Material change for a better environment

WAS 003-003: Offsite Construction Case Study

Waste Reduction Potential of Offsite Volumetric Construction

Volumetric offsite construction reduces the production of waste to 1.8% through efficient design, continuous process improvement, involvement of the supply chain as well as procurement strategies and, ultimately, erection on site.

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Front cover photograph: Yorkon – Installation of a module on a three-storey designed building.

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Executive summary

Offsite methods move construction site activities into a controlled environment where rationalisation and organisation of the work force into a production line allows manufacturers to achieve high quality standards, high productivity and better overall waste minimisation. Recent reports suggest that volumetric offsite construction systems can reduce waste on site up to 90% when compared to traditional construction.

Volumetric construction is widely used for temporary as well as permanent buildings and covers housing projects, hospitals, hotels, student accommodations and office buildings. The design and manufacturing processes allow the manufacturers to better control the flow of materials and, by involving their supply chain, ensure that the resources necessary for the construction of modules are efficiently used. This integrated design, procurement and management can help to significantly reduce the amount of waste sent to landfill.

Yorkon is a good example of how the integration of the design, manufacturing process and procurement chain can result in reduced wasatge. Overall, Yorkon generates waste equivalent to around 1.8% of the total material use through the manufacturing process. Of this waste, 65% is recycled or reused. Yorkon's achievements have been attained by a better integrated design and material process that involved the supply chain. By ensuring that their sub-contractors deliver products suited to its own needs, Yorkon has been able to reduce the waste due to cutting and adaptation required when using generic construction materials. Furthermore, the Kanban system used for sundries (bolts, rivets, etc) eliminates the need for stock management, and eliminates packaging. Framework agreements with windows suppliers and steel contractors have also help Yorkon to decrease the waste generated at its facilities from 3.6% in 2004 to 1.8%. Table 1 lists the major improvements made to the whole factory process, from inception to completion on site, and the impact on waste.

Table 1: Summary of saved materials and waste generated (Yorkon as an example)

Activities	***Waste generated***		***Waste disposal (%)***			***Saved Material (%)***
	Type	***%***	***Reuse***	***Recycle***	***Landfill***	
Design						
Optimisation of design	None					-50%
Design review	None					
Standard Details	None					
Manufacturing						
Kanban racking and supply system	None	-/-	-/-	-/-	-/-	Packaging (-100%)
Large floor deck	None	-/-	-/-	-/-	-/-	Timber (-100%)
Structure - Walls	Timber	2%	0%	100%	0%	-/-
Steel structure – floor & ceiling	None	-/-	-/-	-/-	-/-	Steel (-100%)
Installation windows & doors						
Wall panels cut outs	Timber	4%	0%	100%	0%	-/-
	Steel	4%	0%	100%	0%	-/-
	Insulation	4%	100%	0%	0%	-/-
	Sundries	Negligible	0%	50%	50%	-/-
Electrical	Wires	Negligible	0%	0%	100%	-/-
Mechanical	Packaging	Negligible	0%	100%	0%	-/-
	Plastics	1%	0%	100%	0%	-/-
	other	Negligible	0%	0%	100%	-/-
Procurement						
Pre-cut steel plate, joist & beams	None	-/-	-/-	-/-	-/-	Steel (-100%)
Steel studs to length	None	-/-	-/-	-/-	-/-	Timber (-80%)
Roofing						
Steel panels	None					Steel (-5%)
1 piece steel flashing	None					
Windows & doors	None	-/-	-/-	-/-	-/-	Packaging (-100%)
Shipping and Site						
Installation and finishes	Various	Negligible	25%	70%	5%	Packaging (-80%)

Contents

1.0 Introduction

Offsite construction methods are techniques that primarily bring construction activities from the building site into the confines of a controlled factory environment. Depending on the degree of sophistication of the method, or the scope of activities, the factory set up allows regular quality checks to be imposed rigorously at strategic stages during the manufacturing process which significantly decreases the risk of errors and, thus, unnecessary generation of waste. Once delivered to site, these offsite products are easily and quickly installed. This shortens the overall site construction programme, decreases the pressure on the project budget and eases the constraints on the critical path of the building process.

