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Morphological analysis of the city for achieving design for disassembly

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Abstract

While it is dangerously tempting to think of the city as a fixed built environment, the result of careful planning and design, it is in fact an ever changing system of infrastructures, buildings, spaces and materials. The commercial and social pressures of modern society demand constant newness and change. Unfortunately most of our cities are not designed or built to accommodate ease of change through disassembly; rather they succumb to demolition and the creation of waste. A strategy of design for disassembly has been successfully implemented in many mass produced products such as computers and cars, but it has not achieved popular or widespread application in the design and construction of cities.

This paper presents a theoretical model for understanding the potential for design for disassembly in the city in order to reduce waste and increase reuse. It explores multiple scales of the city from materials and elements, through rooms and buildings, to urban form and territories. The paper draws on a typo-morphological analysis of the city through the theories developed by both the Italian and British schools of urban morphologists. It establishes a structure of time-related layers of the city and proposes ways to interact with those layers in a sustainable and systemic way. A morphological analysis of elements, structures, systems and organisms, is applied to a number of case study buildings and city territories in order to assess their disassembly potential, and through analysis, develop principles of design for disassembly that operate at a whole of city scale.
Keywords: design, disassembly, urban morphology, scales, time, layers, architecture, building, city.

1 Introduction

The dominant way of thinking about our modern cities and the buildings within them is that they are a whole and single entity; permanent and designed and built to outlast us. The reality however, when viewed over time, is that they are temporary and ever changing. Such ‘temporary use is not a new social phenomenon; temporary ventures have always been a feature of cities that were conceived and built for the long-term’ [1, p. 21]. Not only do cities change as parts of them come and go, but whole cities in themselves can be impermanent and transitory. ‘History abounds with examples of mighty cities that turned out to be temporary’ [2, p. 12].

This being said, the pace and extent of contemporary change is well beyond a sustainable level. ‘Buildings are deigned to last seventy to one hundred years, yet today buildings with an age of fifteen years are demolished to give way for new construction’ [3, p. 134]. The consequences of this are that many construction materials and components that are still perfectly serviceable are being demolished and wasted long before their usable service lives have been reached. In fact we are designing and building with many modern materials and components that have high levels of durability and increasingly long service lives, but incorporating them into increasingly short lived buildings. We are, more than ever, building cities with multiple lives at different scales; a four dimensional city [2].

As the population of the world becomes increasingly more urbanised, it becomes ever more critical to review our understanding of cities. In the early part of the twenty first century it is apparent that cities are no longer designed and built with the same sense of permanence that we once attributed to them. The buildings that we design and build now are living shorter service lives than previous eras. Buildings are being demolished after just a few decades. A recent study by the Athena Institute in the U.S.A. found that 30% of demolished buildings were less than thirty years old, and that 27% of buildings that existed in 2000 will be demolished by 2030 [4]. Another North American study found that 57% of non-residential buildings were being demolished before they were fifty years old [5].

The commercial reality of a capitalist culture is driving a desire for change and renewal that outpaces the material service life of the building and city structure. This fast paced cycle of building and demolition is creating an increasingly temporary city, and an increasingly complex city, that is increasingly difficult to understand and explain. ‘If we acknowledge that cities are almost intractably complex and diverse, can we expect to have a simple explanation of them that can be understood at a single sitting’ [6, p. 119].

One aspect of cities that needs further explanation, if we are to understand them and avoid the negative impacts of their temporary nature, is how to accept this rate of change but work with it to reduce the rates of material waste. This understanding will bring together an appreciation of the current rates of reuse, how this can be improved, an understanding of the city as a series of hierarchical layers, and the principles of design for disassembly that operate at a city scale.

2 Re-use of materials

The re-use and recycling of building materials and components has always been a part of the built environment. From the earliest recorded times humans have designed and built with an understanding of the temporary nature of buildings and the potential for reuse of materials and components. 'Buildings have long been mined and harvested for their materials' [7, p. 266]. A survey of historic examples of temporary buildings has shown that in the past there has been a good understanding and appreciation for the reuse of building materials [8]. There has however been a significant shift in the past century that has seen such patterns of reuse become the exception rather than the norm. This has led to a disturbing state of affairs in the construction of our contemporary cities.

'The Organisation for Economic Co-operation and Development found that globally buildings are responsible for about 30% of raw materials used, 42% of energy used, 25% of water used, 12% of land use, 40% of atmospheric emissions, 20% of water effluents, 25% of solid waste and 13% of other releases' [9]. With the increasing rate of demolition in our cities this materials usage is of concern; especially when considering the low rates of recycling.

