Modular Prefabricated Residential Construction

Constraints and Opportunities



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EXECUTIVE SUMMARY

The current practices in construction industry are labor-intensive and surrounded by significant risks associated with market, site and weather conditions. In addition, the construction industry has been critizised for lower productivity relative to other US industies in the last fourty years. Many seek efficient improvements with respect to time, cost and quality. Modular construction moves the construction site to manufacturing facility for a major part of the building and, in this way, improves its predictability, increases productivity, and reduces the risks inherent in construction. Modular buildings also generate great cost savings opportunities as a result of compressed construction schedules.

The key objective of this report is to provide a review of the potential for modular prefabricated construction for mid- to high-rise residential buildings in Seattle. To achieve this objective, we identified 9 major constraints and 3 main opportunities in implementing this type of construction. The constraints include market demand, transportation, logistics, costs, codes, permitting and inspection, labor and unions, architectural design and delivery, and regional manufacturing. Structural design is another constraint that is not covered in the present report, but should be carefully considered particularly in seismic regions such as Seattle. Furthermore, the major opportunities of this type of construction include schedule, cost, and quality. We also studied several case-studies of modular mid- to high-rise buildings from a varity of regions including the US, Europe and Australia to understand how this construction method has been utlized globally. Finally, we present the design and analysis of three student studio teams in an Integrated AEC studio which was conducted as part of Skanska's innovation grant. The student team proposals are for mid-rise residential modular buildings in a hypothetic site in Seattle.

We conclude that there exists a great potential for modular construction in the delivery of highrise residential buildings. There is a strong demand for multi-family housing in the Tri-county region, however, there appears to be significant oversupply of multi-family units coming onto the market in the medium term, which should be considered prior to any release of units onto the market. Therefore, it is suggested that further investigation is conducted to understand the fluid nature of the housing demand and supply in the region. When such a project is undertaken, the size and weight of the modules to be used in a modular building should be carefully considered with respect to transportation, logistics. Typical module sizes are 11 feet high, 12 to 16 feet wide, and 55 to 65 feet long. A maximum 200-mile distance from the site location is probably the most cost-efficient option with respect to transportation costs are minimal as compared to the potential for reduced site construction and financing costs as a result of smaller crew sizes and shorter construction schedules.

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1. INTRODUCTION

Since the industrial revoltion, designers and builders have explored prefabrication concepts, means, and methods. This type of construction is the practice of assembling the components of a building in factory and then transporting them to the construction site for installation. **Modular prefabricated construction** represents a specific type of prefabrication in which the *module* building components are assembled off-site. Modules are complete box-shaped units, containing walls, floor and roof with the interior space, which are built in factory, shipped to the site, installed, and connected into a complete building. Faster speed of construction and thus, faster return on the investment, is one of the major drivers of this type of construction which can take place at a variety of scales, from single-house to high-rise, and for various types of functions including residential, student housing, and commercial. Other benefits include safer more productive working conditions in manufacturing settings, which is of particular value in extreme climate regions. The manufacturing setting also presents challenges in terms of inspections, permitting, labor organization, transportation and logistics.

Design and construction of modular buildings, however, require high levels of collaboration among project parties, especially architect, structural engineer and manufacturer, in the early design process to account for major constraints in the design with respect to transportation of modules, installation logistics, permits and inspection schedules. More specifically, weight and size of the modules to be transported and installed, and the structural capability of the final product need to be carefully considered in the design of modular buildings. Buildings with this type of construction are subject to the local codes in the United States, enforced by the Department of Labor and Industries and local government agencies responsible for enforcing the construction codes.

In addition to other limitations, modular buildings, especially in housing market, may face market resistance if manufactured housing is perceived to be of lower quality. In our research, we have found that this public perception may not extend to mid-rise and high-rise building stock, and efforts in Europe and Asia are changing the public perception of modular construction to one with potential for high design and a modern high tech image.

We start this report with a detailed review of some of the major constraints that surround design and construction of this type of development in Seattle, followed by the opportunities to achieve viable development models, and finally, we present some case-study examples from around the world.

2. CONSTRAINTS

The main constraints associated with modular construction have to do with market conditions, transportation, logistics, costs, codes, permitting and inspection, labor and unions, architectural design and delivery, and regional manufacturing.

2.1. Market conditions

Market analysis for the modular prefabricated housing product will be discussed in 3 ways; with reference to supply, demand and perception of the product. Modular prefab for the purposes of this study falls within the category of multi-family housing. Within the multi-family housing market, any given property can generally be occupied in terms of a *lease* or *purchased outright*. Hence, any given property competes with other housing assets in two main arenas: Sales market and Rental market. Within these two markets, any given property also needs to compete with new supply (i.e. currently marketed projects) and existing housing stock. We will look at the trends in these two markets in turn with respect for supply/demand and how the property can best be positioned in the market.

2.1.1. Supply/Demand

The modular prefabricated housing market is still nascent, particularly in the US, despite having been in existence for at least 25 years. The shipping container approach was, for instance, first "patented as a Modular Container Building System in the USA in 1986" (Boyd et al, 2012). It is difficult to find statistics on the exact number of modular prefabricated buildings, let alone the number of multi-family modular prefab housing projects in the past, or necessarily the percentage of projects by value. The numbers that are available are presented here.

National Market

According to the 2011 US census statistics reported by Modular Building Institute (MBI), an industry body which accounts for about 60% of modular contractors, modular construction makes up a small but growing percentage of the total construction industry (MBI 2012). The statistics reveals that the total value of construction industry is \$787 billion annually (\$244 billion residential + \$543 billion non-residential). \$183 billion of the non-residential share of this market represent lodging, office, commercial, healthcare, educational and religious building types. Only 1.5% (\$2.7 billion) of this \$183 billion construction value is the share of permanent modular construction (MBI 2012). It is worthwhile to note that this figure does not include residential construction.

The question now is where modular housing stands in with this small market. Looking at the market share breakdown (by revenue) reported by MBI member organisations, it seems that multi-family and student housing comprises 20% of the permanent modular construction market (figure 1).



Figure 1. Non-residential modular construction breakdown (by revenue) (Data source: MBI 2012)

Extrapolating the data, we estimate that the multi-family modular market in 2011 was \$675 million annually. This figure is only a conservative estimate as MBI does not represent some of the significant modular construction builders, especially in the northwest region (e.g. Guerdon).

Moreover, considering the number of projects being designed as modular and forecasted in Engineering News Record (ENR)—projects such as Atlantic Sports Yards—we estimate that the multi-family share in modular construction market is actually closer to \$1 billion annually as a conservative estimate.

A separate report by McGraw Hill construction indicated that the usage of prefab/modular processes was common in 85% of industry players and 98% of respondents stated they would be using it by 2013 (McGraw Hill Construction, 2011). The companies surveyed were contractors, subcontractors, developers/owners, engineers and architects. 37% of the respondents stated they had been using prefab/modular on more than 50% of projects, and by 2013, the survey suggested that, the 37% would grow to 45%. Note the report does not clearly delineate offsite modular construction from lower levels of prefab systems (e.g. off-site precast concrete components). Importantly, the report highlighted three major issues with respect to modular construction (McGraw Hill Construction, 2011):

• Reasons for non-usage

The primary reason why projects did not include modular was due to owner resistance (39% of architects, and 54% of those currently not using prefab gave that as the reason). This puts the impetus on developers for driving this model.

