The architecture of reuse

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Abstract. The starting point for designers in a circular system will often be identifying an inventory of potential second use materials and components. They then develop their design ideas around the tectonic characteristics of the materials. This can be seen as a restriction or a positive inspiration for creating meaningful ecological architecture suitable for the circular economy. Since availability of reclaimed materials and components is currently less predictable, flexibility in design and tolerance to alternatives by the project team and owner are important. The building design community needs to review and adapt conventional practices to increase demand for, and effectively integrate, reclaimed materials and components. This paper considers the architectural process implications and opportunities from reuse. As design teams adopt strategies to increase use of reclaimed materials and components, it is likely that the standard project management stages used by design teams may need to be adapted to facilitate a process better suited to circular strategies. New partnerships need to be formed, and new tools developed. Learning from existing projects a series of strategies are reviewed.

Keywords: Reuse, circular design, closed-loop architecture, resource efficiency, sustainable design.

1. Introduction
Urban metabolism is the description and analysis of flows, mapping their systems and providing a holistic model of the resource flows of a city. The concept is based on systems theory and thermodynamics. It is defined by Kennedy et al as, “the sum total of the technical and socio-economical processes that occur in cities, resulting in growth, production of energy, and elimination of waste” [1]. Urban metabolism principles have been employed to analyse the interrelations between environmental, sociological and economic factors of cities, to understand the flow of resources through a city, as well as the relationships between urban areas and their hinterlands. A review by Kennedy et al of 20 comprehensive urban metabolism studies indicated that contemporary cities have become increasingly material intensive in the past few decades [1].

Groak [2] observed that creating contemporary urban environments and buildings depends on tapping into and benefiting from a complex web of flows for energy, water, air, materials, money, food, etc. Construction materials are usually durable and long lasting and so accumulate in the urban fabric.
and their stocks grow slowly overtime. A significant quantity of the total extracted natural resource stock used for producing such materials resides as stocks in the current urban fabric and they form a potential resource which can offset new materials coming into the system. There are many opportunities for these resources to be treated in a circular way in order not to burden the available virgin (and non-renewable) resources.

From a construction materials perspective it is important to look at flows through the city but also within the city - circulating in loops, and at stocks available within the existing fabric. For example, Falk used lumber production and housing construction and demolition data to estimate that 2.2 million m$^3$ of timber is available annually from house demolition in the U.S.A [3]. Ergun carried out a study of the available bricks within Toronto that are stored in single family houses and could be made available for further use at the end of their current life, offsetting the use of new brick and reducing waste flows [4]. Such analysis can help understand the stocks of resources available in a city and they can also help highlight opportunities for change.

However, the demand for increased flows of resources depends on the age and stage of a city’s development. New and growing cities have large and expanding in-flows of new construction materials to create the new buildings and infrastructure. Conversely, they have small stocks within the urban fabric, and small outflows of construction materials as there is little demolition. New cities also have growing energy needs with potential to integrate energy efficiency and renewable energy sources. For example, according to Brunner [5] fast-growing Asian cities have an input-output ratio for solid materials greater than 10:1. For such cities, the potential for recovery of materials from the urban stocks is low due to small stocks. On the other hand, old established cities have less need for new materials to create new infrastructure, so they have reduced inflows. But they have large stocks within their fabric, and greater outflow of demolition waste which offers potential for reuse. They may also need greater volumes of energy to satisfy population demand due to old infrastructure. Brunner suggests that for cities in steady state, it is conceivable that 80% or more of primary resources could be substituted by secondary resources found within the city [5].

For building designers, the challenge is to learn to tap into these existing stocks and flows. This requires both technical and process changes, including reconsidering the procurement and design process. This paper explores the characteristics of how the design process needs to change to maximise reuse. This research is based on a study of over thirty projects that have introduced circular approaches. Learning from these projects provides insights for how designers need to approach creating new buildings with used components.

2. Implications for designs

Architect Jeanne Gang suggests that “By proposing a building made from materials at hand, the project introduces an entirely new paradigm for a project delivery process that has not changed substantially in the last fifty years. It radically alters the way a building is both conceived and made: form follows availability” [6].

In “The Science of the Artificial “– Herbert Simon describes design as “the process by which we devise courses of action aimed at changing existing situations into preferred ones” [7]. If we wish to create a more ecologically grounded built environment, based on circular approaches, we need to go beyond the design of more sustainable buildings, to more fundamentally devise processes, systems and an infrastructure that will achieve this.

