Paper No: 383 Encapsulating sustainability principles for structural design of buildings

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Abstract

Adaptive re-use of buildings is seen by many as a key mechanism for developing a sustainable urban environment. How many buildings are actually designed with adaptive re-use as one of the requirements? This paper is concerned with how new building designs can take into account the future need for renovation, revamp and retrofit. At the outset of a building project, one cannot know for sure what modifications will be needed in the future. However, there are considerations that can be incorporated into the initial design and construction that will facilitate future renovations. Likewise there are practices that are undertaken now that will make renovations more difficult in the future. This preparation for the future re-use of buildings is an area of sustainability that has not received much attention. Examples of buildings that were originally designed with future modifications incorporated illustrate that long term thinking can lead to long term gain. There are also barriers to the long view. Economic drivers favour short term gain. The costs are levied up-front but the return on investment is many years later. The paper finishes with two case studies that demonstrate a long term sustainable approach.

Keywords: sustainable structural design, adaptive re-use, building longevity

1. Introduction

Sustainable design of buildings has rightly concentrated on issues that bring immediate to medium term benefit. The main thrust of green ratings for new buildings such as LEED in USA or Green Star Rating in Australia [1] concerns the reduction of energy in construction and running costs of buildings. However, as Sassi [2 p9] points out, it does not matter how efficient a building is in relation to embodied energy or water usage, it is a major waste of resources if no one wants to occupy it. Buildings must be adaptable to the needs of the community if they are to remain useful.

Construction and architecture that creates buildings that are durable, adaptable and energy efficient will also produce buildings that will have long useful lives. Longevity is a key principle in sustainability that has received little attention. In addition to robustness and adaptability, the buildings that endure often include physical features such as larger volumes and floor plates as well as a degree of over engineering [3].

2. Adaptability leading to sustainability

2.1 Environmental sustainability

Since the construction industry is a major consumer of raw materials, each new development adds to the 3 billion tonnes of new resources required by the industry. Furthermore, if the development requires the demolition of an existing structure that causes stress on the already overflowing landfill sites. Within Europe some 72% of demolition waste ends up in landfill with only 28% being recycled [4]. In the hierarchy of ecological sustainable living, the three R's of reduce, re-use and recycle indicate that where it is feasible, then re-use is preferable to recycling.

It is better to re-use buildings or re-develop brown field sites than to exploit new green field sites. The main argument for this is that the existing buildings are already serviced by local infrastructure whereas the green field site requires a range of ancillary construction to take place.

2.2 Economic benefits

While the benefit to society in the long term may seem clear, there are tensions and economic barriers to creating buildings that will last longer and be more adaptable.

The up-front cost of cleverer design and incorporating adaptable features can be significant. There may be other risks, as we cannot predict the future with certainty. We may end up with empty properties no matter how well designed they are. Or we may never actually implement any of the adaptable features.

Wilson and Tagaza [1] conclude that the benefits of a green building are realised over a 20 year period. They also put the additional cost of the green building at 1-25%. One of the main contributors to the longer term savings is that the more efficient buildings lead to productivity gains for the workers who occupy them.

With longer lasting adaptable buildings, there are also long term productivity gains. Many adaptive re-use projects can take place with the building remaining "live"; thus avoiding temporary relocation of the business and staff.

The economic uncertainty is that the costs and benefits are not equally shared by the parties in the development. The three stages, construction, building use and disposal/re-use involve different players [5]. The users and re-developers are the ones who benefit most but it is the initial project promoter that carries the cost.

There are some signs that the real estate market is willing to pay this premium for having better designed and performing buildings, but the economic benefits are far from guaranteed.

2.3 Social benefits

Demolishing buildings is a dangerous activity. The methods used are generally dictated by the need to rapidly clear the site for the new development. This prevents a more methodical deconstruction where elements might be salvaged for recycling. With tall buildings in built up locations, demolition is even more disruptive. Hence, if buildings can be adapted instead of being demolished and replaced, the intrusive construction work will be reduced.

3. Structurally adaptable features

3.1 Layout

The question that arises now is "How can one achieve a more adaptable structure?" Finch [3] has indicated that large volumes and areas are desirable. He points to the examples of large structures such as churches, schools and power stations finding new uses with clever adaptive re-use. The Tate Modern Art Gallery in London, UK [6], created from the Bankside Power station and the Magna Science Adventure Centre in Sheffield, UK [7] are examples of large industrial buildings changing into innovative public spaces. Railway stations also have this capability, examples being the GMEX centre in Manchester [8] and the Musée D'Orsay in Paris [9].

However, it is not feasible to create most commercial buildings with such cavernous spaces. The reality is that larger column-free areas cost more than a smaller floor plate. This will always be a trade off between flexibility of the space, structural performance and cost. In Australia, there is a reluctance to move to longer span floors for medium rise buildings, while in Britain it is much more common.

