Modularization impact to product end of life cycle

Viktoria Bashkite, Roman Zahharov
Tallinn University of Technology
viktoria_bashkite@yahoo.com, roman.zahharov@gmail.com.

Abstract
The emergence of green construction solutions as the combination of environmental and economic opportunities has been driving several construction related industries towards usage of approaches provided by the green building movement. Within construction industry modularization of building and right green engineering of product life cycle emphasizes these and related issues. It is very important to consider every period in a product’s life cycle management due to its use of energy (producing, running, maintaining, recycling and disposing). The objectives of this paper are comparison of different modular building types versus conventional construction and overview of possibilities with regards to material consumption at the end-of-life phase through Design for Destruction approach (DfD). Life cycle expectancy of modular building, regardless of its type, is at least the same as of conventional one. While importance of sustainability is gaining momentum with every day, world leading companies in the construction industry are as well seeking for effective solutions, modularity is one of them. There are several fundamental principles intrinsic with the modular construction process, which makes it more eco-friendly than conventional construction. There is no experience with modular building landfilling since 1986.

Keywords
Product life cycle, end-of-life strategies, modular building

1. Introduction
What humans have not done to destroy and harm the natural atmosphere and eco-system of this world and what a man is not doing to save the earth again? It is a positive sign that many people are heading towards much eco-friendly alternatives in all areas of their lives. Even the manufacturing sector has realized the importance of earth saving alternatives and the productions are now based on reusable resources and materials. Yet still the most important role in this cause can be played by the smart modifications that should be employed. The main objective of this paper is to show on practice how different end-of-life manufacturing principles can be applied to several building construction types through its modularization. Speaking more precisely, research will touch comparison of different construction buildings, product’s life cycle engineering perspectives, real-life implementation benefits and consequences and the possible end-of-life opportunities [1]. The scope of this paper is to describe possible real life case study: design for deconstruction.

2. Modular building types
There are 5 different types of modular buildings:

- **Type I** – typically, concrete frame buildings made of noncombustible materials. All of the building elements (structural frame, bearing walls, floors and roofs) are fire resistance rated.
- **Type II** – these buildings are constructed of noncombustible materials. Typically, masonry bearing walls structures with steel studs for walls and steel bar joists for floor and roof structures. II-A has fire rated building elements (structural frame, bearing walls, floors and roofs). II-B is the most common construction type for commercial buildings because the building elements are not required to be fire resistance rated but still must be noncombustible.
- **Type III** – construction in which the exterior walls are made of noncombustible materials and the interior building elements are of any material permitted by the code (combustible or noncombustible). This is typical of buildings with masonry bearing walls and wood roofs or floors.
- **Type IV (Heavy Timber, HT)** – type of construction in which the exterior walls are of noncombustible materials and the interior building elements are of solid or laminated wood without concealed spaces.
- **Type V** – typically wood frame construction. Type of construction in which structural elements, exterior walls and interior walls are made of any materials permitted by the code.

If we look at all these types the definition of modular building can be next: “An off-site project delivery method used to construct code-compliant buildings in a quality-controlled setting in less time and with less materials waste.” This definition is not limited to Type V construction. While Type V construction is much more prevalent within the modular industry, several companies have successfully designed and built all types of facilities for a multitude of purposes utilizing modular construction processes [2].
2.1. Comparison of modular building and conventional construction

Modular construction holds many advantages when compared to conventional construction. Relocate and reuse the modular room is the first serious advantage. All the components are 100% reusable. The number one reason for buying modular office is the ability to take the building down and relocate it. This feature benefits the small firm that leases because the modular rooms always remain their asset, when it is time to move, the modular rooms can go with them. This feature also benefits the larger company. Should their needs change and the modular room would be better suited elsewhere then it can be moved and they never lose their original investment.

Companies grow, needs change and so can the modular room; redesign your office - adapt to new requirements. Whether you need more space or need to change your current modular room configuration you are not locked into your original design. All panels are interchangeable and can be assembled to fit any current need. The non-progressive post design provides the ability to swap or replace individual panels without disturbing adjacent panels. For example, if a solid wall panel now requires a door it can be switched out for a door panel in a matter of minutes.

Stronger construction - suited for an industrial environment. Many rooms today are built using drywall and studs, leaving unsupported cavities that can be punctured easily. Modular office rooms use much stronger materials and utilize an important design feature, fully supported wall substrates using either insulated polystyrene or honeycomb cores; this gives the walls true impact resistance for long useful life. In addition the availability of steel facings adds even more strength.