The building design community needs to review and adapt conventional practices to increase demand for, and effectively integrate, reclaimed materials and components. As design teams adopt strategies to increase use of reclaimed materials and components, it is likely that the standard project management stages used by design teams need to be adapted to facilitate a process better suited to circular strategies. Issues of availability, supply chain, ownership, detailing, codes and standards, acceptability, and availability of information may all impact the design and delivery process. This situation may change as the supply of reclaimed materials and components improves and knowledge of how to use them becomes more common. However, the different characteristics and patterns of availability of previously
used components needs to be recognised and accommodated. Also, a different supply chain requires flexibility from design teams, so they can to develop their proposals around available reclaimed materials and components rather than the traditional process of designing the main features of the building and then identifying the components that will meet the required specifications. Based on the review of over thirty projects, including interviews of project participants, some key characteristics have emerged. These are discussed below.

3. Design process characteristics

3.1. Strong commitment and setting goals

Since using reclaimed materials and components is still more difficult than using off-the-shelf components, a successful project needs commitment from the entire design team and client. Setting and committing to clear goals with defined targets early in the process can help to unite the team, avoid conflicts and guide the design through the development stage to the more detailed specifications. If structural reuse is expected the structural engineer needs to be on board. Having someone on the team with experience of previous projects that feature reuse is also helpful. Without previous experience target setting can be difficult. The level of reuse targeted can be based on the following criteria:

- Smaller projects can have more ambitious targets due to the relatively small volumes of reclaimed materials currently available.
- Previous experience of the design team and contractor with the use of second use materials.
- The amount of flexibility in time available during both design and/or construction phases.
- Client commitment.

A clear decision-making process is needed with criteria (or a protocol) for making decisions about types of reuse which may include technical, aesthetic, economic, and environment considerations.

3.2. An integrated & expanded design team

Experience suggests that design teams that use an integrated design process (IDP) gain a clear benefit and a greater likelihood of successfully reusing materials and components. A decision-making process that involves the whole design team, and profits from the creativity, expertise and ideas of all the participants is more likely to succeed. The process may require the team to revise their normal working practices, include additional expertise such as demolition consultants or reclaimed materials brokers, and be prepared to take the initiative when it comes to overcoming unpredictable hurdles that may present themselves. Collaboration and enthusiasm are both important. Involving trades, suppliers and contractors is also helpful. Possible additional design team members may include:

- Salvage materials broker/consultant
- Demolition consultant
- Construction manager
- Materials scientist
- Specialist trades
- Product developer

3.3. Flexible approach to process and timing

Since availability of reclaimed materials and components is currently less predictable, flexibility and tolerance to alternatives by the project team and owner are important. This allows opportunities to be grasped when they present themselves, even if it is not at the appropriate time in the schedule. This is assisted by an integrated design approach. The design team needs to be prepared to revisit decisions when new material opportunities arise.
Material availability may occur early or late in the process. For early materials they may need to be secured/purchased and stored before construction has started, so the client needs to put into place a mechanism to make this happen. This may include early commitment of funds. Involvement of the management contractor at the design stage can help with this. Materials that become available later may involve late changes and some redesign. The design and construction teams should be prepared for this. Building flexibility into the structural design and particularly the depth allowed for accommodating the structure can allow adjustment of the design to suit component availability later in the process and the ability to accommodate components with small variations in specification. This requires appropriate contractual procedures to be used, as the final materials may not be specified at the time of tendering.

A further aspect of timing is the need to connect supply with demand. For example, if materials are coming from a demolition site elsewhere, when will this occur? And will they be available at the time needed for the new project? Until suppliers begin to store significant amounts of reclaimed materials and components, coordinating timing between deconstruction and reconstruction projects will be necessary. From the time something is schematically designed until it is constructed is usually many months or years. This means that to design for the use of a specific reclaimed component may involve some risk about its availability if it is not procured or reserved during the design process.

### 3.4. New relationships

Sourcing reclaimed materials and components requires designers to foster new relationships with organizations they may not traditionally be in touch with. This can improve their choices when used components are desired. Designers can benefit from developing working relationships with:

- Local salvaged material handlers who may have access to useful materials.
- Demolition contractors who are aware of buildings which are up for demolition and could be deconstructed.
- Materials brokers.
- Industries with waste streams that may have value in construction.
- Contractors of infrastructure projects who may need to dispose of materials that have a construction use.
- Specialist reclaimed materials procurement consultants who are emerging in some locations and can take on the task of identifying particular used materials. Their experience can reduce the risks of disruption or delay.

