# REUSE – ISSUES AND CHALLENGES IN STRUCTURAL ENGINEERING APPLICATIONS

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**Abstract:** Reuse of structural elements, frames or modules in buildings and structures, as a concept towards improving sustainability in the built environment poses a number of issues and challenges. These issues and challenges arise as early as the conceptual stage. What are the structural elements to be considered for reuse ? How are they to be designed to allow for this possibility and to facilitate the process of reusing them as elements, elsewhere ? Are new concepts for such element types (ie non-traditional structural forms) needed or can traditional forms, but with reuse concepts in mind, still be viable propositions ? For example, there are plenty of opportunities for innovation in which the structural integrity of concrete is provided mainly by external confinement in order that the amount of cement binders in the concrete can be reduced to facilitate reuse of the aggregates. What are the limitations (Architectural as well as Engineering) that would be associated with designing such elements for their possible reuse ?
These and a number of other questions are discussed and some ideas offered towards addressing them are then compiled in this paper.

**Keywords:** reuse, recycle, reduce, sustainability, structural system innovation

## 1. Introduction

Sustainability, in its many forms and how it may be implemented in buildings and building construction, is receiving a great deal of attention from designers, owners, occupiers and other interested stakeholders, nowadays. Much of this attention has been directed towards improving efficiencies in energy consumption and in the air conditioning of these buildings, when in service – the Reduce part of the so-called 3R's of sustainability (Reuse, Recycle and Reduce). Whilst some attention has also been directed to possible Recycling options in buildings (eg in waste disposal, water supply, in the salvaging of copper in electrical wiring and even in the construction materials themselves (eg concrete from building demolition being recycled after processing for use as road base material, [1], in general concrete applications, [2], or for high-strength concrete, [3]), not so much attention has however been directed towards Reuse possibilities in building construction.

It is quite easy to see the reasons why this is so but not so easy to see how these obstacles may be ameliorated, or even overcome, if we are to see reuse options being seriously exercised in buildings and building construction, [4]. This paper therefore explores the inhibitors of reuse concepts in buildings and building construction and provides some suggestions and ideas that are needed to be able to "move forward" with reuse concepts in the construction industry.

## 2. Inhibitors of Reuse Concepts in Buildings

When one starts to consider the reasons behind why possible reuse concepts may be difficult to implement, often to the point that they are therefore not exercised (allowing for some few exceptions), these are found to be easy to identify. Some scenarios of possible reuse strategies or ideas are presented here to illustrate these inhibitors depending upon the situation.

### *2.1 Reuse of entire buildings*

When an existing building of some years comes onto the market, its attractiveness to a prospective purchaser for reuse, either for its original intended purpose or for some viable alternative, and this only when any modifications necessary are minor, is dependent primarily on how “dated”, or conversely, how “fashionable” it may be perceived as a marketable proposition. Here we may be considering medium to high-rise office buildings, say of 30 or 40 years of age. Architects may advise to level the building concerned and to create a “fresh new one”, with more modern layouts, fixtures and features that would attract prospective tenants a lot more than would the original building after minor or even significant refurbishment.

Some exceptions here, drawn from the experience in Australia, would be:

- conversion of an office building to apartment style housing in the centres of such major cities as Melbourne say, where inner city apartment style living is “catching on” from when it was once (not so long ago) virtually non-existent,
- heritage buildings which are protected from demolition by local legislation and which have significant restrictions placed on the style of refurbishment and reuse that may be considered for the building structure, where this is seen as a marketing edge by the owners (as opposed to an inhibitor). Examples here, may range from heritage ex-church, council and bank buildings, (often converted to dwellings/apartments, restaurants or even fast food outlets, see Fig. 1), and older style cinemas (often converted to ballrooms/reception centres), which although do not appeal to everyone do attract a significant clientele to become viable or even attractive,
- warehouse buildings in inner suburbs, which can be appealing because of their generally high ceilings, after significant refurbishment can be converted to restaurants and dwellings/apartments.