Better sound deadening than conventional rooms is also a great benefit comparing to conventional offices. Modular enclosures create a comfortable work area even in the loudest manufacturing plants. Installing an industrial modular room is more than just putting up walls; it involves utilizing a system that will meet the specific requirements of the plant. One of the most important requirements is sound control, without the proper sound control a room could be rendered useless.

Faster occupancy provides the fast come back to business. Modular building installation is faster up to 75% than stick-built. The standard small modular room is assembled and ready to move in, in one day, with conventional construction that time can be weeks. Weeks of sub contractors and inspections can put any company behind schedule and this can translate directly into money lost. The faster you are back to normal the faster you get back to business.

Modular building construction reduces labor costs by up to 50%. This could be a very conservative figure considering the installation speed of modular offices products and the reduction in trades necessary to build, the savings are tremendous. It takes only one crew to assemble a modular offices building, and several trades like glazers, painters, carpenters etc. to build conventionally the larger the project, the more the savings.

Fewer plant disruptions - minimize productivity loss that can cause expensive loss of productivity. All construction even modular causes plant disruption, however the longer it takes to complete a project the more disruption gets. A serious evaluation of costs would include this often over looked expense; most people are amazed how fast these costs add up. For an estimate, multiply the number of people in the area of construction by just 10 minutes of distractions, then multiply that by the number of days it takes to complete the project, from this you can determine the number of hours lost, now multiply this by the average cost per labor hour. The loss of productivity is real and expensive.

Less mess to contend with construction process means lower cost. Sealing off areas, and detailed cleaning of equipment all can be expensive for the average industry, but if a company is involved in food processing or clean environments the costs to shut down and handle this are enormous.

Permits are not always needed. Small modular rooms within a plant can usually be assembled without permit. This is never the case with conventional construction; it always requires a permit and can tie up a project for weeks. Of course, everything depends on country laws where the project has to be executed.

Quality of modular office is much higher than conventional one. Modular product is quality inspected before it ships and is manufactured to exact standards. The finished product is never questionable, a clear point that conventional construction can not make. How good is conventional construction? It depends on the work crew. The truth is that most construction, if not closely watched can turn into a disaster. Table 1 describes all the differences between modular and traditional home buildings.

2.2. Costs savings

It proved that it is possible to save up to 33% over conventional methods. The reason is high speed and automated manufacturing processes. This productivity can not be matched by any construction crew. As any experienced builder can tell you, site construction is labor intensive and expensive. Simply put, modular products are reusable. When the change is needed there is no lose in investment, re-use it. Compared to conventional methods, that's like getting materials free over and over. Thousands of modular building users benefit from this advantage every year. There are no dumping fees to remove demolished construction. All these savings are aside, there is something far more important; the environmental impact. Reusing modular building because of relocation or by changing a configuration is recycling at its best. This is a very important aspect of modular product life cycle design, because the importance of conservation is taken into account.

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### Table 1. Comparison table Modular building versus traditional construction methods [4].

<table>
<thead>
<tr>
<th></th>
<th>Modular homes</th>
<th>Traditional homes</th>
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<tbody>
<tr>
<td><strong>Build codes</strong></td>
<td>Modular homes are treated as traditional homes and must follow the local building codes and regulations. Also it must follow local zoning regulations.</td>
<td>Traditional homes are subject to the local buildings codes and to the local zoning regulations.</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>No construction occurs until the homeowners pick the design. Most builders provide sample plans to help guide you in your customization. Modular homes are normally highly customized in their interior and exterior appearances. In some cases it is even possible to have your personal architect design a home and then forward the plans to you modular building centre.</td>
<td>Can be customized to the owner’s preferences. Sometime developers will buy large plots of land, divide it into smaller plots and build identical homes next to each other. You can also hire an architect to design your home according to your preference or purchase home plans online and then hire a contractor to follow those plans.</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>These homes are built in a climate controlled factory using high quality materials and more precise building techniques that are capable inside a factory. Modular homes are intentional designed with additional insulation and other energy savings to reduce your maintenance costs.</td>
<td>Since they are built on-site in all types of weather the quality of the product varies greatly. Research has shown that traditional homes are more likely to require repairs and higher maintenance costs.</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Modular homes increase in value over time. Once they are completed it is near impossible to tell the difference between traditionally built homes and modular homes. These homes can also be improved or expanded.</td>
<td>Traditional homes will increase in value over time. They can be improved and expanded to accommodate new owner’s preferences.</td>
</tr>
<tr>
<td><strong>Resell value</strong></td>
<td>Appearance can be the same as any traditional site-built home. You can add any style of window, door, wall or architectural feature you prefer. Once completed you can not tell the difference between modular and traditional homes.</td>
<td>The appearance can be customized to the home owners’ preference. Traditional homes can accommodate any architectural preference.</td>
</tr>
<tr>
<td><strong>Timeframe</strong></td>
<td>This normal timeframe is 8-14 weeks. There are some time savings since construction can begin in the factory at the same time your foundation is being created on your site. Also weather has almost no impact on the schedule.</td>
<td>The normal timeframe is several months. Since all construction occurs on site, work projects can not start until the previous project is completed. The work schedule is dependent on the weather conditions.</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td>It enjoys the benefits of assembly-line building. In a manufacturing factory. The removes delays cause by the weather and vandalism damages. This more efficient process reduces the cost when compared to traditional homes.</td>
<td>The most costly building process which requires almost the entire house to be custom constructed. It will require more people which will take more time since they do not work on the same type of house everyday. It is also vulnerable to weather delays and vandalism costs. This process is the most likely to result in damaged building products like warped wood from rain exposure.</td>
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#### 2.3. Seven reasons why modular building is Green