Rates of recycling for construction and demolition waste vary greatly across the world, as does the associated legislation. In some countries, such as the United Kingdom, Germany, Denmark, Ireland and the Netherland rates are as high as 70%, but in others rates are as low as zero [10]. Only about 40% of construction and demolition waste, in the USA, is reused, recycled or converted to energy [11]. It must be noted however that most of the recycling of demolition waste is down-cycling, such as crushed concrete being used as road-base or as low grade aggregate; only small proportions are reused to take advantage of their original material or component properties.

'Several ecological footprint studies have shown that cities greatly exceed, or overshoot, their bio-capacity by typically 15–150 times' [12, p. 3]. 'The World Watch Institute estimates that by 2030 the world will run out of several raw materials for construction' [11, p. 350]. With 30% of raw materials making their way into our cities as infrastructure and buildings we must return to our understanding of the city as a temporary fabrication and start to see those materials as resources rather than as waste. 'By harvesting urban resources, global impacts can be reduced and the resilience of cities can be improved as well' [12, p. 3]. This form of urban metabolism is well understood in the reuse of energy and water, and at times domestic waste; construction and demolition waste is however seldom considered despite it being of such great magnitude and significance. Not only is the material itself able to be recovered to reduce the quantities of waste, research [13] has shown that up to 40% of the embodied energy of a building can be recovered just through harvesting this material for recycling. More strategic reuse of whole materials and components (as a higher level recycling strategy) could increase this percentage significantly.

The current low rates of reuse of building materials and components are a result of the complexities of our contemporary cities and societies. The specific reasons for low rates of reuse and recycling have been identified as follows: social factors such as lack or education, environmental factors such as hazardous materials, economic factors such as increased cost of disassembly, material factors such as jointing methods, stakeholder factors such as contractor's lack of experience, and regional factors such as cultures and traditions [11]. The most significant issue is simply that buildings and infrastructure are not designed for future material recovery, thereby making the recovery of materials and components difficult, time consuming and expensive. Our cities are still being designed and built as if they are to be permanent rather than temporary. As such it is the designer who has the greatest ability or capacity to influence this system and affect the future rates of reuse and recycling [11]. What we must do is design our cities to facilitate future reuse; a system of design for disassembly.

In order to implement a strategy of design for disassembly at a city scale we also need an understanding of the city from a morphological perspective. The city is not simply a collection of buildings, and a sustainable city is not simply a collection of sustainable buildings.

3 Urban morphology

Urban morphology is the study of the shapes and patterns of the built forms of human settlements. As such it is a way of understanding this complex and diverse environment, the city. Urban morphology deals with an understanding of the physical built form of the city; what are the fundamental individual elements and how are they arranged together [14]. At its most basic, we can understand 'urban morphology as a study of form in space' [15, p. 117]; 'the shape of a city, including its architecture, layout of streets, and different densities of habitation' [6, p. 108].

A typomorphological analysis of the city deals with both the typology of buildings and spaces, and the urban forms of buildings and spaces; it considers the city at all scales from the material to the large grain street pattern, and it considers the city as dynamic and ever changing [16]. This final point is of significance; urban morphology incorporates an understanding that the physical form of the city is something that changes over time; 'the physical city is not an object but a process' [16, p. 292].

It is because of this understanding of the city as something that is constantly changing, temporary, that 'typomorphology serves as a rich launching ground for studying the nature of building design, its relationship to the city, and to the society in which it takes place' [16, p. 290]. It is also why urban morphology is so compatible with researching and understanding the sustainability issues of the city. 'This approach is suited to research and practice where the focus is on urban metabolism and the comparative environmental performance of urban form… but further research and application across a diversity of urban configurations are clearly required to validate and demonstrate the utility of the method' [17, pp. 17–18]. This research project has sought to demonstrate how this approach of urban morphology can support an analysis of the city for opportunities to implement the strategies of design for disassembly, with the intent of increasing levels of sustainable practice.

4 Hierarchy of city layers

One of the greatest challenges of the field of urban morphology is to establish the classification framework and basic units of morphological description; that is a shared understanding of the physical and material scales at which the city can be analysed. This is based on the premise that ‘a consistent system of morphological description can assist both research and practice’ and that ‘a shared representation of urban form facilitates comparison and synthesis across different types of investigation and ultimately provides greater knowledge of the human habitat’ [17, pp. 5–6]. It is for these reasons that this research has used a morphological understanding of the city to investigate the sustainability potential of design for disassembly. Such a classification framework recognises that cities are ‘more accurately characterised as overlapping sets rather than strictly nested sets’ [14, p. 43].