• Current Usage

Among the current users, healthcare and dorms/educational buildings were estimated to use modular process at 49% and 42% share, respectively. Only 23% of multi-family housing, according to this report, was estimated to use modular processes.

• Future Potential

In terms of future, the respondents stated that the biggest potential markets for modular construction are: healthcare (14%), commercial warehouses (11%), hotels (11%), manufacturing (8%), high-rise office (8%), schools 7% and multi-family (7%). This may give credence to the business strategies focusing on modular prefab processes.

The implementation of modular construction techniques can also be justified on the grounds of rapid growth of multi-family housing, which lends itself to modular practices. Compared to 2011, the overall construction market has experienced a 6.5% growth. Indeed, the value of construction market in 2012, excluding public projects, is \$837 billion compared to \$787 billion in the year before. The share of multi-family housing has been \$23 billion of the market in 2012, which represents a 44.8% growth, compared to 2011. Altogether, multi-family housing accounts for 7.7% of the total \$273 billion residential market in 2012.

This growth is evident in the increased number of housing units. Indeed, new residential construction increased from 647,000 units in 2011 to 872,000 units in 2012; a 34.8% growth. The census data breaks this down with data for single family, 2-4 unit developments and 5 + unit developments. Single family housing accounts for 70% (603,000 units) of new residential construction in 2012. This represented a 43% increase compared to the 2011 figures. Multi-family residential with 5 or more units also experienced the growth, with an increase from 219,000 in 2011 to 260,000 units in 2012.

King County Residential Market

According to a 2012 report by Washington Center for Real Estate Research (WCRER 2012), there exists 249,070 potential rental apartments in Seattle. Based on a WA Office of Financial Management (OFM, 2012) report, the total housing units in the King County area as 861,895, the share of rental apartments accounts for 29% of the total housing units. Figure 2 illustrates a breakdown of this market for rental apartments.



Rental Apartment in King County

Figure 2. Rental apartment market in King County (Source: WCRER report)

As at Spring 2012, the average rent in King County area was \$1098 with an average apartment size of 826 square feet. The Table 1 shows the average rent and size for 1-bedroom and 2-bedroom apartments.

Apartment type	Average Rent (\$)	Average Size (sf)	Vacancy Rate (%)	
1-Bedroom	1001	686	3.7	
2-Bedroom-1 Bath	1024	875	4.3	
Average	1098	826	4.1	

Table 1.	Average	rent and	size for	apartments	in King	County area	a.

More recent data from September 2012 determined by both Apartment Advisors and Dupre + Scott⁴ quoted in the Seattle Times suggests the following changes since the figures in the Apartment report by the WCRER:

In the Tri-County area:

- The average rent is \$1,103 up 3.7% from March (and, about 5% annually).
- The average vacancy rate is 4.27%.
- Interestingly and as a side note, Trulia data⁵ gleaned from USPS statistical data indicates those properties receiving mail and those not, shows a vacancy rate of 2.4% for Seattle.
- Apartment Advisors reports an average rent of \$1,628 in downtown, Belltown and South Lake Union, \$1,756 in Bellevue.

With respect to the **housing market**, including condominiums and single family housing in King County, the following statistics were provided by WCRER based on the Spring 2012 data which is available on the WCRER website:

- Building permits 146.2% annual increase (966 units authorised in March 2011)
- 3.1 months of housing supply available versus 5.3 in 2011. (Note: Months-of-supply is the number of months it would take to sell the housing inventory based on the current annualized sales rate).
- 4,978 housing units available (-34.4% compared to 2011)
- 12.1% increase in existing home sales
- \$322,400 median price (drop of 6.6% from 2011 annual median)

More recent data can be obtained from the Northwest Multiple Listing Service (MLS)⁶. Professor Glenn Crellin indicates that the Northwest MLS represents accounts for approximately 80% of the market. According to this data, as at September 2012:

⁴<u>http://seattletimes.com/html/businesstechnology/2019251870_apartmentrentsxml.html</u> - accessed October 22 2012

⁵ <u>http://www.forbes.com/sites/trulia/2012/08/03/housing-glut-or-housing-shortage-americas-got-both/</u> - accessed October 22 2012

⁶ <u>http://www.nwrealestate.com/nwrpub/common/mktg.cfm</u>

Northwest MLS website, Marketing Statistics, accessed October 20 2012

- King County had 6,312 total active listings (vs. 10,382 in Sep. 2011); a 39.20% drop.
- Pending sales figures are up from 2718 to 3,072 a 13.02% increase.
- Closed sales figures are up from 1,999 to 2,312 a 15.66% increase.
- The median reported increased to \$355,000 from \$310,000 a 8.06% increase.
- Seattle in comparison to last year in particular had 36.12% fewer listings, almost 19% greater sales figures (both closed and pending which increased to 888 from 748) and a median that increased 2.2% to \$370,000 (from \$362,000). Of these, condos had the following breakdown:
 - 42.32% fewer listings (from 983 to 567)
 - Pending sales at a 2.48% increase
 - Closed sales up 43.8% (from 197 to 137)
 - A median of \$250,000 (up 4.17% from \$240,000)

Based on the comprehensive data above, it appears that Seattle is a strong and healthy market and there is a particular appetite for condo projects, as evidenced by the falling number of listings for the sale market (42% fewer listings), and the drop in vacancies in the rental market (4.1% as at March 2012). Additionally, the average prices have increased for both housing and rentals. The Northwest MLS further reports the median price at 8.06% higher (to \$355,000) for housing (houses and condos), and there is a 4.5% increase in the \$1,635 Zillow rent index.

New Supply in the Seattle region

In order to effectively evaluate future market demand, the anticipated new supply of multifamily units in the region should be considered. These can be determined from the Seattle Department of Planning and Development (DPD) website. In any given zone, generally the planning department keeps a record of the permitting activity. For Seattle, these can be found at: <u>http://web1.seattle.gov/dpd/maps/</u>

The city records the scale and type of project and thus the number of multi-family residential projects can be identified, the city does not record the type of construction and thus the number of modular buildings approved for construction cannot be identified. Whilst accurate, the website is not indicative of what projects have completed at any given time. Therefore, we quote here the research from Apartment Insights and Dupre+Scott, two main research houses for apartment development in the Puget Sound Region. In April 2012, Apartment Insights⁷ suggests that in the Tri-county region (considering 50+ unit projects only):

- 8,155 units under construction (up from 6,457 in Q4 2011)
- 3,119 units expected to open in 2012.
- 5,539 units expected to be released in 2013
- Additionally there are 9,428 in the design review/permitting process, or which have already completed it, and an additional 9,953 units, which have rezone applications.