So two inhibitors of reuse of buildings (when perceptions are adverse) are identified here – “marketability” and “fashion”, though one may consider these to not necessarily be entirely mutually independent.

### *2.2 Reuse of building modules or components*

When buildings are to be demolished, attractive elements for reuse (and recycling) are identified and salvaged prior to the more rigorous and damaging process of serious demolition taking place. These elements would include:

- Copper piping and wiring (attractive because of its value for recycling).


Figure 1: Examples of Heritage and Church Building Reuse

- Bathroom and other fixtures that can be reused, especially if of heritage or artistic value. A striking example "close to home" is the entrance to the underground car-park at The University of Melbourne - itself a heritage listed structure because of its unique use of a regular grid of hyper-parabolic shell roof elements supported by hollow circular columns, [5]. The doorway to the now demolished Colonial Bank originally in Elizabeth Street has been reused at one entrance and a 1745 wooden door from a house in St Stevens Green Dublin, donated by the government of Eire to the University, has been reused at another entrance, (see Fig. 2).
- Items that could be of limited intrinsic value other than in terms of memorabilia, eg portions of carpet, [6], wall paneling, brass coat-hooks and other fixtures when the old grandstand portion of the MCG was demolished to make way for the construction of the Great Southern Stand.

Seldom would building elements or even building materials be salvaged for reuse from a building demolition site for a number of reasons (or "inhibitors"), which would include:

- Cost – construction elements and materials are generally not designed to facilitate their removal intact, so this tends to make it difficult and costly to salvage them
- Safety issues – as, again, because ease of removal has not been considered in their design, to access primary elements, in particular, by attempting to remove tertiary and secondary elements and to then disconnect them would often pose high risk.
- Integrity issues – the fitness for purpose (or reuse) of construction elements and materials may be questioned as their strength and integrity may have been compromised from adverse loading effects, during their history of operation, or as a result of the removal process itself.

There are, however, some notable exceptions to the reuse of entire structures and building components that can be found in the offshore oil and gas industry. For example, jack-up rigs can be reused in their entirety by the offshore wind industry [7], (see Fig. 3), and modular topsides elements can be refitted to other platforms, once no longer required at their original site.

A particular driver for reuse of building materials is in situations of extreme poverty which virtually dictate this to be the only option as the cost of producing a structure anew is prohibitive.

This situation is notably exemplified in the case of Toni 'el Suizo' Rüttimann – bridge-builder, [8]. Toni is indeed a unique individual who, through his bridge-building, based upon a suspension bridge design that he has more-or-less perfected over 23 years, a design that is based virtually entirely of reused components/materials, has transformed the lives of many thousands of residents in remote locations in South America and South-East Asia. Over 500 bridges have been constructed by the local inhabitants/villagers in these remote locations with Toni's help. Figure 4 illustrates the design concept for Toni's suspension bridge via an example of a bridge under construction and another of the completed product.

Figure 2: The two entrances (both examples of reuse options) and the Underground Car-park at The University of Melbourne

Figure 3: Example of a Jack-up Oil

Figure 4: Rüttimann's Suspension Bridges– under construction (Ecuador), completed (Vietnam)

The rectangular frames, in this design, are welded tubular members salvaged from the offshore oil industry and the cables are ones that have been removed from service (according to statutory requirements) that once supported cable-cars in Switzerland. The vertical stringers have also been salvaged. The only "new" material tends to be that used for the wooden/steel plate decking.

## 3. Reuse Innovation in Buildings and Building Construction

In the situation of a building which is free of heritage protections, the owner may decide to demolish and rebuild in view of marketability and fashion considerations. Whilst the original building cannot be preserved in its entirety, there is plenty of scope for innovation to be introduced to salvage materials from it for reuse in the building that is intended to replace it and hence reduce the consumption of energy and the need for new materials in the rebuilding process. This can be achieved by either (i) the reuse of members or (ii) the reuse of materials.