The work of the Italian school of urban morphology, particularly Caniggia and Maffei, has two approaches to urban morphology, spatial and temporal; also referred to as copresence and derivation where the city exists on multiple scales at the same time but also changes over time and derives its form from what went before [6]. Caniggia and Maffei developed a hierarchical understanding of the city in four scales or levels: elements, structures, systems, and organisms [14]. These four scales can be interpreted as: buildings, groups of buildings, the city, and the region [16]. Caniggia’s understanding of the city is based on how objects (materials, rooms, buildings) fit into each other at different scales, operating with a sense of modularity, wherein an understanding of any sale must understand the scales above and below [18].

The work of the British school of urban morphology, particularly Conzen, is also quite explicit is its establishment of a hierarchical structure, all be it one of just three levels or layers: building patterns, plot patterns, and street pattern [14].

These scales, and those of other urban morphologists, have been aggregated into the following assembly by Kropf : ‘materials such as bricks, tiles and timber are the elements that go together to form structures such as floors, walls and roofs; structures go together to form rooms, stairs, corridors and the like, which in turn go together to from whole buildings. The schema is then used to extend the hierarchy upward by taking building as the element and identifying the further levels of urban tissue, urban quarter and settlement’ [14, pp. 45–46].

Kropf goes further to suggest that an understanding of the physical materiality of the city must engage with the concept of coextensive forms, in which each level or layer of the city is defined both as one part of the next level up, and as an aggregation of parts from the next level down [14]. The basic morphological principle presented by Kropf is that each part of the city must be considered for both what it is a part of and what parts it is made up of.

Kropf’s final framework of hierarchical levels is: materials, structures, rooms, buildings, plats, plot series, streets and urban tissue [14]. Kropf proposes this framework as a ‘critical tool’ to ‘allow us to investigate the diversity of built form, construct more rigorous and nuanced explanations, and get better results when we participate in its formation and transformation’ [14, p.56]. It is precisely this last point of getting better results during transformations of our cities that makes the morphological analysis a useful tool when paired with the principles of design for disassembly.

‘In fact, the geometric or topological relationships of interest here are not limited to any particular scale’ [15, p.119]. We can use ‘topological graphs’ as a way of understanding the spatial and material structure of a building or city and we can use ‘containment structures’ to understand the hierarchical relationships of parts to the whole [15]. ‘Within urban morphology there is general consensus on the core, fundamental elements of physical built form: streets, plots and buildings. Similarly, a common feature in the definition of built form is the hierarchical structure of elements based on the relationship of part-to-whole’ [14, p. 42].

Table 1: Interpretation of Kropf’s taxonomy of built form, based on Osmond [17].

City	City or town
Street	Including groups of plats, squares, city blocks
Plot	Cadastral zone with one or more buildings
Building	Detached buildings, multi-unit housing, office buildings
Room	Including stairways, corridors, lift wells
Structure	Masonry wall, timber framed wall, roof assembly
Material	Bricks, beams, rafters, concrete slabs

Research by Sanders and Woodward [19] has shown how urban morphological analysis of the city can be used to dissent the city into its constituent parts at different scales (layers or level) and use this analysis to critique the city as an assemblage; what Caniggia and Maffei refer to as the system organism or scalar components.

The urban morphologists are however not the only researchers to establish an understanding of the city as an assemblage of different layers. Writers such as Habraken [20], Duffy and Henney [21], and Brand [22] have explored the construction of our cities and established frameworks of building layers, each with its own separate time scale and life expectancy [23]. Earlier research into the work of these authors has established a framework for understanding the temporal nature of the city and its impact on the embodied energy therein [24]. The framework established on the basis of that research disaggregated the city on the basis of layers that were defined by their life expectancy, rather than their physical scale as is the case with the urban morphologists. What follows is an expansion and development of the time-based framework to incorporate the broader categorisations and physical scales of the urban morphologists, and analysis of the new framework’s interaction with the principles of design for disassembly in the construction industry (see Figure 1).

What Figure 1 shows is the different scales at which a design for disassembly strategy can work on the city, from materials to urban, and the hierarchy of reuse or recycling capabilities at each scale. This framework can be used to critique the strategies of design for disassembly with particular reference to the larger scales and the prospects of a sustainable city.