⁷ <u>http://www.apartmentinsightswa.com/press.html</u>

Apartment Insights, On-Site Magazine April 2012 - accessed October 22 2012

In the Apartment Development report⁸ published in September 2012, Dupre+Scott presents even larger numbers for the Tri-County region (based on 20+ unit projects):

- Almost 36,000 in the development pipeline (planned or under construction) for Seattle between 2012-2017
- 6,239 completed or under construction for 2012
- 8,167 planned or under construction (7,694 underway) for 2013 release
- 10,787 planned or under construction (3,834 underway) for 2014 release
- 7,381 planned or under construction (606 underway) for 2015 release
- Between 2012-2015 32,574 units planned or under construction

2.1.2. Demand Drivers

Demand drivers for multi-family residential renters include:

- Population
- Household formation (non-child rearing ages)
- Local Housing affordability
- Employment Growth

This report is not designed to include macroeconomic data including unemployment/median income/household formation. However, a pertinent question is whether the growth in household formation, and removal of existing housing stock (due to obsolescence/conversion of use) is sufficient to warrant the large supply coming on line.

According to the Washington State Office of Financial Management (2012), overall the predicted population increase for the tri-county region is predicted to be 155,275 from April 2010 to April 2012. The population increase from April 1 2010 to April 1 2012 has been 25,751, 9,565 and 12,975 for King, Snohomish and Pierce Counties, respectively. In other words, a 48,291 net population increase in 2 years in the tri-county area. In terms of housing units, The OFM data from 2010 to 2012 actually indicates that 18,420 new housing units were created (OFM, 2012).

Delving deeper, we can do a quick analysis of this. In 2012, the average household size was 2.354 (OFM, 2012). But in reality the size of the households being formed by the population increase infers a new household size of 2.621 (calculated from 48,291/18,420). This would indicate the size of each household is getting bigger or that perhaps housing preferences is for more people per household. However, this doesn't tell the whole story given that vacancy rates have been falling and old stock has been taken up. This means the actual number of new housing units + some of the existing stock were taken up by the additional population, and hence the household size calculation of new households formed should be (48,291 / (18,420 +

⁸ <u>http://www.duprescott.com/productsservices/articleinfo.cfm?ArticleId=583</u>

Dupre + Scott, Build it and they will come, September 24 2012 - accessed October 22 2012

existing stock taken up). Other possible suggestions for the increased household size could be an indication of more subleasing occurring.

Shortfall is one thing, but the anticipated supply coming into the tri-county region is another. The actual number of units being released in 2013-2015 will be approx. 27,500 (from the previous section) in the tri-county area. Assuming the OFM calculations are correct, population growth should be approx. 107,000 new residents, and assuming the same rate of housing unit formation (2.621 persons per housing unit), we can come up with an approximate no. of required units as 40,800. Therefore, the supply of 27,500 new multi-family units in 2013-2015 (in the previous section) assumes that approx. 2 in 3 new households will be happy to live in the multi-family housing units coming online. Indeed this could be a conservative estimate and there is probably closer to 10-20% more units coming up in 2013, 2014 but the D+S data doesn't include projects smaller than 20 units, hence we could almost suggest that 3 in 4 new households are supposed to take up the new multi-family units on offer.

Population Projections

As mentioned earlier, The OFM (2012) provides data on population projections from 2012. Current to May 2012, the data indicates that, between 2010 and 2015, the population growth will be 155,275 in the Tri-county region. Taking into account the 48,291 already moved in from April 2010 to April 2012, this would indicate approximately 107,000 new people needing to be accommodated within the tri-county region.

Some demographers point to the Gen Y generation – for instance the population between 18-35 who are now leaving home and renting or purchasing their first homes. As presented at the ULI Fall Convention 2012 – the presentation suggested that this is an extremely nascent market – a growing number of 18-35 year olds are looking for such multi-family properties but are subject to capital constraints in light of low starting salaries and debts out of college. A RREEF study⁹ in May 2011 provided shed some light on the exact figures of this demographic – Generation Y (1983-2000 birth years) make up 80 million people, whilst Generation X (1965-1982 birth years) make up 65 million residents. Moreover, the % of single households, will be increasing to 38% (from 34% over 2016-2020),

An important question is in regards to what the population projections are for this demographic segment as they are the most likely occupiers of multi-family housing. OFM (2012) provides a breakdown of different age brackets, and for breakdowns of each county. Taking into account the demographic segment between 18 and 34 years old, between 2010 and 2015, the state population growth in is due to be 38,311, out of a total 297,000 growth for the state (between 2010 and 2015). In the Tri-county area, the projection is for a growth of 13,130 in this 18-34 demographic according to medium estimates, compared to a total Tri-county growth across all age groups of 155,275. This accounts for scarcely 10% of the projected growth. Given these

⁹ RREEF research report:

http://www.rreef.com/content/_media/Research_Demographic_Changes_May_2011.pdf

rather small figures, the question this raises is one of whether the demand exists for the multifamily product type which many deem as being perfectly suited for the 18-34 demographic.

We should also look at the population of retirees who desire smaller, multi-family dwellings as a lower maintenance option in their retirement. The question is what the trends are for this demographic. The OFM publishes population projections for each county breaking down into age groups. This is available online.¹⁰ Statewide, the over 65 population is 13.12% in 2012 estimates (894,811 persons, 40,000 more than 2011). In the Tri-County region it is: King (11.67%, 228,477), Snohomish (11.12%, 80,375), Pierce (11.73%, 94,781).

In 2015 this is projected to be: Statewide: 1,020,605 persons accounting for 14.53% of the total, King (12.52%, 252,100), Snohomish (12.02%, 90,203), Pierce (12.46%, 103,731). Thus we can see that this target market is substantially increasing with the addition of almost 45,000 additon more people in the 65+ age bracket in 2015 compared to 2012.

Household Formation Projections

Using the existing average household size as a guide, the metric would be for a requirement of approximately 45,500 new housing units from April 2012 to April 2015. This is based on the average household size 2.354 holding true (from Census data), and an increase of 106,984 (calculated from 155,275 less population increases from April 2010 to April 2012).

As previously shown in the supply side section, half of the units permitted to September 2012 were multi-family (5 or more). This number is rising. Not including the 6,239 released in 2012, 26,000 of them are already earmarked as being due for completion in 2013-2015. Given what we have just calculated in terms of household formation, we estimate that close to 2 out of 3 new households (26,000 multi-family units out of the projected 45000 housing units required) will be living in multi-family.

This forecast does not match historical housing patterns and should be analyzed in more detail. There are less than 1 in 3 current households living in multi-family currently (250,000 existing apartments out of 860,000 total in King County)¹¹ and we would suggest that there needs to be a significant structural change in housing preferences that number to double to account for the 2 out of 3 new units which are being released as multi-family. Some have postulated this is as being necessary to cater for demand. This demand it is suggested is being driven by the influx of young professionals drawn to Seattle to work for companies such Amazon and other major corporations in inner Seattle.

