedded into the structure in such a way as that it would be difficult to alter them without major intervention.

5.2. Reduce

Where an existing structure cannot be re-used, then any new structure should be designed to reduce the amount of resources consumed. This can include a number of approaches:

- Using recycled materials where appropriate
- Use materials/elements that serve more than one purpose
- More accurate analysis

The first two points are discussed in sections 5.3 and 4.3 respectively, but analysis methods should be considered in more depth. When analysing structures usually a key assumption is made – is a connection pinned or fixed? Is it free to fully rotate? Or can no rotation occur. In practice, very few connections meet either condition and yet it makes a fundamental difference to the outcome of the analysis. Even just looking at some simple situations such as uniformly distributed load on a single span demonstrates that the choice of end fixity makes a significant difference (see Figure 12). It can be seen that the maximum moment in a member decreases by 50% and moves from the centre of the span to the ends. When deflection is considered the impact is even more significant as the difference is a factor of 5. With modern software it is possible to model supports with spring stiffness, but there

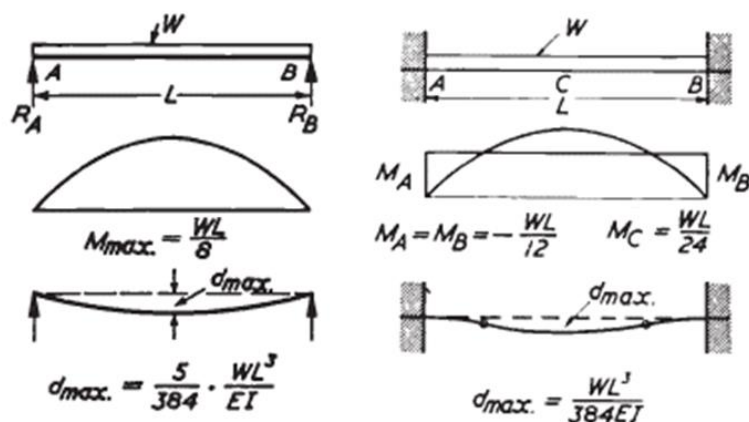


Figure 12: Analysis of simply-supported and built-in beams

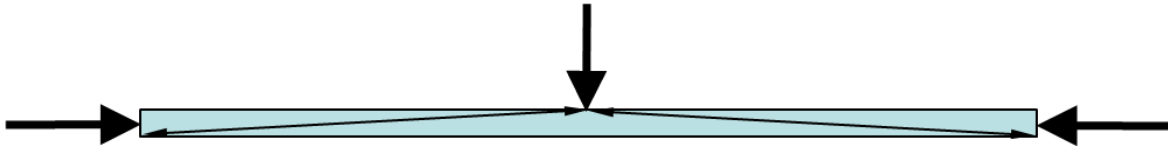


Figure 13: Compressive membrane action

would appear to be little research and guidance as to how to do this accurately and consistently for the range of connections that are in use.

Another area of strength is routinely ignored is the benefit of compressive membrane action (see Figure 13). A large slab area will often have some form of restraint, e.g. walls, effectively forming an arch. If this could be modelled accurately then concrete plate structures would be working more efficiently.

Accurate modelling affects not only the design of new structures, but also the ability to assess existing structures. It has already been noted that the first step in sustainable structural design is to re-use a structure. Often structures are replaced because the load-capacity is considered to be inadequate for a new use. With more accurate modelling it may be possible to demonstrate that an existing structure has greater capacity or that the capacity can be increased with relatively minor strengthening.

It is therefore considered that potentially significant material savings can be achieved and the ability to re-use existing structures increased, if structures can be quickly and confidently be modelled more accurately.

5.3. *Recycle*

To maximise the recyclability of structural materials a structure should be designed for deconstruction, and the following principles can be adopted¹⁰:

- Separability – recognise the lifespan of the various elements and plan for replacement of shorter life components.
- Specify appropriate quality.
- Specify short-life components that can be recycled more easily and/or have value the end of life.
- Elements to be maintainable.
- Information trail passed on with the building (in durable and future-proof format)
- Use standardisation
- Use removable fixings (aim for mechanical not chemical).
- Use simplicity

The same principles apply when considering using recycled materials, and in particular, what information is available, or can be obtained through testing for the materials that are potentially to be recycled.

6. Conclusions

If sustainable construction was simple to achieve then many more structures under construction would be designed using these principles. However, this is not the case and this paper has highlighted that sustainable construction requires consideration of the bigger picture, before the detailed considerations

can take place. It has identified that a change in thinking is required, particularly with regards to costs, and notes that there are signs of a mindset shift in this area particular in the finance industry.

It has been noted that to achieve sustainable construction, full consideration of the whole range of potential impacts must be considered at an early stage in a project, and that it will be necessary for designers from a range of disciplines to work together to have the greatest impact. Before undertaking the design of a new structure careful consideration should be given to re-using existing structures. There is also the potential to achieve material savings through more accurate structural modelling. Though, currently this would require more guidance so that this could be achieved accurately and efficiently for a range of situations.

Finally, structures should be designed not only to minimise material use at the point of construction, but to maximise the opportunity to re-use and adapt them throughout their life, and then at the end of life it should be possible to deconstruct them and for their components to still have value.

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