### 3.5. Material and tectonic centred design

Until a market for salvaged materials and components with regular availability and easy exchange through web sites, suppliers and other market mechanisms is created, the starting point for designers will often be identifying an inventory of potential second use materials and components and developing design ideas around their tectonic characteristics. This may be perceived as a restriction, or as a positive inspiration for creating meaningful ecological architecture suitable for the circular economy. Architect Jeanne Gang suggests that used materials should not be a straight replacement for new, but rather their particular features offer unique solutions which need to be explored [6]. Design concepts can come from an understanding of the characteristics of reclaimed materials and components locally available.

### 3.6. Opportunistic

The creative ability to see the opportunities presented by available materials and components (and to look for ‘materials of opportunity’) helps to increase the possible scenarios of reuse. A simple and flexible design helps to maximise opportunities. For structural design, the size and length of the available members can be used to determine the bay sizes in the new structure, thus maximising structural efficiency from the available components. This approach requires that the available components are identified early in the design process, and that they are purchased or reserved to prevent the salvage
contractor from selling them elsewhere. If the intention is to reuse all or part of an existing building in situ, the search for a suitable building will need to commence at the pre-design stage of the project.

Other areas to look for opportunities are in the labour cost for processing reclaimed materials. Some projects have used not-for-profit youth training programs or government job re-skilling programs as a way of providing economic opportunities for the less fortunate and lowering the cost of material re-processing.

3.7. Design-build
Ken Shuttleworth of Make Architects suggests that for innovation and advancing knowledge of the circular economy architects need to get involved on site, working very closely with construction teams [8]. Often in reuse projects the boundary between design and construction disappears, as construction decisions and materials purchasing may occur well before work starts on site, and conversely design revisions need to be made late on in construction if materials become available. Normally these may be practices to avoid, but with reclaimed materials opportunities can be lost if the process cannot adapt to suit them. Design-build management of the process has often been found to be appropriate, and even extending this to deconstruct-design-build can give greater control of the materials supply chain. For example, tres birds workshop is a Colorado based design firm that has established the capability to take on deconstruct and build roles. This allows them to be nimble and make a quick decision when an opportunity to get used materials arises. When working on the Posner Centre the opportunity arose to remove components from the Hewlett Packard Technology Center in Colorado Springs that was being demolished due to structural problems. Within 2 weeks, they were able to see the demolition site, get client approval for the used components, and extract them. As a result, a variety of components were salvaged for reuse.

3.8. Research and experimentation
Due to the innovative nature of most reuse projects they may require considerable additional research by the design team at the front end of the project to: identify, locate, inspect, choose, adapt, and prototype appropriate materials and components. Responsibility for identifying reclaimed components needs to be clearly established - who is responsible for sourcing a particular component? Often the starting point is a research process about available local material sources and the opportunities and limitations to their use. This may require audits of locally available suppliers, and demolitions. Investigation on how materials have been used in the past and what possibilities exist may follow. Sometimes mock-ups and tests are required to prove performance and aesthetics.

The design team may need to establish procedures for assessing and grading sourced materials and components to ensure they meet functional requirements and regulatory standards. This may require protocols and weighted analysis using agreed criteria to assist with selection and to convince the client of the appropriateness of a material. The process may require visual inspection, structural or other testing, prototyping and possible refurbishment. This helps to ensure approvals and successful inspections as some municipalities are often unfamiliar with and therefore hesitant to allow the use of reclaimed components.

3.9. Aesthetic concerns
Many old buildings, often with worn material surfaces and imperfections, are seen as full of character and uniqueness. However, materials with similar characteristics in new buildings are often regarded as unacceptable, poor quality, tacky, and second best. Some reused materials such as structural steel components are usually buried deep in the building envelope and not apparent, so aesthetic imperfections are unimportant. But many reclaimed material and components have unique aesthetic characteristics and when exposed they can become distinctive and inspiring architectural features. Sometimes exposing the uniqueness of old materials is what makes a project successful and popular.

The concept of StoryWood is interesting in the context of aesthetics [9]. StoryWood is wood from urban sources, with a "compelling history and unique provenance that sets it apart from other building
materials” [9]. This is timber material that has been mined from reclaimed wood and trees harvested in urban areas that has a history.

StoryWood highlights the fact that such materials have a unique and interesting past and a story to tell. The value of the wood component depends on how its story is expressed through its end use. So rather than trying to make such materials mimic mainstream, new, materials, designers should understand these stories, feature them, and make them transparent. In this way the richness of the wood’s story gives a competitive advantage and can add value to projects. Use of StoryWood can also support social and economic sustainability goals, including: job creation, local business, and community cohesion. The StoryMaterial concept can be applied to other materials such as bricks coming from urban mining and even industrial steel, encouraging designers to think of these materials in a different way to new materials from primary sources. The value of the material’s story depends on how its history is captured and expressed through its end use.