Furthermore, this demographic has certain preferences for housing – which many developers are suggesting is the well located, transit oriented, multi-family housing type. To an extent, this form of housing, is also necessitated by a lack of land supply, and significant population increases of certain demographics (the X and Y Generations) in particular areas such as South Lake Union – where housing needs can only be met by multi-family.

¹⁰ OFM Population Projections: http://www.ofm.wa.gov/pop/gma/projections12/projections12.asp

¹¹ Combination of OFM data and WCRER mid year report 2012

Job Growth

The OFM statistics factor job growth in, in their population growth calculations. However, for the sake of clarity, we use the Bureau of Labor Statistics data:

- March 2011-March 2012: Job growth¹² in the Seattle metro is 11,590 according to the bureau of labor statistics (2.5% annual growth).
- From Sept 2011 Sept 2012: in the Seattle- Tacoma –Everett- Bellevue area, 39,300 jobs were added.
- From August 2012 Sept 2012: 33,300 jobs were added.
- Unemployment has gone from 8.4 to 7.3% (from Sept 2011 to Sept 2012).

Weekly wages in March 2012¹³:

- \$1,265 in King (\$65,780 pa)
- \$1,061 in Snohomish (\$55,172 pa)
- \$840 in Pierce (\$43,680 pa)
- National average: \$984 (\$51,168 pa)

These figures state that job and wage growth seems strong, however the issue is whether the estimated 2 in 3 new households (based on the population growth) will choose multi-family living based on the supply coming through. Hence the question is, is it a sustainable venture to keep building multi-family? Conversely, with no new/limited land supply, do we have any other choice. It remains to be seen whether the socio-economic fundamentals will support the shift to multi-family housing in the Seattle region.

2.1.3. Perception

- The main concept is that prefabricated housing should not look like prefab housing but rather like any other typical housing unit. The house purchase is a major decision as it ties up substantial financial resources over time. Here are several key facts in regards to housing purchases – From international studies done in Turkey (Apaydin 2011), Slovenia (Koklic and Vida 2011), and the UK (Edge *et al* 2002).
- Price may be perceived as an indicator of quality (low cost might indicate low quality) (Apaydin 2011).
- Prestige is reflected through the products image
- Housing is a representative of personal identity/self-concept buyers those need customizability (Koklic and Vida 2011). The individualization and reflects the tenants' lifestyle whether ideal or actual.
- Buyers are under time pressure, and other people's opinions are important. People need others' experience/information in order to make effective decisions. (Koklic and Vida, 2011).
- First impressions of the company/manufacturer are highly important (Trust in the process of production and delivery of house). (Koklic and Vida, 2011).

¹² http://www.seattle.gov/economicDevelopment/indicators/jobGrowth.htm

¹³ http://www.bls.gov/news.release/cewqtr.t01.htm

- Follow-ups are important in order to promote positive feelings toward a modular product. (Koklic and Vida, 2011).
- Consumers frequently seek external information to increase knowledge and decrease perceptions of risk and uncertainty. (Koklic and Vida, 2011).
- Customers exhibit limited pre-purchase information search even for expensive durable goods (Koklic and Vida, 2011).
- There is an antipathy to prefab (i.e. postwar prefab type) but new products need to distance themselves from that, as customers will only have partial resistance to new ideas and need to understand the value proposition. (Edge *et al* 2002)
- The UK study has approximately 88 ideas noted down in regards to optimizing preferences towards modular prefab construction– (Edge *et al* 2002)

A case study in point provides a glimpse into how one project tackled the issue of perception of modular housing. This building, called Little Hero and located in Melbourne, Australia, was built by Unitised Building, an offshoot of a medium-sized general contractor called Hickory. This was a groundbreaking new project and highly publicized. Several things mentioned in media reports and the case study done by RMIT university (Boyd *et al*, 2012) which helped in selling the product include:

- 'Normalizing' the façade/integrating it with the Central Business District building fabric
- Association with high profile builders/architects and industry trade organizations
- Positive media coverage
- Having a price point not abnormally low, \$369,500 per unit, which was normal in Melbourne at the time of release (2009)

Perhaps the most pertinent study was a study performed by the Department of Housing and Urban Development (Cantrell *et al* 2007). This study canvassed the opinions of 12,700 consumers (10,000 through a web-based survey and 2,700 in a phone survey). The results are summarized as below:

"Site-built housing, in addition to receiving the highest ratings against particular factors, is the type of housing that respondents would likely purchase, followed by modular homes. Respondents indicated that they are about equally likely to consider panelized and manufactured homes for purchase.

In general, respondents who lived in site-built housing prefer that type of housing to all of the three other types, and so would be less likely to consider purchasing a modular, manufactured, or panelized home. Lower income respondents are more likely to consider purchasing a manufactured home, as are respondents who value the ability to construct a home quickly. Lower income and older respondents are more likely to consider purchasing a modular home, as are respondents are more likely to consider purchasing a modular home, as are respondents are more likely to consider purchasing a modular home, as are respondents who live in the Northeast. Moreover, respondents who are knowledgeable about factors associated with each housing type are more likely to consider purchasing modular and panelized homes.

A key result in this study is that the telephone respondents who rated non-site built housing types more favorably based on specific housing features were less likely to consider purchasing these homes. In comparison, Web-based respondents who rated the homes based on photographs of each housing type decided favorably on the likelihood to purchase them..."

This finding suggests that consumer willingness, (or lack thereof), to consider purchasing a factory-built home is less a function of rating individual elements than the overall look of the home.

Based on the attitudes of respondents, the marketing recommendations are derived from the following key principles:

- Quality of construction is important to respondents.
- There is a distinction between respondents' product knowledge and product experience.
- A marketing message and its medium of delivery should target those markets that show the greatest promise for non-site-built housing technologies.

2.2. Transportation

Studies have shown that shipping modules becomes cost prohibitive when they must travel more than 150 to 200 miles from factory to site (Smith, 2011). The industry generally recognizes 125 miles as the maximum practical distance modules should need to travel from factory to site. For the current study average transportation costs could not be determined.

2.2.1. Transportation by Truck

Transportation limitations for roadways in and around Seattle are determined by the Washington State Department of Transportation and the Seattle Department of Transportation. The table below shows the allowable dimensions for transportation by truck (Washington State Department of Transportation, 2013).

	Maximum Dimensions				
	Not Requiring	Subject to Special	Requiring Special		
	Permits	Requirements	Approval		
Width	Up to 8.5 Ft.	Up to 16 Ft.	Over 16 Ft.		
Height ¹	Up to 14 Ft.	Up to 16 Ft.	Over 16 Ft.		
Single Trailer Length	Up to 53 Ft.	Up to 56 Ft.			
Multi Trailer Length	Up to 61 Ft.	Up to 68 Ft.			

¹ All heights are measured from the roadway.

Weight Restrictions

The maximum allowable weight is dependent on tire size and number of axles. The Washington State Department of Transportation guide lists criteria for determining the maximum weight once a truck has been selected.