How are modular structures more beneficial? Modular construction techniques have been shown to be inherently advantageous in 7 major areas:

- Less materials waste – pre-fabrication makes it possible to optimize construction materials purchases and usage while minimizing on-site waste and offering a higher quality product to the buyer. Bulk materials are delivered to the manufacturing facility where they are stored in a protected environment safe from theft and exposure to the environmental conditions of a job site.
- Less material exposure to inclement weather – many of the indoor air quality issues identified in new construction result from high moisture levels in the framing materials. Because the modular structure is substantially completed in a factory-controlled setting using dry materials, the potential for high levels of moisture being trapped in the new construction is eliminated.
- Less site disturbance – the modular structure is constructed off-site simultaneous to foundation and other site work, thereby reducing the time and impact on the surrounding site environment, as well as reducing the number of vehicles and equipment needed at the site.
- Safer construction – modular construction is a safer alternative. Conventional construction workers regularly work in less than ideal conditions dealing with temperature extremes, rain, wind, or any combination of natural conditions. This, by its very nature, is a much more challenging environment to work safely in. Additionally, the potential for injury including falls, the most common work site risk, is much higher. In a factory controlled setting, each worker is typically assigned to a work station supplied with all the appropriate equipment needed to provide the safest work environment possible. Off-site construction also eliminates the hazards associated with materials, equipment and an incomplete construction processes typical of construction sites that can attract curious and unwelcome “visitors” (i.e. students on a school expansion project).

- Flexibility – when the needs change, modular buildings can be disassembled and the modules relocated or refurbished for their next use reducing the demand for raw materials and minimizing the amount of energy expended to create a building to meet the new need. In essence, the entire building can be recycled in some cases.

- Adaptability – modular buildings are frequently designed to quickly add or remove one or more “modules” minimizing disruptions to adjacent buildings and surroundings.

- Built to code with shorter build times – the bottom line is that with modular construction you can get a facility built to the same local codes with construction quality as good as or better than a comparable site built building in much less time. Additionally, the abbreviated construction schedule allows you to get a return on your investment sooner while minimizing the exposure to the risks commonly associated with protracted construction schedules [5].

3. Modular building end of life cycle planning

Under ideal circumstances, buildings would be designed for deconstruction and built using materials recovered from other buildings that themselves had been designed for deconstruction. In reality, unfortunately, it is not yet possible to achieve a closed-loop building life cycle (i.e., to eliminate the need for any new materials or systems). But adhering to life cycle construction principles whenever possible can provide meaningful benefits by reducing the energy and resource consumption required to produce the necessary building materials and systems and by reducing solid waste. In the near term, three specific life cycle construction practices will be offering the greatest potential:

- Demolition – destruction of older buildings that were not designed for deconstruction, with reuse of salvaged materials in other building projects whenever possible;

- Design for Deconstruction (DfD) and Materials Reuse – construction of new buildings using DfD principles and, where possible, incorporating salvaged building materials; and

- Green Building – retrofitting and new construction of buildings to include green building elements such as sustainable site planning, energy efficiency, safeguarding water and water efficiency, conservation of materials and resources, and improved indoor environmental quality. The main idea of Green Building is the closed-loop life cycle of it. The life cycle of it is known from the beginning till the end.