Volumetric construction methods are amongst the most effective offsite methods. As such, volumetric (or modular) construction imports most, if not all, of the construction site activities within the factory. The technique consists of manufacturing large modules that are designed and fabricated to include electrical and mechanical fixtures, finishes (interior and exterior) and fixed furniture such as sanitary ware.

2.0 Volumetric Construction

In North America and Europe, volumetric (modular) construction has been associated with temporary buildings. These temporary buildings had to be rapidly built and delivered, with a minimum disturbance on site. Manufactured modular buildings were perfectly suited for these purposes and were adopted as temporary structures.

The factory based production lines of modules are very efficient and allow quality control at critical times through the construction of the modules. Today's modular building covers a large spectrum of applications with examples listed below.

- Housing
- Hospital (operating theatres as well as rooms)
- Schools
- Hotels (low and medium rise)
- Multi-storey office blocks
- Multi-storey apartment blocks
- Temporary accommodation on construction sites (office, social room, show rooms, etc.)
- Temporary offices and classrooms
- Ministry of defence complexes and housing (temporary or permanent)
- Student residences

The main forms of volumetric construction in the UK include:

- **Shipping Container**: This method relies on the strength and flexibility of the shipping container designs. These elements are delivered in 2.5m wide by either 20m or 40m long. The interior is complete with fixtures and fittings for temporary offices, toilets, storage, kitchens. The main use of these stackable container-like structures is in risk areas such as construction sites.
- **Rigid frame construction**: This method relies on a main rigid structural steel frame that is then completed with a roof and walls. This system allows for side and end walls to be left open to create large interior spaces. The level of finishes varies to suit the client needs. This system is used for permanent or temporary buildings.
- **Panelised system**: These modules replicate the timber or light steel frame methods, and are generally designed for permanent construction in housing or small offices. The structural stability relies on the diaphragm effect of the walls, floors and ceilings.

Whichever construction system is used, the manufacturing process remains precise and controlled, which ensures high structural resistance for transporting, lifting and high quality levels of finishes. This report however focuses on the waste minimisation potential of rigid frame construction.

2.1 The system

Volumetric offsite construction methods are the ultimate example of transferring construction site activities to a controlled factory environment where quality control can be applied to both materials required for the construction of the modules, as well as the finish product. Furthermore, the construction tasks are divided in such a way that the production of modules replicates, to some extent, automotive production lines.

In general, the manufacturing of the modules will include the following groups of activities:

- Floors
- Main frame
- Walls
- Ceilings/roof (including mechanical and Electrical)
- Exterior finishes
- Interior Finishes

The first step in the factory process is the assembly of the floors. These would typically comprise either hot-rolled section welded together or galvanised cold formed profiles bolted/screwed together. A weather board is then fixed on the underside of the floor structure to prevent moisture accessing the floor voids and the insulation laid between the joists. The floor deck is composed of plywood or alternative materials such as Fermacell[1].

At the same time, the modules main frames are composed of stronger structural elements that are attached to the floor structure. The steel frame is designed to sustain the performance load of the finished building as well as the temporary lifting and transport loads.

Walls are generally manufactured as in-fill panels that are attached to the rigid frames. The walls can be either, composite panels (steel composite panels, structural insulated panels, etc), timber or steel frame - prefabricated in-fill panels or timber or Steel frame – stick built.

In the case of composite panels, a variety of interior and exterior finishes can be applied to the insulation core.

Ceilings can also be pre-fabricated and installed directly on the rigid frame or, in some instance, be directly built from the rigid structure itself, depending on the manufacturers working methods. In most cases, however, the ceiling is designed as a roof system so to provide protection to the modules against weather conditions during transportation and installation on site.

Substantial electrical and mechanical installation is also carried out at the factory as a sequential process to the erection of the floor, ceiling and walls. The interior is finished in accordance with the clients' schedule and requirements. The exterior finishes can be applied either off-site in the factory or on site.

Once delivered to site, these modules are bolted together. The activities on site, for the whole project, are then limited to groundwork and foundations, assembly of modules (requires a crane), minor finishing work to the exterior elevations, minor finishing work to the interior walls, floor and ceilings, connections to mains and commissioning.