Oversize Loads

Oversize vehicles (width, height, or length) are required to be marked "oversize load". Escort vehicles are required when:

- 1. The vehicle(s) or load is over 11 feet wide. Two pilot/escort vehicles are required on two-lane roads, one in front and one in back.
- 2. The vehicle(s) or load is over 14 feet wide. One escort vehicle is required at the rear of the movement on multi-lane highways.
- 3. The vehicle(s) or load is over 20 feet wide. Two pilot/escort vehicles are required on multi-lane undivided highways, one in front and one in back.
- 4. The trailer length, including load, of a tractor/trailer combination exceeds 105 feet, or when the rear overhang of a load measured from the center of the rear axle exceeds one-third of the trailer length plus load of a tractor/trailer or truck/trailer combination. One pilot/escort vehicle is required at the rear of the movement on two-lane highways.
- 5. The trailer length, including load, of a tractor/trailer combination exceeds 125 feet. One pilot/escort vehicle is required at the rear of the movement on multi-lane highways.
- 6. The front overhang of a load measured from the center of the front steer axle exceeds 20 feet. One pilot/escort vehicle is required at the front on all two-lane highways.

- 7. The rear overhang of a load on a single unit vehicle, measured from the center of the rear axle, exceeds 20 feet. One pilot/escort vehicle is required at the rear of the movement on two-lane highways.
- 8. The height of the vehicle(s) or load exceeds 14 feet 6 inches. One pilot/escort vehicle with height measuring device (pole) is required at the front of the movement on all state highways and roads.
- 9. The operator, using rearview mirrors, cannot see 200 feet to the rear of the vehicle or vehicle combination.
- 10. In the opinion of the department, a pilot/escort vehicle(s) is necessary to protect the traveling public. Assignments of this nature must be authorized through the department's administrator for commercial vehicle services.

In addition to signage and escort vehicles, overwidth vehicles (greater than 8'-6") are subject to curfews (see Table 3 below).

Permitting Fees

Fees for oversize loads are minimal and range from \$10 to \$150 depending on the period of time and type of permit required. These permits only allow oversize loads to operate on state roads, additional costs for escort vehicles will most likely be far greater.

City of Seattle Restrictions

For oversize and overweight loads, independent permits to transport material in the city of Seattle are required. Pilot car requirements within the city of Seattle are as follows:

- 1. Front and rear pilot cars are required when the load extends beyond the centerline or center of the road on all two-lane roads.
- 2. On multiple-lane roads, a rear pilot car is required when the load is between 12' and 13'-11".
- 3. Both a front and rear pilot car are required when the load is 14' to 15'-5".
- 4. A Seattle Transportation CVEO Traffic escort is required when the load is 15'-6" or wider.
- 5. A front pilot car is required when the vehicle load combination is 14'-1" to 14'-11" high.
- 6. A front and rear pilot car are required when the vehicle load combination is 15' to 15'-5" high.
- 7. A Seattle Transportation CVEO Traffic escort is required when the vehicle load combination is 15'-6" or higher.
- 8. A rear pilot car is required if the vehicle is 81 to 89 feet long.
- 9. A front and rear pilot car are required if the vehicle is 90 to 99 feet long.
- 10. A Seattle Transportation CVEO Traffic escort is required if the vehicle is 100 feet or more.
- 11. A front and rear pilot car are required if the overhang is more than 15 feet from the rear axle.

Vehicles are considered over-weight when the single-axle weight is greater than 20,000 pounds or the dual-axle weight is greater than 34,000 pounds. Also, the maximum overhang is one-third the total length of the vehicle.

Washington Department of Transportation issues curfews for major roads in the Seattle vicinity as outlined in the table below:

Vicinity	SR	Direction	Mile Post	Location and Boundaries	Hours (M-F)	Width
Seattle -	2	EB	(MP) 0 - 2.42	I-5 to SR 204	3-7 PM	9'
Everett	125	WB	(MP) 2.42 - 0		6-9 AM	9'
	5	NB	(MP) 127.48 -155.94	SR 512 to SR 599	6-9 AM, 3-6 PM	10'
	1.25	SB	(MP) 155.94 - 127.48		3-6 PM	10'
	11.2	NB	(MP) 155.94 -174.58	SR 599 to SR 523	6-9 AM, 3-6 PM	9'
		SB	(MP) 174.58 - 155.94	and the second second second second second	6-9 AM, 3-6 PM	9'
		NB	(MP) 174.58 -199.11	SR 523 to SR 528	3-6 PM	10'
		SB	(MP) 199.11 - 174.58	A state with the second	6-9 AM, 3-6 PM	10'
		NB	(MP) 199.11 - 206.08	SR 528 to SR 531	4-6 PM	10'
		SB	(MP) 206.08 - 199.11		7-9 AM, 4-6 PM	10'
	18	EB	(MP) .01 - 4.15	1-5 to SR 164	6-9 AM, 3-7 PM	10'
	11.5	WB	(MP) 4.1501	Mark States of the	6-9 AM, 3-7 PM	10'
	111	EB	(MP) 4.15 -11.38	SR 164 to SR 516	6:30-8:30 AM, 3-7 PM	10'
	1.00	WB	(MP) 11.38 - 4.15	1 d	6-9 AM, 3-7 PM	10'
	90	EB	(MP) 2.54 - 9.93	I-5 to I-405	6-9 AM, 3-7 PM	10'
	1125	WB	(MP) 9.93 - 2.54	and a second	6-9 AM, 3-7 PM	10'
		EB	(MP) 9.93 -18.36	I-405 to Sunset I/C	3-7 PM	10'
	in the	WB	(MP) 18.36 - 9.93		6-9 AM, 3-7 PM	10'
	167	NB	(MP) 5.98 - 14.33	SR 512 to SR 18	6-9 AM	10'
		SB	(MP) 14.33 - 5.98		3-7 PM	10'
		NB	(MP) 14.33 - 26.29	SR 18 to I-405	6-9 AM, 3-7 PM	10'
	11.5.1	SB	(MP) 26.29 - 14.33		3-7 PM	10'
	405	NB	(MP) 0 - 30.32	Entire Route	6-9 AM, 3-7 PM	10'
	pinte.	SB	(MP) 30.32 - 0		6-9 AM, 3-7 PM	10'
	518	EB	(MP) 0 - 3.81	SR 509 to I-5	6-9 AM, 3-7 PM	10'
	118.1	WB	(MP) 3.81 - 0		6-9 AM, 3-7 PM	10'
	522	EB	(MP) 11.10 - 14.09	I-405 to SR 9	3-7 PM	10'
	100.1	WB	(MP) 14.09 - 11.10		6-9 AM	10'
Tacoma	5	NB	(MP) 118 - 127.48	Exit 118 to SR 512	6:30-8:30 AM, 4-6 PM	10'
		SB	(MP) 127.48 - 118	The second second	6:30-8:30 AM, 4-6 PM	10'
	16	EB	(MP) 10.28 - 0	I-5 to Olympic Drive	6-9 AM	10'
	à	WB	(MP)0 - 10.28	the second second second	3-7 PM	10'
	512	EB	(MP) 0 - 8.74	I-5 to SR 161	3-7 PM	10'
	112	WB	(MP) 8.74 - 0		7-9 AM, 3-7 PM	10'
		EB	(MP) 8.74 - 12.06	SR 161 to SR 167	3-7 PM	10'
		WB	(MP) 12.06 - 8.74		3-7 PM	10'

Table 3. Curfew for truck transportation in Washington State

Transportation Route

For transportation planning purposes, a theoretical site at 800 Stewart St., Seattle, WA was investigated. This site is immediately adjacent to the Seattle Downtown Traffic Control Zone (Appendix A) restricting daytime access from the southwest. Truck access to the site would most likely be via the route shown in the figure below.



