CUSTOMIZED CONTAINER ARCHITECTURE

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INTRODUCTION

> "…the concept/perception of modular construction is cheap, temporary and lightweight… with our product, there has been a deliberate policy of over-design. It needs to feel like a building. You can't tell that it is a modular building…."
> Colin Harding (co-founder of Verbus)

The use of shipping containers as building units has been widely reported, including 2008 ACSA Proceedings [35]. The re-use of existing containers in buildings solves simultaneously the environmental issues of steel container waste and reduced embodied energy for construction materials.

An alternative approach for container buildings is to use new, purpose-made manufactured units. These units are based on the ISO standard container platform but fabricated to better suit typical room sizes. While not waste-saving in the same way as buildings made from re-used units, the units are self-contained, with simple robust connections, that are easy to disassemble.

Buro Happold consulting engineers have led the design of freight container buildings in Europe, starting with Container City in 2001 by Urban Space Management, followed by the Travelodge & Premier Inn hotels from 2003 – 2009 with Verbus, the Nomadic Museum in 2005 by Shigeru Ban, the pan-European Hotel product in 2006 by KKA Architects, 'MySpacePod' by Will Alsop in 2008, and more recently, the temporary event hotel product for 'SnoozeBox' in 2011 - 2012.

This paper is written in three parts; using case studies it charts some key architectural, technical and product development issues of containerized buildings. Part I - Container Architecture, describes the history of freight transport, leading to the large-scale availability of redundant containers, the social and economic factors for containerized buildings. Part II - Container Technology, describes standard unit configurations and the European technical certification and code requirements for steel modular units. Part III - Product Design and Parametric Digital Architecture, discusses issues of prototyping, standardization, customization and platform design. It also looks at recent models for scalable building designs that optimize geometric components, quantities, cost data and carbon footprint.

PART I – CONTAINER ARCHITECTURE

Intermodal Freight Transport

The shipping and railway industries used "intermodal" container boxes to transport furniture from France to England as early as the 1890's, over 50 years before the modern intermodal container with its characteristic twist locks emerged in 1956. [21].

The container is the central product of an automated system used to deliver goods anywhere in the world with minimal costs and complications. Such is the imbalance of trade between producers and consumers that it is less expensive to abandon containers at the point of delivery rather than transport them back empty. Added to this have been global fluctuations in world trade and shifting preferences in sizes of containers for shipping [21], which has resulted in a surplus of steel units in many ports. The Dry Freight container is the most common, and in 2005 it was estimated that there were at least 125,000 units in the UK and 700,000 empty units in US ports alone [23] [19].

Container Buildings

Architects have observed that stacked units in ports look like neighborhoods and provide a type of ready-made construction system [19]. Redundant reclaimed containers, also called 'deadheads' [4], have been adapted and assembled with other more conventional building elements to create low cost, low carbon footprint buildings. Although there is no shortage of containers for re-use, their take-up for construction has been relatively small. With the units' external appearance left exposed they present an uncompromising aesthetic: a kind of 'cosmopolitan building block' [19], and the standard dimensions of a container, determined by shipping and transport requirements, do not immediately suit habitation use. This has led to some novel applications and configurations of units [19]. Fortunately the standard container has a robustness and rigidity that suits modification.

Social and Economic Factors for Containerized Buildings

Kotnik describes the cultural development of the container building as 'bottom-up' [19]; containers were first used as shacks and shelters in low economy countries before they became popular with architects.

Containers have been successfully deployed in areas prone to extreme environmental conditions [23] and used as emergency shelters and medical centers such for post-hurricane housing [6] [11].

Container buildings are cheaper than most modular building systems, which in Europe can be anything from 5 to 20% more costly [24] than traditional on-site construction. Modular buildings bring other commercial benefits to a project such as program savings, more predictable quality, and reduced snagging, but other factors may come into play in the choice of modular units, such as issues of access, and local availability of skilled labor.

Case Study 1 – Uxbridge Travelodge

The Uxbridge Travelodge is an eight storey hotel building completed in 2006. The site was located adjacent to a 24-hour bus terminus. All site deliveries including the container modules had to be delivered across the main access road, and at no time could a bus be delayed by more than 10 minutes during site deliveries. Due to its layout, the building required additional steel framing and some non-standard units. The building took 16 months to complete. It was clad in traditional brickwork.

Large hotel operators who are 'repeat-order' clients [9] [30] may be looking for a module supplier who can bring long-term value, maintain a consistent output, and develop strong commercial relationships with their framework contractors.