The time required on site is limited and allows the potential for better resource management.

[1] *Fermacell is a high performance multi-purpose board for walls, ceilings and floors. It is fibre reinforced plasterboard manufactured from a high proportion of recycled materials in a fully recycling process.*

2.2 Market

In 2005, the value of the volumetric market was considered to be £200m excluding temporary modules and bathroom and kitchen pods.

The major manufacturers in 2005 included the following; listed alphabetically:

- Britspace Modular Buildings
- Caledonian Building Systems
- Elliott Group
- Portakabin
- Rollalong
- Terrapin
- Thurston Building Group
- Unite
- Waco
- Wernick
- Yorkon

Imports are marginal in this sector, estimated at less than 2% and exports even lower at less than 1%. The level of added value achieved within the factory produced element appears to vary significantly between the manufacturers, with some producers delivering up to 85% of the finished building value in the factory.

2.3 Volumetric and waste

Volumetric manufacturers offer their clients a complete package that includes design, manufacture, delivery and assembly (including finishes) of the modules on site. Some of the manufacturers act as principal contractors on some projects and carry out the groundwork, foundation and landscaping activities. In this case, the manufacturers would sub-contract groundwork and foundations to companies with whom they have framework agreements. This ensures that the complete building, be it a house or a hospital, is designed and built following the same rigid manufacturing/factory led mentality and drive, to the same tight tolerance and to the equivalent rigorous quality levels.

Bearing in mind that modules sent to site are almost completely finished, the work required on site is rather limited and, hence, generates a negligible amount of waste. On site, the installation of volumetric modules generated waste through excavation waste, small amounts of concrete from foundations, small amounts of plastic packaging from independently delivered items, some packaging and protection necessary for transportation and protection of the modules, small amounts of waste generated by assembly of modules on site (e.g. finishes at junctions).

Using volumetric construction has been estimated to reduce waste on site by between 70% and 90% of what might be generated using more traditional construction approaches[2].

This case study utilises data from Yorkon to demonstrate the potential for waste reduction through the use of volumetric modules produced in a modern manufacturing facility and its impact on the overall generation of construction waste.

[2] *WRAP. "***Current Practices and Future Potential in Modern Methods of Construction – Final report***". 2007. Document available on www.wrap.org.uk*

3.0 Yorkon

For over 25 years, Yorkon has developed a solid reputation and thrives to provide its clients on time and on budget. Yorkon has been working closely with suppliers in order to improve its efficiency and significantly reduce the amount of energy used and waste generated within its own factory. This approach also prevails when designing modules to ensure that the end client benefits from the best practices in sustainable construction methods and materials.

As a subsidiary of Portakabin, Yorkon is part of the Shepherd Group – one of Europe's largest privately owned building companies. Established in 1890 by Frederick Shepherd, the Group now employs around 4,000 people worldwide and has a turnover of £600m. It is still controlled by the Shepherd family, giving it complete independence and a strong financial base.

3.1 Yorkon's attitude towards waste

Overall, Yorkon generates waste equivalent to around 1.8% of the total material use through the manufacturing process. Of this waste, 65% is recycled or reused.

Compared to other offsite methods, volumetric construction encompasses a wider scope of activities and complexity, including electrical and mechanical installations as well as various fittings and finishes. Therefore, the whole design and manufacturing process has been developed in order to provide the design and manufacturing teams with the best tools and management systems to ensure a continuous and smooth construction process that alleviates unnecessary wastage of time and resources.

Yorkon's commitment to the protection of the environment has led the company to consider all the aspects of the manufacturing process from inception through to delivery and final connections on site. Yorkon has identified various elements and procedures that required major improvements to the manufacturing process in order to be more sustainable and remain competitive. As for most of the industry, Yorkon has put in place some simple steps to improve their productivity, reduce wastage of resources, and to lower their impact on the environment. Such measures are as follows:

- **Involving the project's architect**. Early commitment of the manufacturer in the design is of prime importance. The design team work with the architect to adapt their design and integrate the limitations and opportunities of volumetric buildings. By working closely together, the designer team and the architect avoid unnecessary waste of resources and prevent costly errors in the manufacturing process due to misunderstandings.
- **Involving the supply chain**. Yorkon's suppliers are heavily involved in helping the company minimise the generation of unnecessary waste. In doing so, and considering the volume of materials used yearly by Yorkon, it has been possible to develop product lines that suit the needs of volumetric construction rather than the volumetric methods trying to advocate standard construction materials. Furthermore, by appointing preferred suppliers, the company also ensures that the delivery mechanisms eliminate non-reusable packaging.
- **Using sustainable materials**. Yorkon, in partnership with its supply chain, makes sure that the products used in the construction and the finishes of its modules are based, as much as possible, on components containing recycled content.
- **Continuous improvement.** Each month, the Director's board looks at the efficiency the process, including the impact of the process on the generation of waste. Specific areas of the production line are identified as needing review which, then, involves the management, the employee and the supply chain into finding appropriate solutions to wastage.
- **Monitoring and informing**. The factory led production allows the management team to precisely monitor the waste generated by the company's activities both in the factory and on site. By constantly reporting the generation of waste, recycling activities and the input from the supply chain, management are then able to identify where there are needs for improvement with the help of the personnel on the factory lines. To ensure that the objectives are met, information boards have been erected all over the factory floor to ensure that all employees and visitors are well aware of the procedures implemented and of their progress to date.

- **Working with the mother company**. Yorkon is a subsidiary of Portakabin. The products for each brand are manufactured in different buildings, but on the same site. Close cooperation between the management teams ensures that a high level of integration of suppliers bring the same benefits to the two businesses. Furthermore, where possible, waste generated by one line is reused by the other line.
- **Involving waste contractors**. Waste contractors are engaged in order to help Yorkon to ensure that all waste across the two businesses are properly sorted and recycled. These contractors are responsible for guiding the company's staff and proposing means of capturing waste, training the staff and ensuring that the implemented waste management procedures are followed.
- **Ensuring continuity of the factory approach to the construction site**. Volumetric construction involves limited work activities on site. However, the environmental and waste minimisation efforts invested in the factory are also reflected in the erection activities on site.

3.2 Waste: everyone's involvement

Conscious of the advantages offered by manufacturing facilities over construction sites, Yorkon has carried out a study to determine its overall energy efficiency. This study has identified areas where energy requirements could be reduce and estimated that the manufacturing process of volumetric construction compared with current traditional practices reduces the overall energy consumption by up to 67% and reduces travel to site by up to 90%. Although not directly impacting on the amount of waste on site, these figures show how offsite construction could help to meet the government's target on CO_2 emissions generated by the construction industry.

Yorkon encourage its workforce to participate in training and seminars on waste minimisation and energy savings. These forums help the management team and the staff to better understand the manufacturing process in terms of waste generation and allow the staff to propose new ways to tackle these issues. By involving the personnel at every level, the manufacturer also ensures that the new procedures implemented are well understood and backed up by the people expected to perform them on the factory floor.

To help and encourage, the manufacturer also implemented a series of prominent boards that clearly provide information on the aims of procedures, the specific objectives and the actual performance. This system has created a sense of responsibility amongst the workforce and, thus, improved the outcome of those procedures.

3.3 Estimation and Design Stage

Compared to other offsite solutions, volumetric (modular) building manufacturers have the advantage of being able to control most of the structural design and can better judge the implications on the structures of all components and work carried out by all the different trades.

Most of the clients contracting volumetric (modular) manufacturers such as Yorkon have had successful experience in adapting their projects to volumetric construction methods. In these instances, the estimation and design process is straight forward. However, for new clients, and as long as it is accepted that the original design could be adapted within limits to volumetric construction, the design team will spend time with the clients and their agents in order to ensure that the final design will meet the requirements and performance expected from the building, as well as respecting the architectural approach. By working closely with the clients, the manufacturer also ensures that the final design is fixed before the start of the manufacturing process. This avoids costly changes to the modules under construction, and, hence, saves unnecessary waste.