While column and solid wall free areas allow horizontal flexibility, greater floor to ceiling height creates more adaptable volumes. Higher headroom also facilitates refurbishment activities. The very large headroom in some buildings such as power stations and railway stations facilitates the inclusion of mezzanine and even larger sub-structures.

Ultimately, layout is controlled by the location and nature of the foundations. The site layout too is a key factor in future modifications. In their paper, "Seven principles of sustainable regeneration and development", Smales et al. [10] discuss "*whole life cycle costs and values*" and "*Design Excellence*" as two of the principles. They have analysed the push from government in the UK for urban renewal and sustainable housing. While the paper concentrates on housing developments, the main tenets are the same for commercial buildings. One of the recommendations is to "*give more consideration and investment to issues of site layout, foundations and frame and less on finishes and fit out"* [10]. Careful positioning of the building's footprint within the site boundaries can allow future extension towards those boundaries. Poorly judged site layout can severely restrict future flexibility for expansion or location of cranes or other equipment.

3.2 Over-engineering

This is somewhat of an anathema for a structural engineer. The education of engineers instils an ethos of miserliness. Structural optimisation in the literature is synonymous with minimum weight design. However, work by Tizani et al. [11] has demonstrated that other considerations such as buildability can reduce costs more than minimising weight. When one considers the longer term performance of the structure under changing uses a degree of over-engineering can be justified.

Finch [3] has alluded to the success of adaptable buildings being a function of their over-strength. It is a common factor in adaptive reuse of buildings that the new function requires a lower live load than the previous one. Throughout the industrialised world, many former dockland warehouses have been converted into shopping precincts, residential developments or hotels. This has worked because the new usage is less onerous than the warehouse loads – even taking into consideration modern restrictions on fire rating and requirements to prevent progressive collapse. Examples of this include Sydney's Finger Wharf at Woolloomooloo (Figure 1) where the heritage listed timber structure has been transformed into exclusive hotel and residential accommodation.

Fig 1. Finger Wharf at Woolloomooloo, Sydney Photo T McCarthy

Designing buildings for increased live loads can lead to greater flexibility in usage. It is common practice for multinational clients to specify live loads of 5 kPa for office space even though 2.5 or 3 kPa may be permissible. The reason stated by developers is that the increased load does not add greatly to the building cost and permits a range of uses. For medium rise buildings, the increased live load increases the structure cost by 8-10%.

3.3 Structural elements

Adaptability can be built in to the structural elements chosen for the building. Accommodating services is often a problem during renovations. The use of castellated beams, cellbeams or Porthole beams (Figure 2) incorporates multiple web openings allowing re-routing of services, without increasing floor to ceiling heights [12].

Similarly, voids can be cast in concrete beams to allow the passage of cables and other services.

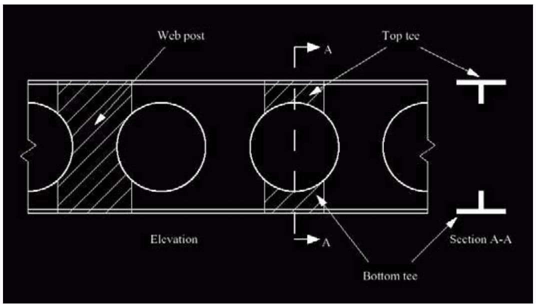

Fig 2. Steel beams with multiple web openings [12]

4 Structural impediments to adaptability

It may be controversial to suggest that some modern construction methods may inhibit future adaptability. Many of these methods have gained popularity because of increased speed of construction and simplification of site management. However, one of the principles of adaptability is whether the structure can be changed at a later time.

Post tensioned (P-T) floor systems have become popular in Australia and elsewhere. They facilitate longer spans which are useful for adaptability. However, it is virtually impossible to alter a P-T floor once it is installed. This makes it difficult to add floor openings, stairwells or other alterations at a later date.

Another form of construction that creates barriers is pre-cast tilt-up construction. While allowing for rapid construction of medium rise buildings, this creates solid concrete walls which are difficult to alter. There is the possibility to include recessed panels that can be knocked-out to form doorways or windows.

Perhaps a compromise can be found between the inflexible forms of construction and the desire for adaptability. Post tensioned floors may include conventionally reinforced panels, or even voids which are in-filled with removable panels.

The converse of the over-engineered structure is the over-optimised one. When design loads are trimmed to the bare minimum and the weights of structural members fine tuned to the maximum stresses, there is little scope for finding new load paths or modifying the usage. Lack of structural redundancy can be a major impediment. For some structures, this can be ameliorated by innovative strengthening solutions.