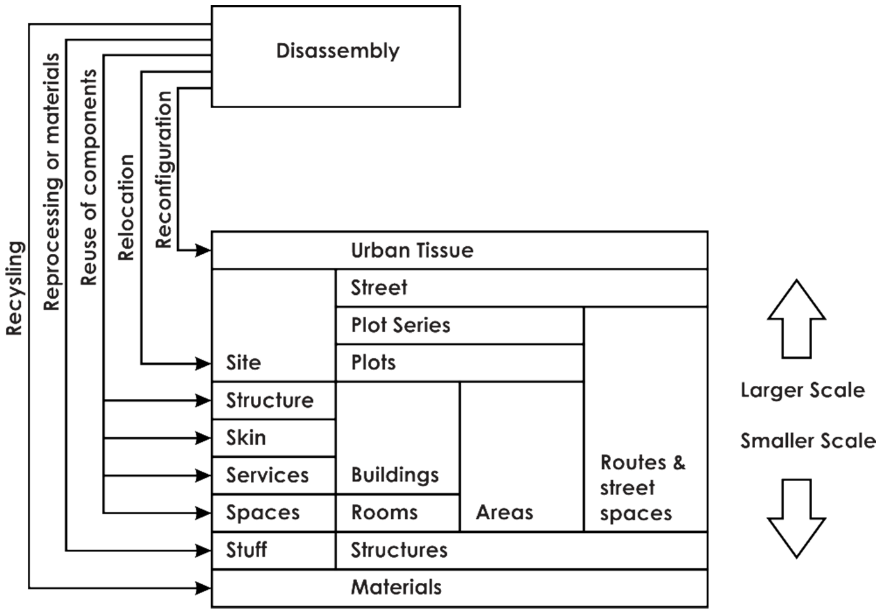

Figure 1: Layers and scales of the city, and their respective reuse and recycling capabilities.

5 Design for disassembly

Design for disassembly is well understood in industrial design and product manufacture. Particularly in Europe, manufacturers of mass produced products such as computers, mobile phones, and even cars, are often held responsible for the return of those products at the end of their service lives. This creates incentive for the manufacturers to design products in a way that facilitates disassembly for material and component recovery and reuse. There is however no such incentive in the mainstream construction industry. That being said there are some examples of buildings and whole cities that have, whether by design or by later necessity, been disassembled for reuse. Analysis of these unique case studies using the techniques of urban morphology, in particular the analysis of the urban scales or layers of the city, can reveal how and where a strategy of design for disassembly can be used to affect levels of material and component reuse. The case study buildings include: temporary housing, festival infrastructure, sporting facilities, markets, emergency settlements/cities, adaptable ‘permanent’ buildings such as Centre Pompidou and Sainsbury Centre for Visual Arts, and unrealised schemes such as the work of Archigram and their Walking City and Plug-in City, the Fun Palace of Cedric Price, Free Zone Berlin by Lebius Woods, and The Cronocaos project by Rem Koolhaas.

One example, the London Olympic stadium of 2012, offers a good illustration of the incorporation of a design for disassembly strategy. This stadium was specifically designed so that the upper parts of the seating could be disassembled after the Olympics and reused elsewhere, so that a smaller, more appropriate, sized stadium would be left on the site. 'The widespread use of temporary buildings as sporting facilities was truly radical, part of a sustainability strategy that argued it was wrong for a city to burden itself with facilities it didn't need' [25, p. 59]. Upon completion of the Olympic Games the upper levels of seating in the main stadium were easily disassembled and reused in the construction of other stadiums.

Another example is the way in which whole houses can be relocated. In Australia where much of the older detached housing stock is of timber construction, it is quite common for whole houses to be relocated by simply raising them above their foundations and placing them on a truck. This is at times carried out by first dissecting the hours into two or three parts, to be reassembled on the new site. Whole houses, disassembled from their sites, are even at times relocated to sales yards to await a new owner and a new site (Figure 2).

Figure 2: Whole house in sales yard, awaiting a new owner and new site/plot.

Analysis of these case study and others as noted above reveals a number of design strategies that enable future disassembly for reuse and recycling. A full list of design for disassembly strategies has been developed in prior research [23] however that was focused squarely at the smaller scales of material structure. Analysis of the above mentioned case studies, at larger scales, highlights new strategies as well as existing ones that operate specifically at the urban or city scale. Table 2 shows a list of twenty seven design for disassembly strategies and their relevance at different scales of urban morphology. What this analysis reveals is that not all strategies for designing for disassembly are equally important at all scales of the urban environment. For example 'avoiding secondary finishes to materials' is critical to increasing the rates of material or component recycling, but

Table 2: Design for disassembly strategies and the hierarchy of urban morphology.