Once the client has finally approved the scheme, the design engineer will prepare manufacturing and erection drawings, and issue a bill of materials. The Kanban software used also optimises the use of materials through the manufacturing process and identifies the materials to be procured from the suppliers with considerations to the order already placed for similar components for projects under manufacturing at the time. This helps to reduce the amount of deliveries to the factory and reduce the waste due to over-ordering. Furthermore, the engineer will also try to reduce the amount of unnecessary materials and waste by considering a number of aspects.

- **Amount of materials**. The design process permits the engineers to quantify the exact number of screws, brackets and ties required for each building. The designer will issue an exact bill of materials for all of the required materials.

- **Number of different parts**. The design engineer will also ensure that, for each of the panels, the number of different parts is limited in order to avoid errors during the manufacturing process.
- **Use of generic details**. The designer will also create the building using a limited number of standard details. These few standard details are well known by the factory and erection crews, thus, reducing the risk of errors and waste.
- **Design review**. All information for each of the buildings to be manufactured is reviewed by the design and manufacturing teams. Comparisons are made with other similar constructions to identify any omissions and design errors that might have occurred. This procedure has proven to be an important step in reducing the costs of errors and any unnecessary delays.

The estimation and design stages represent very important steps in the optimisation and reduction of the use of resources (personnel and materials) and of waste throughout manufacturing and erection processes. Furthermore, careful planning of the manufacturing process and rigorous management of the stocks led Yorkon to reduce by 50%, the waste sent to landfill since 2004. Yorkons manufacturing process generates 1.8% waste of the overall quantity of the materials used, of which 65% is recycled.

3.4 Manufacturing of Modules

The production of modules consists of a series of steps, each of which has specific tasks. Each of the components is designed to optimised the manufacturing process and ensure waste minimisation.

3.4.1 Floors

Floors can be made of hot rolled steel sections welded together, or constituted of galvanised cold formed joists and beams bolted together. In both cases, the cutting pattern of the structural components from standard lengths is carefully planned to reduce, if not eliminate, wasted materials. However, the steel off-cuts are collected in designated skips and sent to the suppliers for re-cycling.

The floor decks are typically constituted of chipboard. Because the standard construction size does not always suit the floor dimensions, there is a small amount of timber based waste. In most cases, this timber based product is either burnt in a wood furnace or sent to landfill. However, Yorkon has worked with its suppliers in order for the floor deck board manufacturer to deliver panels that suit the dimensions of the floor frames. This had a direct effect on the productivity of the floor line by reducing the amount of operations required, and eliminating the production of timber based waste.

3.4.2 Walls

The wall construction adopted by Yorkon is a composite panel consisting of one layer of Fireline board and one layer of Plastisol-coated steel on either sides of a polyurethane insulation layer. The boards are kept apart by timber studs and foam spacers. The panels are designed to sustain the loads for transportation and lifting, as well as to limit the air infiltration through the wall itself. The standard assembly details also provide instructions to limit air infiltration through the interfaces with floors, ceiling and adjacent panels.

The wall panels are manufactured to be of the length of the wall in order to avoid redundancy in the structure, thus limiting the use of materials and resources. Furthermore, Yorkon has recently introduced a lower density material for insulation (40 kg/m^3 instead of 45kg/m^3). This change in insulation specification, whilst having limited impacts on the thermal performance of the panels, has reduced the quantity of insulation materials used per unit built.

Windows are installed in openings cut out of the wall panels. The offcuts are recovered and stripped. The steel is stripped and sent for recycling, whilst the insulation is reused for floor insulation of standardised Portakabin

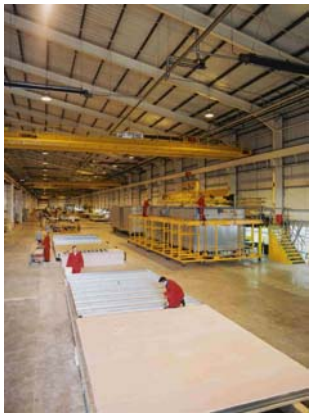
closed modules. Therefore, the production and assembly of wall panels does not generate any waste that is sent to landfill.

Three years ago, Yorkon established that packaging constituted the largest area of waste generation through the manufacturing operations. Since then, Yorkon has worked with its supply chain to ensure that such waste would be eliminated. Windows, for examples, are now delivered to the factory on steel stillages that are return to the window manufacturer for reuse.