5. Case studies

5.1 General

There are many examples of adaptive reuse of buildings and many examples of structures that have withstood the test of time. Royal palaces of bygone eras are now museums and art galleries (for example the Louvre in Paris). However, these do not represent the best examples of forward thinking. In many instances they are the result of excess and, in modern times, the cost to replicate their flexibility is prohibitive. It is not feasible now to design and construct the pyramids of Egypt.

Despite this, there are examples of foresight and examples of incorporating future demand in the original design. The following pair of examples illustrate buildings where the original design overestimated the financial capacity of the time but allowed for the future completion of the vision.

5.2 Scot's Church and Assembly Hall aka Portico [14]

In 1927 O. Beattie won the architectural competition for a ten storey church and assembly hall, the Presbyterian Scots Church at York Street in Sydney (Figure 3). As a result of the Great Depression, construction was halted in 1931 when 5 storeys had been completed.

Over eighty years later, the City of Sydney's Design Excellence programme launched an


Fig 3. O. Beattie's Scots Church in 2000 Photo courtesy of City of Sydney Archives [13]

architectural competition for the completion of the building. Tonkin Zulaikha Greer's winning entry added a contrasting modern cap to the original structure. By employing lighter structural materials than the original design, engineers, Van Der Meer, were able to add more floors than the original design. The extension also had to incorporate new regulations relating to sunlight to the nearby open space at Wynyard Park. This was achieved by stepping the roof line at an angle of 45 degrees.


Fig 4. Tim Greer's Adaptation of Scots Church in 2006 [14]

5.3 Masonic Centre, Sydney

The 1972 Joseland Gilling concept for the Sydney Masonic Centre included a six storey HQ with a 26 storey tower atop. The 6 storey part of the late 20th century brutalist project was completed in 1974. This included the core and foundation for the tower to be built at some time in the future. Thirty years later, the tower was added, PTW being the architects and Connell Mott MacDonald the structural engineers. In addition, a glass and steel envelope was created around the exterior of the six storey base, softening its brutalist lines and increasing the ground floor accommodation.

The original footings and acoustic bearings were employed with some modifications to support the innovative structural form. Concrete filled tubular steel members fan out from the core at level six to support the tower façade.

This project demonstrates how the opportunity afforded by the original foundations enabled the developer, Grocon, to create 23000m² of grade A office space in the heart of Sydney with a minimum of demolition. Indeed, the existing Masonic Centre remained occupied throughout the tower construction.


Fig 5. Gilling's Masonic Centre in 1974 [15]

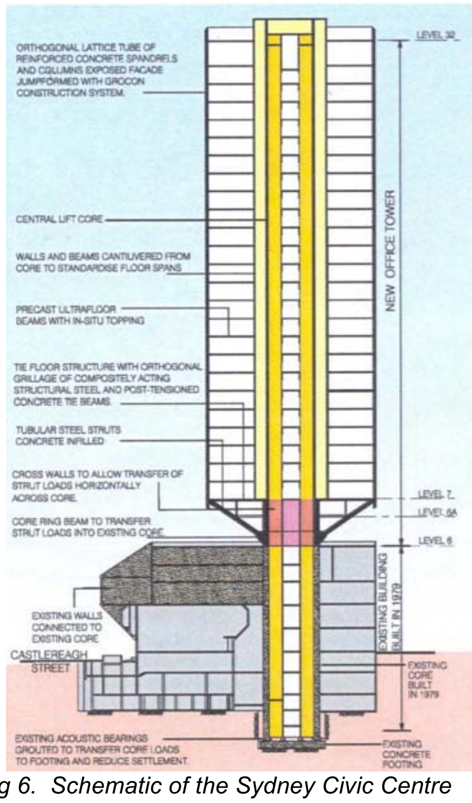

Fig 6. Schematic of the Sydney Civic Centre Tower (Courtesy of Connell Mott MacDonald)

5.4 Discussion

Both of these case studies demonstrate how buildings can have greatly extended useful lives when their foundations and lower structures are capable of supporting additional floors. A long term vision, stretching over many generations, can ultimately bear fruit. The original designs incorporated schemes for future modification and extension. This meant that the new buildings could be added without the need for demolition. Furthermore, the new lease of life has helped preserve excellent examples of Sydney's architecture.

The challenge for today's developers, architects and structural engineers is to create a body of work that will display similar longevity and adaptability.

The factor which makes buildings adaptable and extendable is the attention paid during the original design and construction. It is the fact that foundations and lower structures are designed and constructed to accommodate the increased load of the final vision.

Fig 7. PTW's completed Sydney Civic Centre Tower (Photo T McCarthy)

6. Conclusion

This paper presents a challenge to developers, architects and structural engineers. To create a sustainable urban environment we must pay sufficient attention to increasing the longevity of our buildings.

The task is difficult but not impossible. There are examples where adaptability has been proven and where the economic benefit is realised. This may take a long time and therein lies the second challenge. How can we create the incentives to promote sustainable structural engineering?

7. Acknowledgements

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