The culture of newness is gradually changing, and creative architectural solutions inspired by old materials can assist with this process. Reuse of materials and components offer an opportunity to celebrate their individual qualities and characteristics and to reinvent and transform them in a creative way to reveal their uniqueness. Often visible scars and features of the old material are left intact and used in a decorative way to highlight the heritage of the material and celebrate its reuse. Many interesting projects accept the damaged character of a material and develop an aesthetic approach that embraces this. This is common with reused brick, old stone, old timber, so why not other materials.

3.10. Economic flexibility
The economics of material reuse is complex. It is important to recognise that projects that use reclaimed materials and components typically have a unique cost breakdown significantly different to a regular building project, as there are non-typical costs. But the overall costs need not be higher and can sometimes be lower. Some of the cost issues include:

- The split between labour and materials is likely to be significantly different. Typically, materials costs go down, as reclaimed materials are often cheaper than new (except for special, heritage and unique items), but more labour is needed to process and prepare them. Since labour is generally expensive, keeping the extra costs under control is important.

Figure 1. Discarded timber components are used to form this interior wall partition system by the Nordic Building Component Reuse project [11].
• There can be additional design team costs. This can be due to additional research, testing, sourcing, and redesign to suit the project. Value based fees, where fees are based on the time/effort/material put in by the designer may be appropriate.
• There is likely to be greater uncertainty over cost early in the process until key components are sourced and secured.
• Deconstruction is generally more expensive and time consuming than demolition but provides useful resources at the end of the process.
• Transport, storage and double handling can add significantly to costs. For this reason, local materials and components are often the most cost effective, except for specialist items. Additional handing and off-site storage can add considerably to costs. It is preferable to avoid moving material several times with the associated loading and storage costs. The highest savings often occur for projects that focus on reuse of what is already on site.
• The cost plan should include sourcing, deconstruction, refurbishment, transport, and testing/verification costs while remaining flexible to allow for market fluctuations in supply and demand.
• Securing materials can require early purchase by the client directly, and so establishing a budget structure that allows this is important. For example, as a designer-builder, tres birds workshop often have to directly purchase items that they may use on a future project. If the team waited for the right project to come along before purchasing, then many reclaimed items would no longer be available.
• In some countries (such as the USA) a powerful tool to encourage deconstruction (and therefore reuse) are tax credits. If a building owner disposes of salvaged materials and components through a non-profit organisation (such as HfH ReStores) they can claim tax credit for the resale value of the donation.

3.11. Knowledge based
Many organisations that have successfully created a business model around designing with reclaimed materials and components have developed a knowledge base and built a database of locally available sources. Many of the pioneers operate an open source policy as they see their work as opening up the market for more circular practices. Warranty and market confidence are a significant issue for reuse and can prohibit interesting solutions and prevent creative reuse. Establishing a common knowledge base helps to grow confidence in this approach.

3.12. Building Information Models (BIM)
BIM modelling can be a valuable tool both for work flow modelling and also for storing information about component characteristics (materials passports) for future reuse.

3.13. Processing, transport, and storage
Processing, handling and storage can add significantly to cost. It is important for the client to understand that materials may have to be acquired early in the process (whenever available, for example from a demolition nearby) and this will necessitate storage. An appropriate location may be required (preferably on site). Careful planning and the involvement of the main contractor in this process can alleviate some of the drawbacks. Timing can be important, for instance when to move materials so as not to double handle them. Transportation may be an additional cost if it is determined that additional processing or storage is required away from the site. This requires coordination with the main contractor, or supplier, and can have a significant impact on costs. This highlights the importance of having the construction manager at the decision table.

4. Conclusion
As Jeremy Till, Jeanne Gang and others point out the emerging conditions of scarcity are rich in possibilities for the design professions. Recognising the challenges and opportunities facing architects
Buckminster Fuller’s called for a new kind of designer, a “synthesis of artist, inventor, mechanic, objective economist, and evolutionary strategist” [10].

To work in a circular economy, designers need to become familiar and comfortable with new ways of organising the design process as well as alternative sources for the materials and components they design with. Innovative design based on availability can increase the chance for a high percentage of reuse being incorporated into projects. This is what is needed to embrace the opportunities that the circular economy and material reuse offers. But beyond this we need to build an infrastructure and accepted processes that embed circular systems into their core assumptions.

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