Some permanent building types: student accommodation and budget hotels have a shorter life-cycle than commercial and residential buildings. Contributing factors include unplanned urban expansion, extreme climate events, and transitory worker populations. This has led to some clients taking a greater interest in building adaptation and the possibility for demountablilty and relocation; qualities offered by containers.

Case Study 2 – Tempo Housing.

The largest container development in the world is 1000 re-used units for a student housing development at Keetwonen, near Amsterdam, Denmark, which was fully completed in 2006. (www.tempohousing.com 2010). The housing is temporary and designed to be dismantled. The extended lease ends in 2016. Tempo housing have also built other residences including a re-locatable five storey worker housing development in Holland, due for relocation in 2013.

These buildings have a financial profile more similar to manufactured products. The buildings are 'semi-permanent' and the characteristics of a commodity, a measured depreciation and a quantifiable end-use value. Due to the projected rise in energy costs, re-used is likely to become a more significant factor in the future choice of building systems.

PART II – CONTAINER TECHNOLOGY

Intermodal Steel Building Units (ISBU's)

Intermodal Steel Building Units or "ISBU's" are re-used containers converted for building use. Units are commonly 8ft (2.4m) wide and 20 or 40 ft (6.1 or 12.2 m) long. There are also 'High Cube' that are 48 to 53 ft (14.8 to 16.3 m) long. These types of modules are used in low-rise construction, and modified to suit normal room sizes by joining units together, with partial removal of side panels. Unit arrangements are sometimes combined with other structures such as open-plan steel frames.

Case Study 3 - Container City, Urban Space Management

Contractor Urban Space Management developed the residential and office building 'Container City', in 2001 (www.containercity.com 2010) the first major UK project to re-use containers, and it was completed in just five months. The containers are left exposed with a 'Lego'-like aesthetic [4]. The success of the first container city project led to a further floor of units being added to the original building and another separate building being added on the same site in 2002 [35]. Urban Space Management followed this project with a college building and a sports hall in collaboration with Architects Scabal [4].

The alternative form of container buildings constructed using purpose-made units are closed-cell, factory finished, volumetric units, varying from 8 to 14 ft (2.4 to 4.3 m) in width and 20 to 53 ft (6.1 to 16.3m) in length. They are stacked to form multi-storey structures. As with other volumetric construction systems they have the advantage of being built and fitted out under factory conditions, but made with the universal ISO components.

Case Study 4 – Verbus System

The Verbus System, a collaboration between contractors George & Harding and Buro Happold, have built seven Travelodge and Premier Inn hotels in the UK between 2003 and 2009. The commercially manufactured modular building units are made and fitted-out at the CIMC factory in Guangdon Province, China.

These oversized units with bolted and corner connections, are shipped to Europe on a standard container ship and transported to site on standard container transport vehicles. The units are fabricated in batches of around 75 to 150 units and take one week to fabricate and two further weeks to fit-out. The CIMC factory at Shenzen is normally fabricate up to 2000 units per week.

The requirement for non-standard containers has been intermittent, typically every 6 months. The module production line benefits from being part of mature and much larger manufacturing plant.

This has meant it can more easily respond to the stop-start demand for container buildings.

The hotel buildings are two to eight stories high with floor areas varying between 25,000 ft^2 and 74,000 ft^2. Despite the distances involved, the overall production cost of shipping container units is comparable to traditional construction. This is due to the low cost of materials and labor in East Asia and the very low cost of container transport.

Where the container is enclosed in external cladding, insulation is placed outside the container. Further insulation may be used inside the container for acoustic isolation and fire protection. The container is a warm frame and its watertight steel shell can be used as the vapor barrier.

Technical Performance & Detailing

Compared to most building systems, container architecture is very recent [21] [19]. The design and detailing of new construction systems often emerges from existing building typologies [14], and containerized construction shares some of its detailing with existing systems, and some of its detailing is completely original.

For prefabricated units to be certified in Europe: 'CE marked', the performance characteristics are described in the Guidelines for European Technical Approval [15].

Among the 'Essential Requirements' in ETAG 023 there are at least four key characteristics for containers: ER1 - Mechanical resistance and stability, ER2 - Safety in case of fire, ER5 - Protection against noise, and ER6 - Energy economy & heat retention [15].