Packaging for ancillary items was also one of the biggest generator of cardboard waste. Yorkon, in cooperation with their suppliers, have rationalised and standardised the dimensions of the fixing, screws, bolts, etc to limit the number of different sundry items integrated into the construction of the modules. The system currently in place allows the suppliers to tour the factory with a small vehicle every two days and to replenish the sundry racks (Kanban) at each work station with supplies that are about to run low. By applying this method, Yorkon and its suppliers have eliminated all needs for packaging, reduce the time lost by the labour for fetching supplies from the stock store, and efforts for keeping/managing stocks in stores.

3.4.3 Ceilings and roofs

Ceiling and roof elements are also assembled together prior to being fixed onto the main structure of the module. As explained previously, the ceiling/roof is designed to be weather tight to provide protection to the interior of the module during transportation and installation on site.



Yorkon has adopted the same buyer-supplier approach to the design and procurement of the components of the ceiling and roof panels. All structural elements are made of galvanised pre-punched steel plates that are delivered on specially designed steel racks. These racks are returned to the suppliers for reuse. The production process of the plates follows the same requirements of optimisation of the use of materials than those described for the construction of floors. Similar procedures are applied to recycling of the unavoidable steel waste.

The roof steel panels covering the modules have been designed by the suppliers to suit the standard roof dimensions of the modules. These are pre-cut and sent to the factory in specially designed racks that are returned to the suppliers for reuse. Likewise, the flashing are manufactured by the suppliers in single lengths and delivered to the factory on special racks that are also returned for reuse.

As for the wall panels and the floor construction, the ceilings and roofs production generates a limited amount of waste (sealant cartridges, plastic covering, etc.) that is segregated in specific skips and sent for recycling.

The Kanban system explained in the wall panel sub-section applies to this section of the factory.

3.4.4 Mechanical and Electrical Equipment

Yorkon has worked with its supply chain in order to ensure that the amount of packaging is reduced to a minimum. The utilisation of reuseable stillage and containers have helped the operations to significantly reduced the amount of packaging cardboard and plastic dealt with at the factory. Wherever there is unavoidable packaging, the subsequent plastic, cardboard and polystyrene waste is sent for recycling.

Electrical waste is now negligible. Again, close cooperation between the manufacturer and its suppliers has evolved enabling electrical wiring to be delivered ready for installation. The marked cable and wiring are installed as indicated on the electrical drawings and does not require cutting other than the preparation of the wire ends for connections. This procedure eliminates waste such as copper wire and cables, timber and cardboard reels.

Plumbing is now carried out with push and lock plastic systems. Currently the waste generated by this activity is recycled.

3.4.5 Finishes

In traditional construction, the fitout phase generates a significant amount of waste. However in volumetric modules the waste generated by finishes is limited to packaging (plastic and cardboard, plastic tins, sealant cartridges, etc). Moreover, due to the large volume of materials used, the optimisation process and management put in place at Yorkon eliminates waste due to spoilage, accidents, over-ordering, etc. Only this rationalisation of the use of finish products based on the factory's overall needs, thus not project specific, can achieve such a dramatic reduction of waste in comparison to the same activities on site.

3.5 Delivery to site

Once the modules are completed, they are loaded on lorries and transported to site. As explained earlier, the roof/ceiling structure is designed and built so to provide weather protection to the interior finishes. However, some of the modules may have open sides, or interior wall finishes that need protection from weather and transport. Yorkon, like some of its competitors, has developed a curtain system that protects the interior of the modules during transportation. Once the modules are bolted together on site, these curtains or transport sheets are brought back to the factory for reuse.

On site, the modules are lifted from the lorry and put into place using a crane. The connection to the services and to adjacent modules and foundations are made within a few hours. Some of the finish has to be completed on-site. This is normally carried out as the erection process continues. All materials are supplied in measured quantities sufficient to carry on the work required with any remaining materials returned to the factory.

Overall, the deliveries of modules to site and their installation on site do not produce waste. Moreover, compared to traditionally managed sites, the number of deliveries is considerably reduced, thus impacting positively on the CO_2 emissions and the CO_2 footprint of the building.