Figure 3. Truck access to the potential site location at 800 Stewart Street

When selecting a site for modular construction, truck access to the site will be important to consider as the accessibility will impact the possible schedule for modular delivery as well as potentially restricting the possible dimensions of the units.

2.2.2. Transportation by Rail

Rail transportation is generally more expensive than transportation by truck (Smith, 2011). Relative costs between truck and rail transportation could not be acquired. Maximum dimensions of modules when transported by rail are 11 to 14 feet with a check to ensure the route supports the necessary clearance. A maximum height of 17 feet is allowed given that the route doesn't have any obstacles that prevent this. There is a maximum length of 59 or 88 feet and is dependent on the type of rail car. As compared to transportation by truck, these module sizes are less restrictive in terms of length and height and more restrictive in terms of width.

2.3. Logistics

While logistical considerations for modular construction are typically the same as traditional construction, there are differences between the two as well. Modules can easily weigh up to 22 tons, and span over 50 feet, which affects crane options. Moreover, the lack of areas for tie-offs can present challenges with transporting materials and crews.

2.3.1. Site Considerations

The following is a description of the typical logistical issues and constraints found once prefabricated modular units arrive at the construction site. A majority of logistics operations and decisions remain comparable from typical on-site construction to modular construction, but differences also exist.

Staging

Due to limited storage space at many urban construction sites, the weatherproof wrapping modules arrive in, and because of delivery distances, a staging area is one of the most important logistical considerations for modular construction projects.

Modular units vary in size, but most often are in the range of 11' wide, 14' high, and 55-65 feet long. Modules for the Atlantic Yards B2 project, a 32-story apartment complex in Brooklyn, New York, have been designed at 14' wide, 10' high, and 36' long. Depending on the project setting, module size can prohibit deliveries and interrupt workflow. Additionally, modular units are shipped from the factory with temporary weatherproofing, which consists of polyethylene sheets or tarp covers. These covers are engineered with proper spacing and attachment points so that the module is properly secured to the truck during transportation.

According to Maslenikov, project manager at Skanska USA Building, when a module arrives on site, time and manpower are required to remove this wrapping. Another reason a staging area is required for modular construction projects is because of the distance the modules typically travel. Jeff Brink, structural engineer at DCI Engineers, explains that relying on just-in-time deliveries has the potential to delay the project and is considered too risky. Accordingly, the modular supplier should deliver units at the staging area, and develop a backlog of available, completed modules. Brink also states that number of units stockpiled in the staging area is a function of how many units the project has, how fast the manufacturer can fabricate and ship the units, and how many units the crews can place per day.

Brink suggests that, ideally, the staging area should be within 50 miles of the project. Gene Rega, the preconstruction director at Skanska involved in the Atlantic Yards B2 project, states that they will have a staging area both at the factory, and at a site within 2 blocks of the project. Staging area workers should prepare units for delivery to the jobsite. These preparations include removing the weatherproofing, and applying the necessary rigging so that it is ready to be picked by the crane when it arrives at the construction site.

A dedicated delivery vehicle should be available to move modules from staging to the site. Based on weight and potential size, the modules will more than likely result in oversized load deliveries. Any special flagging, street closure, or special permit considerations should be evaluated once the staging area is selected.

Elevators and Vertical Worker Transport

One concern with modular construction is vertical transportation for field crews. Based on the speed of construction, time to erect personnel and material transport platforms can be a challenge. At a Skanska site for Swedish Edmonds Cancer Care Center, a local, 2-story modular construction project, the building's core elevator shaft will be constructed prior to the placement of modules, and used for material and personnel transportation. A mid-to-high rise project could follow this example and construct the core prior to placement of modules. This option would result in scheduling delays, but more importantly, if a traditional elevator core and shaft are not part of the design plan for the building, challenges can persist.

As discussed in a previous section, another option is a prefabricated elevator shaft. Companies such as InnoShaft in Illinois, or NEAPO in Finland, can deliver factory-finished elevator shafts and staircases up to 50' in height.

Andrew Morrow, of Morrow Equipment in Seattle, states that material hoists can be used, but that there are considerations to be made. A hoist is typically installed with the building structure at approximately every four floors. A tie-in from the hoist mast to the structure is installed approximately every 25' for support. Typically the hoist can typically travel one floor above the uppermost tie-in. For modular construction, the hoist can tie in, but jumps would have to be made more frequently based on the speed of construction. Morrow suggested the possibility of creating an independent tower structure for the hoist to tie-in.

Atlantic Yards B2 in New York, the tallest modular building in the US, will use a hoist the same way a conventional project would, with jumps occurring more frequently due to the speed of construction. The project will have one hoist, tied into the center of the building attached to modules. The modules used for tie-in will receive finishes on-site, after major construction, to reduce the potential for damage to the units. The hoist will span a 32-story section of unitized curtain wall. The project team is planning to construct and use a mini-crane on the roof to lift and set materials after the hoist is removed.

Other costs for the lessee include: equipment footings, electric power, erect/dismantle of the hoist, and equipment operators. For budgetary purposes, Andrew Morrow suggests:

- Hoist erect/dismantle...\$35,000 total (with jumps)
- Equipment operator...\$70 per hour base, \$90 per hour overtime

2.3.2. Crane and Rigging Considerations

The following is an examination of crane and hoisting considerations that should be made when working with modular units.

Hoisting and Final Positioning

Modular structures undergo the greatest force during hoisting. Careful planning and consideration is necessary to reduce and minimize the amount of time the module spends suspended on the crane. Some designers, including Kullman Buildings, which publishes an annual modular design manual, suggest including a 1/2" clear space between the modules to help speed the placing process (Garrison and Tweedie, 2011). There are also options that include a special pin and loop rigging system to allow for quicker attachment and removal of the module rigging.

The critical goal of rigging is to reduce damage to the module. Rigging should be designed so that no hoisting loads are imposed on the unit walls, which could cause the structure to shift or warp. Lifting points should be located so that there is no uneven weight distribution. The preferred lifting point location is at the bottom of the unit and located at 25% of the module's length (Garrison, Tweedie, 2011). Additionally, when units are maneuvered across the floor, live loads and clearances must be taken into consideration. Jacking points should be incorporated for finite adjustments (Gibb, 2008).

Damage to exterior cladding is not usually a problem, since modules typically arrive with only sheathing and a vapor barrier. Exterior finishes are added on site once the units are placed.