ER 1 - Mechanical resistance and stability

The requirements are for safe transmission of vertical and horizontal loads, and prevention of collapse. In containerized construction, vertical load is transferred directly through the corner columns, which are restrained laterally against buckling by the steel infill panels. Horizontal loads are transferred through the sidewalls of the containers for buildings up to 11 stories or for higher buildings through a combination of braced steel cores and the container walls. Like many cellular buildings, containerized buildings use frames to transfer support loads from the modules to more open plan areas. In the event of collapse of the module or its support, containers are linked horizontally, so that the weight of the units can be carried by adjacent units. This is similar to the way that other volumetric building systems work.

ER 2 - Safety in case of fire

Fire resistance, the statutory time that a structure that although weakened, still remains stable after a fire has taken hold, is defined through code requirements An alternative method is achieved by calculating a temperature-time response of materials with an actual fire load using a thermal model. The complex interaction of material strengths, stiffness and load paths can be evaluated by design calculation and finite element thermal modeling, leading to the estimation of a reduced strength for a given time period [36].

Case Study 5 – Hull Premier Inn

The Premier Inn owned hotel in Hull is the tallest structure in Europe to include containers as part of its permanent load bearing structure. A 6 storey modular structure sits above seven-storey car park and hotel reception. The regulatory 2-hour fire performance was re-negotiated with building control inspectors through a 'fire engineering' approach permissible under UK regulations. A predicted fire load with fire evacuation strategy combined with an analysis of steel temperature gains on the steel in the containers led to a 50% saving on fire boarding protection in the units.

ER 5 - Protection against noise

Buildings are susceptible to high levels of external noise and problems with internal noise transmission. Airborne sound tests measure the reduction in noise through walls and floors for sounds at a number of different frequencies with a standard reverberation (decay) time, and adjusted using a sound reference curve to establish a single minimum figure at 500 Hz which is a frequency level corresponding most appropriately to human hearing. Impact sound tests measure the sound level in a room below a floor that is subjected to a standard impact source. Direct sound transmission occurs through a separating structure, but there is also flanking transmission through building elements adjacent to the separating structure being measured.

Acoustic Criteria UK Building Regulations Part E	Measured on-site noise levels D_{nTw} + C_{tr}
Airborne Noise: Separating Walls	> 50 dB (min value 43 dB)
Airborne Noise: Separating Floors	> 54 dB (min value 45 dB)
Impact Noise: Separating floors	< 55 dB (max value 62 dB)

Figure 1. Site Measured Noise and Impact Reductions through separating walls and floors

Figure 1 Shows the noise performance on recent container buildings. Containerized construction benefits from isolation, materials layers and cavities similar to other volumetric systems, but its greater mass also means that it can match the performance of more massive construction.

Case Study 6 - Heathrow Travelodge.

Completed in 2007, this hotel was built directly under the flight path of the second runway at this major international airport. Peak external noise levels above the building were measured to be 100+ dB. The building modules and external envelope accommodated triple glazing and additional acoustic insulation layers. The roof was covered with a concrete slab for sound reduction. This was supported off the units without additional strengthening.

ER 6 - Thermal Performance

Thermal performance of building systems is calculated for the conservation of fuel and power. Under UK national regulations, aspects will include not just the fabric performance, but also mechanical and electrical systems and the regulations specify minimum requirements.

In containerized construction there are two different basic build-ups of insulation materials. In containers where the external surface of the container is left exposed, the walls are effectively a cold frame, and insulation layers have to be built up inside the container, including a vapor barrier on the warm side of the insulation. This becomes problematic when the external shell of the container passes through an envelope to become an internal wall and has to be insulated. Often circulation spaces outside containers are not totally enclosed in order to avoid this issue.

Case Study 7 – MySpace Pod, Will Alsop

MySpace Pod is a prototype student pod with a similar configuration to Tempo Housing with exposed container walls. A significant design challenge with these types of structures is to establish a continuous thermal barrier in order to avoid a cold-bridge forming where the external surface of the container enters the interior, which would otherwise result in significant heat loss and internal condensation.

PART III – PRODUCT DESIGN & PARAMETRIC DIGITAL ARCHITECTURE

Freight Container Product Design

Freight containers come from a customizable product family of modular elements [27] with interchangeable sub-assemblies and component groupings to an ISO standard configuration. Containers are described as having a platform architecture; a platform being a collection of assets with component designs that are shared by multiple products [34]. As a product family on a common platform, these containers meet a variety of market needs [31].

Customisation and Platform Design applied to Buildings

Container buildings use the platform concept for the container units and building designs. In this standard building configuration, a platform architecture approach is being used at two different levels: the ISO standard platform for the containers, and the whole building platform made up of varied configurations of modular building elements.