In this article, the DfD will be described more precisely; due to the result of this procedure is more perspective from every point of view; economical and environmental.

4. Design for Deconstruction

The ultimate goal of the Design for Deconstruction (DfD) movement is to responsibly manage end-of-life building materials to minimize consumption of raw materials. By capturing materials removed during building renovation or demolition and finding ways to reuse them in another construction project or recycle them into a new product, the overall environmental impact of end-of-life building materials can be reduced. Architects and engineers can contribute to this movement by designing buildings that facilitate adaptation and renovation. What was yesterday a functional building is today a worthless pile of rubble sitting on the site for all to see. However, the real benefits of deconstruction – including Designing for Deconstruction (DfD) – is about closing the loop of resource use. It is about reusing these “waste” resources to avoid logging or mining new virgin resources from our ecosystems. Designing for Deconstruction is about designing in such a way that these resources can be economically recovered and reused. In contrast to the conventional linear model of extraction, use, and landfilling, DfD envisions a closed cycle of use and reuse [6].

4.1. What determines if buildings get deconstructed?

Deconstruction is often discussed primarily as a strategy to meet environmental goals, but it can meet social and economic goals as well. There must be an infrastructure of contractors skilled in deconstructing buildings, the cost of deconstruction and the recovered materials must be competitive with alternatives, and there must be a market for the recovered materials. Some of the key factors determining if buildings are deconstructed include:

- The local cost of landfill tipping fees
- The local cost of labour and equipment
- The ease of disassembly which affects labour cost
- The value of the materials recovered
- Having adequate time available for deconstruction
Landfill tipping fees – charges for depositing waste on a landfill – vary greatly by region from less than €35 ton to over €45 ton in states. In areas with high tipping fees, deconstructing buildings can avoid substantial tipping fees, which can help offset the additional labour needed to disassemble the building. Labour and equipment costs also vary greatly by region, and significantly affect the economics of labour-intensive deconstruction. The value of the materials recovered is also a key factor. The booming salvaged wood market has spurred increased competition for buildings containing large timbers or high quality old-growth lumber. Many homeowners are willing to pay a premium for recycled wood that has a story and “character.” Salvaged components such as antique fireplace surrounds, light fixtures, hardware, and other ornamental pieces can be shipped to a national market and command high prices, as a quick search on E-Bay will show. Designers can increase the likelihood that a building will be deconstructed if they choose quality materials that will have a high value in the future. Deconstruction does take longer than demolishing a building with heavy equipment, if this is not considered, it likely will not happen. If demolition of an existing structure is part of a construction contract for a new building, the contractor will often want it down as quickly as possible to start on the new project and meet that schedule. It often makes sense to issue a separate contract prior to and separate from the new work to relieve some of the schedule pressure. If the building to be demolished is in use or generating revenue from a lease, these can present real obstacles. The ease and speed of deconstruction is a key factor that this Handbook most directly addresses. How can architects, engineers, and builders put buildings together that are easier to take apart? Do the fastening methods allow disassembly, and are these connections accessible? Are there too many materials or are they assembled in a complex, intertwined manner? Are hazardous materials intermixed with the valuable ones? Are the components visible or identifiable on existing drawings? Are glues and composite materials avoided? The designers and builders of our structures have a major impact on how readily they can be deconstructed. Often a simple mental shift to just think about the ease of disassembly during design and construction reveals numerous strategies that can be easily adopted.

Deconstruction strategies:
- Use of modular building components/assemblies
- Provide access to components/assemblies (windows, etc)
- Provide access or tie-offs for work at height
- Accessible information:
- Construction drawings & details
- Identification of materials and components
- Structural properties

Modularization and prefabrication can promote reuse and recycling at a larger scale – whether modules of assemblies or their component materials. However, modules and components should be dimensioned for reuse. It only makes sense to modularize a particular assembly if it makes construction and deconstruction easier. And if modularization complicates assembly or if it involves the modularization of overly specific pieces, then it may in fact force creative reuse at best [7].

5. Conclusions
The green engineering design and manufacturing are affecting every aspect of our life. The green revolution will be even bigger than the Internet revolution is. Greening has already attracted a wide area of research topics and will attract more and more. At the moment the most important thing what engineers can do is to provide the sustainable product life cycle strategy. As above mentioned case studies proved the life cycle engineering holds the guiding product life cycle management. Our goal is to promote the product life cycle engineering in green way by using successful practices from different industrial areas all over the world.

References
5. Kobet, R. J., Modular Building and the USGBC’s LEED; Building rating system. Ver. 3.0, 2009.