On an innovative note, at a previous project completed by Skanska, the modular electrical and telecom rooms had flat concrete bottoms, which had to be set on ice in order to remove the slings. As the ice melted, the units dropped into their final positions.

Crane Options

Crane selection is based on weight and reach, and for modular construction, typically requires a greater reach than with on-site construction. Also, modular construction can require a crane with a capacity of up to 40 - 75 tons, depending on design (Garrison and Tweedie, 2011).

Andrew Morrow, of Morrow Equipment, suggests using a tower crane for constructing a midto-high rise building in an urban setting. Because of the estimated size and weight of the modules, he recommends the Liebherr 630 EC-H 20 Litronic, as the tower crane of choice. The Atlantic Yards B2 project in Brooklyn will also use a tower crane.

Regardless of whether the developer, contractor, or manufacturer coordinates the crane, it is a costly part of the construction process, so coordination efforts should be made to ensure the crane is never idle. Other costs for the lessee include: equipment footings, electric power, erect/dismantle of the crane, and equipment operators. For budgetary purposes, Andrew Morrow suggests:

- Crane erect/dismantle...\$90,000 total
- Equipment operator...\$70 per hour base, \$90 per hour overtime

In terms of speed of construction, Jessica Fabro at OneBuild, a Seattle-based modular fabrication facility, estimates the crane can set 8 modules a day. Gene Rega, at the Atlantic Yards B2 project in Brooklyn, states that they placed their 6-module prototype in 3.5 hours. They are estimating they can place 10-12 modules per day.

2.4. Costs

Cost constraints of modular buildings primarily result from materials, labors, design and coordination, transportation, and logistics.

2.4.1. Materials and Labor

The following is a description of the typical materials and labor cost issues and constraints found in prefabricated modular construction, when compared to on-site building methods.

Financing

On-site building allows for materials and labor to be spaced and phased throughout the construction schedule. Due to the way work is divided and completed, payments can be made throughout the construction process. With modular projects, however, there is a larger concentration of payments and financing needed up-front. Because each module acts, in essence, as a miniature building, trades move through the schedule more quickly to complete their scopes. In many cases, the manufacturer will require a sizeable deposit, if not a paid in full requirement, prior to starting fabrication (Pickerell, 2012). Additionally, construction loans and financing typically only cover on-site work.

Jeff Brink, structural engineer at DCI Engineers, explains that the potential for a higher concentration of upfront costs does not necessarily equate to higher overall costs. The overall cost benefit of modular construction will be discussed and examined in the Cost Opportunities section of this report.

Union and Open Shop Labor

Much of the labor on modular construction, from structure to specialties, can be completed in a factory setting. Providing a controlled environment has a host of benefits including quality control, safety, and labor costs. These benefits will be discussed in greater detail in upcoming sections. Despite its many rewards, a factory work environment has the potential to conflict with regional union agreements.

Off-site construction has caused concern among some labor unions. One concern is the reduced crew size. At the Atlantic Yards B2 project in Brooklyn, NY, it is estimated that 190 fabrication workers will be needed to complete construction of approximately 930 modules in the factory (Bagli, 2011). At the Miami Valley Hospital project in Dayton, OH, only 18 factory workers were needed to preassemble 178 patients' rooms (Post, 2010). Another concern is factory location, which might invite owners to set up modular construction factories in states or areas with lower labor costs, and then ship the finished modules to the more expensive area for site assembly (Kastenbaum, 2012). In the case of Atlantic Yards, a union agreement is needed prior to securing a bank loan (Post, 2010) and as such might be a topic of consideration on other modular construction undertakings.

The Swedish Edmonds Cancer Center, a 2-story modular construction project in Seattle, has not encountered any issues with union agreements. As Pete Maslenikov, the project manager

overseeing construction on that project explains, although signatory to unions, the contractor does not produce the module; the manufacturer is responsible for who works on its factory floor.

Redundant Materials

When two separate modules are stitched up to form two separate units, the potential for redundant materials exists. For instance, if two apartment units are stitched together, both come prefabricated with partition assemblies. When those two apartments are placed next to each other, there is now a double partition. This is great in terms of acoustic control, but for larger projects, especially in an urban setting where space is limited, critical useable space is lost (Cameron and Di Carlo, 2007).

Another example of redundant materials is additional structural material needed for hoisting the modules into place. Andrew Morrow, of Morrow Equipment, states that the module may need to be reinforced with temporary structural elements due to connection stresses.

Fabrication Costs

Although it operates on a shorter timeline, and assembly workers in a factory setting are often paid less than on-site laborers, modular construction can have comparable or even more expensive fabrication costs (Schoenborn, 2012). Manufacturing facilities require overhead for utilities, equipment, and overall maintenance, which can affect pricing. Manufacturing facilities are not always used at full capacity. Additionally, there is a potential for higher material costs, especially due to transportation issues. It is possible for finished items to become damaged if they are not properly secured during shipment. Project teams may need to keep an attic stock of materials to replace damaged items on site.

2.4.2. Design and Coordination

This section examines and discusses potential cost constraints caused by, or affecting, the design and coordination of modular construction.

Design

With modular construction, a majority of the design must be completed prior to the start of construction. A strong and complete design can help organize the flow and work of trades within the modular factory. Although there is a heavy push for up-front designs and coordination, design fees for modular construction are typically comparable to on-site construction, with a few minor exceptions. According to Scott LeBenz, principal at GroupArchitect, MEP costs can be higher because Labor and Industries requires plans to be submitted rather than relying on design-build during construction. Another area involving the potential for increased costs involves how RFIs are handled during modular construction projects. Because of the faster pace of fabrication in the factory, design decisions need to be made upfront or run the risk of stopping construction, and delaying the schedule.

One way to potentially offset design delays and subsequent scheduling issues is to prepare a full mock-up. Mock-ups allow the project team to predict the outcome of the modular unit's design and construction to a high degree of certainty (Garrison and Tweedie, 2011). Mock-ups can be produced at a much lower cost than with on-site construction mock-ups, and typically take around a month to complete. With on-site construction, a mock-up does not replicate the process, rather the end result. With modular construction, however, the process is prototyped along with the actual module, which allows for a smoother process going forward.

VDC/BIM

Because of a faster construction schedule and multitrade setting in prefabrication factories, modular construction requires a meticulous level of coordination and management. Having the capability to use BIM on modular projects is essential. Helen Juan, VDC/BIM Manager at Skanska USA, states that modeling plays an important and critical role in design coordination; a seamless and efficient design, especially when unique assemblies or heavy MEP work are involved, helps cut down on defects and construction scheduling times.

Firms using modular construction are typically higher users of BIM. One survey, conducted by McGraw-Hill Construction, shows that of the respondents who have used modular construction, 78% use BIM on other projects; of the respondents who have not used modular construction, only 48% use BIM (McGraw-Hill, 2011).

2.4.3. Transportation and Logistics

There are cost considerations and constraints relating directly to transportation and logistics, primarily including modular size and shipping distance. These issues are discussed specifically in both the Transportation and Logistics sections of this report.