Legend - level of relevance: Very relevant / Relevant / Not normally relevant

No.	Principle	Materials	Structures	Rooms	Buildings	Plots and Streets	Urban Tissue
1	Use recycled and recyclable materials	Very relevant	Very relevant				
2	Minimise the number of different types of material	Very relevant	Very relevant				
3	Avoid toxic and hazardous materials	Very relevant	Very relevant				
4	Make inseparable subassemblies from the same material	Very relevant	Very relevant				
5	Avoid secondary finishes to materials	Very relevant	Very relevant				
6	Provide identification of material types	Very relevant	Very relevant				
7	Minimise the number of different types of components		Relevant	Very relevant	Very relevant		
8	Use mechanical not chemical connections		Very relevant	Very relevant	Very relevant		
9	Use an open building system not a closed one			Very relevant	Relevant	Very relevant	Very relevant
10	Use modular design			Very relevant	Relevant	Very relevant	Very relevant
11	Design to use common tools and equipment, avoid specialist plant		Relevant	Very relevant	Very relevant	Very relevant	
12	Separate the structure from the cladding for parallel disassembly			Very relevant	Relevant		
13	Provide access to all parts and connection points	Relevant	Relevant	Very relevant	Very relevant	Very relevant	
14	Make components sized to suit the means of handling		Relevant	Very relevant	Very relevant	Very relevant	
15	Provide a means of handling and locating			Very relevant	Very relevant	Very relevant	
16	Provide realistic tolerances for assembly and disassembly			Very relevant	Very relevant		
17	Use a minimum number of connectors		Relevant	Very relevant	Very relevant		
18	Use a minimum number of different types of connectors		Relevant	Very relevant	Very relevant		
19	Design joints and components to withstand repeated use			Very relevant	Very relevant		
20	Allow for parallel disassembly	Relevant	Relevant	Very relevant	Relevant		
21	Provide identification of component type		Relevant	Very relevant	Relevant		
22	Use a standard structural grid for set outs				Very relevant	Very relevant	Very relevant
23	Use prefabrication and mass production			Very relevant	Very relevant	Very relevant	Very relevant
24	Use lightweight materials and components	Very relevant	Very relevant	Very relevant	Very relevant	Very relevant	
25	Identify points of disassembly		Relevant	Very relevant	Very relevant	Relevant	
26	Provide spare parts and on site storage for them during disassembly				Very relevant		
27	Sustain all information of the building components and materials			Relevant	Very relevant	Very relevant	Very relevant

is not particularly relevant to relocating whole buildings or reconfiguring the urban tissue of a city.

This research shows that the previously un-researched scales of the urban environment, plot and streets and urban tissues, would benefit from strategies related to building modularity, standardisation, and open design systems. The value of complying with a strict module of design is in the compatibility with other building materials, components, and systems, which will permit higher levels of reuse through relocation. This form of dimensional and systematic modularity is most crucial at the junction between the different urban scales. It is at this junction where most disassembly and reassembly will occur. Through open building systems, the ability to disassemble components without disassembling adjoining ones is a valuable principle to reduce negative impacts of disassembly. This is especially true if the adjoining components or materials are from different scales or layers. It cannot be assumed that the disassembly of scales with very short life cycles (such as building cladding) will coincide with scales with longer life cycles (such as structure).

6 Conclusions

This research has explored not only how to design for disassembly, but importantly where to design for disassembly; at the junctions of these morphological scales or layers. It has also explored the relationship between the strategies for design for disassembly and the morphological scales; which strategies are most important or relevant at different scales. Lessons learned from these case studies can be used to develop strategies for design for disassembly.

This understanding of design for disassembly has the potential to significantly reduce the rates of material and energy waste in our urban environments. With our cities being responsible for such a major proportion of our natural resource use, we must reconsider them not just as a consumer of materials but as a source of materials. Such consideration needs to take into account the different scales of urban morphology and how different strategies will be appropriate, or more successful, at different scales. Appreciating that our cities are not permanent, but temporary, highlights the need for designers to take a lead in treating our cities not as monuments, but as transitory environments operating in a complex way at multiple scales. We must appreciate that our cities can be designed to facilitate future reuse at those different scales.

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