### *3.1 Reuse of Members*

Significant savings in both energy and materials can be achieved by reusing structural members that can readily be detached from the existing structure. The reuse of structural steel girders and columns is already common practice given that bolted connections require a relatively small amount of effort to undo. Reuse of dismantled components for rebuilding on the same site is the ideal arrangement from the perspective of maximising savings. However, this *direct reuse* approach is not always viable with contemporary design practices. The concept of direct reuse should therefore be incorporated into the architectural and structural design of buildings to facilitate this practice in the future. For example, an existing building and its replacement could adopt a similar modular design in order that beam and column lengths are kept the same. Consequently, members can be directly reused in the replacement structure on the same site.

Alternatively, dismantled members can be distributed to different sites for reuse which has the obvious advantage of increased flexibility in design. However, the challenge with this *re-distributed reuse* approach is the development of an efficient and effective co-ordination scheme for stockpiling, sorting and redistribution of such members and components.

Whilst salvaging bolt connected steel members is immediately practical, extending this reuse approach to floor slabs that are typically built of concrete would represent a major challenge. Building floors are commonly built using *in-situ* concrete, concrete cast over corrugated steel, precast hollow core units or waffle slabs. These concrete units are difficult to separate given that their connectivity is typically achieved through the use of grout or *in-situ* concrete. The same can be said of concrete walls and facades. The sheer weight and size of precast concrete also means it would generally be costly to handle and stockpile precast units following their detachment from the structure concerned. Thus, the reuse of concrete is not as straightforward as steel. However, there is plenty of scope for innovation in the design of concrete floors in terms of facilitating the removal of precast concrete planks (or similar floor elements) from their supporting girders.

### *3.2 Reuse of Materials*

The authors have identified considerable scope for future innovation with the reuse of materials as opposed to the reuse of prefabricated units. The recycling of concrete aggregates is a well known example of the reuse of building materials. A drawback with recycling is that a considerable amount of energy needs be expended for breaking up concrete into smaller particles, separating the aggregates, and re-introducing cement to bind the aggregates to form a new structure. Reuse should be distinguished from recycling in that reuse effectively short circuits the process of renewing in order to save energy as illustrated in the schematic diagram of Figure 5.

The primary challenge with the reuse of concrete materials is the irreversible binding actions of the cementitious materials. A potential breakthrough with the innovative reuse of concrete is circumventing the use of the cement binder. As is widely known, the intrinsic compressive and shear strength of concrete is primarily attributed to the cement binders. However, similar strength could be achieved by exploiting the advantages offered by confinement and arching action through suitable choice of geometric configuration. Importantly, the cement binder is not an essential ingredient in achieving the desired strength provided that the required (compressive) load paths have been facilitated in the structural form. This “innovation” is nothing new given that the design of stone arches in historical structures has been based on this concept. The major challenge is in adapting this old concept into contemporary construction, (here exemplified in terms of a floor system in a building), without significantly altering its form.