ISBU's use pre-assembled components of the container such as the rails, walls and corner fittings that create a volumetric box, and it is then further modified for building use, with insulation, linings and internal fittings and finishes added to suit the required internal environment [29].

The units are assembled into the whole building, where the final shape of the building is determined by the arrangement of modules, in response to the overall building site plan, the client brief and the financial model for the number of habitable spaces that need to be provided. In product design terms this is similar to a configurational product family design where a platform is made up from a number of modules that can be added or removed to generate variety [32] [33].

The development of purpose made building units based on a container platform can be described as a top-down approach in product development terms [32] because of the deliberate decision to use an existing universal platform. Similarly, the re-use of containers is a 'bottom-up' process [32] that has emerged and developed through trial and error followed by a rationalization of the design.

Building Information Modeling & Parametric Designs

A further development of the customized container product has been the development of a standard building configuration for hotels and other residential buildings, based on a 'complete building' platform with customizable architecture with clear advantages for a parametric approach to building modeling and production.

Case Study 8 – Pan European Hotel Product

Buro Happold collaborated on a 'pan-European' branded building product with KKA architects based around an optimized configuration of the Verbus System components. The client for the hotels was a budget airline company serving multiple flight destinations at smaller out-of-town airports in Europe. The airline recognized that their flight patterns could change over time, and were therefore interested in a more easily demountable hotel building. The product was designed to an advanced stage with full prototypes manufactured in China and shipped to the UK. However, the project was not taken beyond the prototype stage.

Parametric Designs

Building Information Models (BIM) are used to generate and manipulate building information using 3D parametric data for geometric components and their layouts, allowing building information to be generated automatically. BIM works by using data with object orientated representations that can be extracted and manipulated to show the best building arrangements and therefore improve the decision making process [2].

ISBU's with their container platform lend themselves very well to a design using parametric models. This is in effect a scalable approach to platform design [37], with some constant variables and others scaled in one or two directions, to generate variable forms within the same product family.

Case Study 9 – SnoozeBox Event Hotel

A self-contained flexible hotel product adapted from single-use standard shipping containers. The building can be set up in 48 hours. The system uses proprietary products and standard container components, as well as some purpose-designed elements, such as the off-grid plant services and collapsible external circulation stairs and balconies.

Parametric models have become increasingly sophisticated, having Building Object Behaviors (BOB) with domain expertise embedded into arrangement of elements [16] [38].

This approach has parallels to agile product development practices [1] where economies in variety, cost control and production are achieved in mass customization of a standard product by actively quantifying the costs of variety of solutions during the different stages of the design and production processes, and comparing this data with their design flexibility for modularization and customization.

During the design process, parametric data can be used to assess costs based on element sizes, materials and location. These values can be further refined by considering subjective factors such as commercial competition and quality [12]. An additional dimension to optimization of parametric design and cost data is the use of carbon data to determine building carbon footprint [38]. The combined data for cost and carbon can be assessed iteratively through feedback loops in order to reach optimized solutions.

CONCLUSIONS

The container is multi-dimensional design solution meeting technical requirements for building use that is predicated by the adaption of a pre-existing industrialized product. Containerized buildings have a hybrid construction typology based on a combination of standard container frameworks, volumetric building technologies and more conventional building construction techniques.

Only re-used containers offer the advantages reduced carbon footprint, but newly manufactured units are robust, highly adaptable and easily transported. The purpose-made units benefit from a product family architecture based on an 'open' existing platform design, produced in a mature manufacturing environment. Its ease of transportation combined with low manufacturing costs makes it a viable commercial alternative to many modular and traditional systems.

ENDNOTES

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portation. Initially used for domestic transfer of goods in North America it was later adopted for overseas exports and was progressively standardized worldwide by the International Standards Organization (ISO) from 1968. The full impact of containerization on the world economy is difficult to quantify, but few economists predicted the impact of a system that effectively reduced the cost of international transportation from 30 percent per item to practically nil. Given that container ships can unload and reload in 24 hours, and redistribute goods efficiently through the rail and road network in a process that took weeks and months using break-bulk method it has become very cost effective to manufacture goods overseas.

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    The interchangeable standard sub-assemblies with component groupings create a variety of different transportation units to ISO configuration: standard dry freight container, 'flat-rack' folding containers, insulated containers, refrigerated containers ("reefers"), open top 'bulktainers', open-sided containers for pallet loading, rolling floor containers, 'swap-body' containers (with self-supporting legs) and tank containers for bulk liquids. All have the same support frame, ISO dimensions and corner fittings in common, but they offer the client choice through a catalogue of pre-engineered design solutions.
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