4.0 Conclusion

Volumetric construction represents the offsite method that brings the most trades and operations from the construction site into a protected and controlled factory environment. The manufacturing process encompasses the design and manufacture of the structural elements of the building as well as installation of electrical and mechanical equipment and all finishes (interior and exterior). Because of the factory and the production line approach applied to the in-house construction process, quality controls are rigorously applied at all critical stages of the assembly of the components, and then to the complete modules. The controlled environment also allows the labour force to apply the finishes in the optimal operation conditions which, in turns, reduces the potential waste associated with errors, accidents or snagging.

Not surprisingly, volumetric construction can reduce the amount of waste generated on an equivalent traditional construction site by up to 90%. As an example, Yorkon's manufacturing process generates 1.8% waste of the overall quantity of the materials used, of which 65% is recycled.

Volumetric manufacturers have the opportunity to better control the flow of materials and to analyse the waste generated by their activities. Such an approach has allowed companies like Yorkon to reduce the waste sent to landfill by 50% (from 1.2% to 0.6% of the total weight of processed materials) since 2004. The company has put plans and programme in place to further reduce the amount of waste sent to landfill to 0% within the next three years. This target can only be achieved with the cooperation and involvement of the work force, as well as the commitment of the supply chain. Already, Yorkon has been able to eliminate timber waste generated by the

floor assembly line by agreeing with the floor board manufacturer that floor board should be delivered in one single platform, and to the specific dimensions of the module.

Cardboard packaging used for sundries (screws, bolts, rivets, etc.) created a significant amount of waste that had to be segregated and sent for recycling. Here again, discussions with the suppliers led to a supply system by which each work station is now equipped with a standard rack that is re-supplied every two days by the suppliers directly from small vehicles touring the factory.

Waste minimisation is recognised by the Yorkon management team as an important responsibility towards the protection of the environment as well as a mean to reduce production costs, thus increasing their competitive position in the market. Table 1 summarise the waste reduction and minimisation achieved by Yorkon.

Volumetric offsite construction also impacts the carbon footprint of the building by reducing the total number of deliveries to sites by 90%, by decreasing the average travel distance of the labour force to the site by 75%, and by ensuring that the waste generated at the factory is segregated at source and recycled appropriately. The report "*'CO_2 emissions from use, scrapping and manufacture of modular buildings"* recently published by Arup Research and Development stated that up to 67% less energy is required to produce a modular building compared to an equivalent traditionally built project.

Overall, volumetric (modular) construction is an effective method that provides high quality buildings whilst significantly reducing the energy demand and waste production.

Table 1: Summary of saved materials and waste generated (Yorkon as an example)

Activities	*Waste generated*		*Waste disposal (%)*			*Saved Material (%)*
	Type	*%*	*Reuse*	*Recycle*	*Landfill*	
Design						
Optimisation of design	None					-50%
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Structure - Walls	Timber	2%	0%	100%	0%	-/-
Steel structure – floor & ceiling	None	-/-	-/-	-/-	-/-	Steel (-100%)
Installation windows & doors						
Wall panels cut outs	Timber	4%	0%	100%	0%	-/-
	Steel	4%	0%	100%	0%	-/-
	Insulation	4%	100%	0%	0%	-/-
	Sundries	Negligible	0%	50%	50%	-/-
Electrical	Wires	Negligible	0%	0%	100%	-/-
Mechanical	Packaging	Negligible	0%	100%	0%	-/-
	Plastics	1%	0%	100%	0%	-/-
	other	Negligible	0%	0%	100%	-/-
Procurement						
Pre-cut steel plate – joist & beams	None	-/-	-/-	-/-	-/-	Steel (-100%)
Steel studs to length	None	-/-	-/-	-/-	-/-	Timber (-80%)
Roofing						
Steel panels	None					Steel (-5%)
1 piece steel flashing	None					
Windows & doors	None	-/-	-/-	-/-	-/-	Packaging (-100%)
Shipping and Site						
Installation and finishes	Various	Negligible	25%	70%	5%	Packaging (-80%)

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