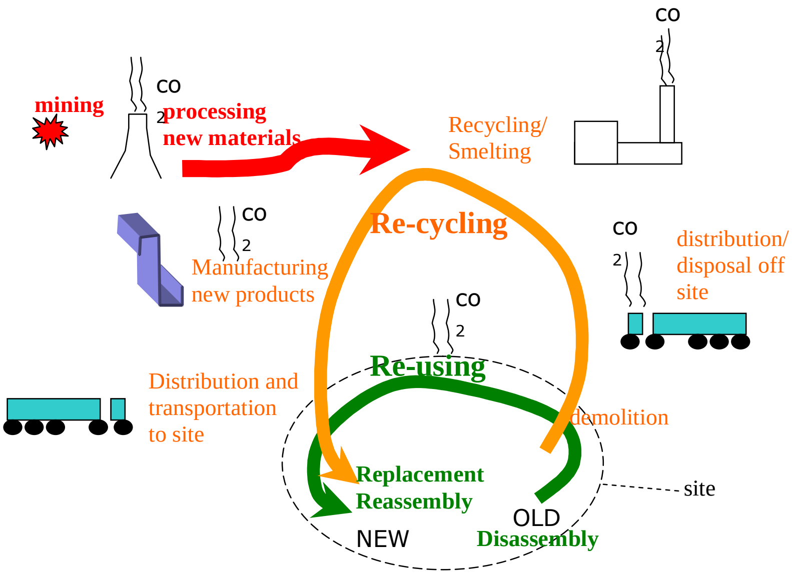


Figure 5: Reusing versus

The authors have designed and built a 1:100 scale model of a building out of pebbles and 1.2 mm thick cardboard to demonstrate the feasibility of utilising arching action in a slab-beam-column form of contemporary construction as depicted in Figure 6. Arching action in support of the floors was enabled via the curved shape of the floor cross-section formed by stiff cardboard and the use of cardboard tie-plates. The columns were essentially supported by the confinement of pebbles in tubes also made of cardboard. Some 20 kg of pebbles essentially were able to be supported "off the ground" by 1.2 mm thick cardboard sheets. Obviously, the reuse of materials with this type of construction would not be hampered by cement binders because such binders are not used, nor required, in this design concept.

Aggregates that have been salvaged through a reuse strategy based upon this design concept can be pumped into silos and extracted there-from as may be required for use elsewhere. The need to handle and stockpile detached units is hence eliminated, as you are dealing more-or-less with the raw materials themselves.

It should be clarified here that the *cardboard-pebble* model is intended only to shed light onto the "character" of the potential innovations that would be needed to allow for effective reuse strategies in building construction. Challenges still remain for delivering robustness, safety, reliability and durability with this form of construction. There would also be additional logistical challenges with construction and re-construction posed by reusing materials from the same site.

This plethora of potential challenges clearly indicates that reuse in construction is a very fertile area for research and development work in structural engineering.

## 4. Concluding Remarks

This paper has explored a number of issues and inhibitors for implementing reuse strategies in the construction industry. These issues and inhibitors pose a plethora of challenges to structural engineers who seek to introduce and facilitate reuse concepts for building elements and materials in their designs of buildings, in particular.

A concept for capatalising on the property of arching action to ensure compression only conditions in a shallow arched floor system has been tested by using simple physical models to demonstrate feasibility of such a system. The idea here is that "loose" lightweight aggregate can form the "fill" for the material in the arch, without the need to "cement" the fill using cementitious binders. The "fill" can therefore be introduced and removed from the floor system housing structure, quite readily thereby facilitating a reuse strategy for floor systems that adopt such a design concept.

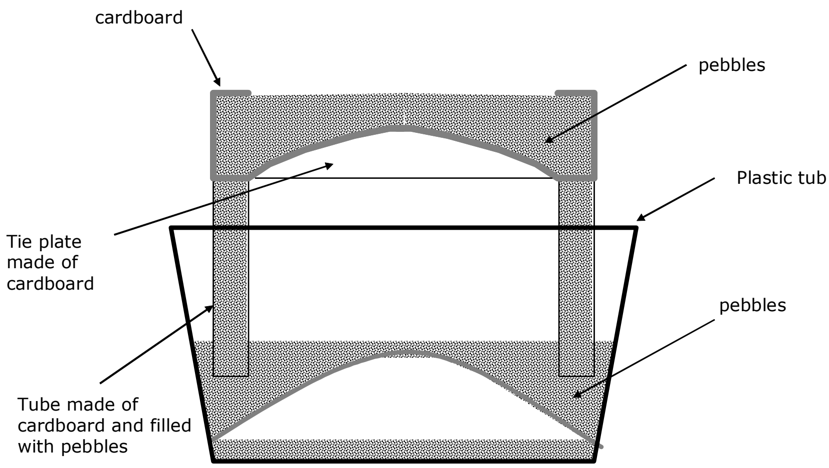


Figure 6: Cardboard-pebble model of a building supported by arching actions

The authors recognise that whatever novel concepts for implementing reuse strategies may be devised by structural engineers, challenges remain for ensuring these concepts meet robustness, safety, serviceability, reliability and durability requirements in the structures they design that incorporate such strategies.

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