Staging Area

It is important for a modular construction project to also have an area where the modules can be unwrapped and prepped. If there is no room to store and prep units on site, a separate staging area will be required. Costs for the space, security, and staff are dependent on the size of the project, but should be considered while preparing a logistics plan.

2.5. Codes

Washington State Legislature oversees the codes for both site-built and factory-built housing. Generally, the standards call for the same code requirements for factory-built as compared to site-built development.

Additionally local government amendments and special rulings may apply to the adopted codes. These are listed on the websites of the relevant local government agencies (Department of Planning & Development for Seattle) and also on the website of the State Building Code Council (SBCC, an advisory board setup to advise on amendments where necessary), if they are residential single/multi-family properties.

For factory-built housing and commercial structures, the codes are defined by the Washington State legislature – Washington Administrative Code (WAC) and Revised Code of Washington (RCW) - as follows:

- 1) The State Building Code (Chapter 19.27 RCW)
- 2) The Energy Related Building Standards (Chapter 19.27A RCW; Seattle Energy Code)
- 3) The National Electrical Code (Chapter 19.28 RCW; Chapter 296-46B WAC)

The State Building Code is listed by the SBCC and is the minimum construction requirement for the State of Washington. The SBCC has the power to amend codes and is defined as the following documents:

- 2009 International Building Code with statewide amendments
- ICC/ANSI A117.1-03, Accessible and Usable Buildings and Facilities, with statewide amendments
- 2009 International Residential Code with statewide amendments
- 2009 International Mechanical Code with statewide amendments
- 2008 Liquefied Petroleum Gas Code (NFPA 58)
- 2009 International Fuel Gas Code (NFPA 54) for LP Gas
- 2009 International Fire Code with statewide amendments
- 2009 Uniform Plumbing Code with statewide amendments
- 2009 Washington State Energy Code
- 2008 National Electrical Code (NFPA 70)

The state codes may have local government amendments which are required by law in RCW 19.27.074. They are listed here on the SBCC website. The amendments are required to cater for:

- Climatic conditions that are unique to the jurisdiction.
- Geologic or seismic conditions that are unique to the jurisdiction.
- Environmental impacts such as noise, dust, etc., that are unique to the jurisdiction.

- Life, health, or safety conditions that are unique to the local jurisdiction.
- Other special conditions that are unique to the jurisdiction.

The site specific local government planning/codes website should be checked prior to beginning a new project. For instance there are local government amendments to date on 38 topics in Seattle. The local government website also lists other changes that may be enacted.

Note every 3 years new codes are released, and the SBCC may recommend the uptake of updated codes. In 2013 this may be as designated in the following website: https://fortress.wa.gov/ga/apps/sbcc/Page.aspx?nid=203

It is noted that while the factory-built housing/commercial structure needs to meet the guidelines in the State Building Code, National Electrical Code and Energy Code, it must be tailored specific to the relevant county in which the site is located. Hence, the code requirement for any particular modular building is the same as that for site built. The enforcement of the code and inspections is conducted by Department of Labor and Industries (L&I) for construction in the factory and by Department of Planning and Development (DPD) for construction on site in Seattle.

2.5.1. Mechanical

The International Mechanical Code 2009 governs Mechanical systems installed in buildings in Seattle. The reference mechanical code document can be found at the following link: http://ecodes.biz/ecodes_support/free_resources/Seattle2009/09seattle_mechanical/09seattle_emechanical_main.htm

The Washington legislature has made several slight amendments for statewide uses which can be found at: <u>https://fortress.wa.gov/ga/apps/sbcc/Page.aspx?nid=14</u>

Some of considerations with respect to mechanical code include:

- The mechanical systems require a permit for work except for that designated by 115.2.1 and 115.2.2 in the Code.
- If the cost of the mechanical systems in the module exceeds \$50,000 a registered and licensed mechanical engineer is required to inspect, stamp and sign each sheet of the construction documents.
- Inspections governed by section 119 of the code do not make a requirement for a cover inspection but doing this would be ideal for practical purposes.
- There are requirements for testing equipment, for example Refrigeration equipment (under Chapter 11) and Fuel oil piping.
- Under section 119.5, approvals are required (i.e., written approval needs to be obtained and the code official satisfied) before the next successive step can commence.

Factory

As mentioned earlier, L&I's mechanical inspector is the code official for inspection of factorybuilt mechanical systems.

Construction Site

Several requirements are noted in here from the Seattle Mechanical Code:

- The Code official is the director of the DPD.
- According to the "Section 104.5: Application to Existing Mechanical Systems Moved Buildings", no building can be moved into the City 'unless, prior to moving, the code official has inspected the building for compliance with its code and the permit holder has agreed to correct all the deficiencies found and has been issued a building permit for the work'.

2.5.2. Electrical

Factory

Chapter 19.28 RCW is the State code that applies to electrical systems of modular prefab housing in factory construction: <u>http://apps.leg.wa.gov/RCW/default.aspx?cite=19.28</u>

Hence, the factory installation of electrical is the same as that on site and the following considerations are applicable:

- The National Electrical Code applies.
- Energy code and Fire Code requirements need to be met.
- A permit is required with some exceptions (but there is no minimum amount of dollar worth for electrical and hence, it is more onerous than mechanical).
- Workers must be licensed electricians, or else a registered electrical contractor.
- In the Puget Sound region, 85% of contractors are signatories to the electrical union, hence shop wages apply for the majority of this work. This was noted in an interview with Tommy Key, a National Electrical Contractors Associations (NECA) representative
- Inspections (and testing): by L&I (under RCW 19.28.321) 'cover inspections' and final inspections, and an inspection on site before the utilities are connected and current is activated.

Construction Site

The Code official for electrical systems on site is the Director of the DPD. The National Electrical Code amended for Seattle notes the following related to movable buildings:

• Section 80.4. Application to Existing Buildings – (E) Moved Buildings: "Electrical permits for electrical work performed on a building or a structure moved into or within the City shall be obtained from the authority having jurisdiction. The authority having jurisdiction

will inspect the electrical system for deficiencies and issue corrections. Deficiencies shall be corrected before a certificate of occupancy will be issued."

- The service to the moved building needs to comply with the code, whereas if the original occupancy classification of the bldg. has not changed it does not need to comply with the code unless it is substantially different.
- Section 80.50 Permits "A permit is required for installation/extension/connection of any electrical equipment in a building". Part of obtaining a permit is submission of plans which meet the National Electrical Code and comply with the Seattle Energy Code (2 copies of plans & specs need to be submitted. They must indicate with clarity the electrical items noted in 80.52. ("Plans and Specifications e.g. circuits, switchboards schedules and layouts, grounding equipment, telecommunications equipment").
- Additionally, the Seattle Fire Code must be met requiring review by the Seattle Fire Department. If the site is in a flood zone it is subject to floodplain ordinance.
- Section: 80.52 Permits Issuance "The authority having jurisdiction may issue a permit for the installation of part of the electrical system of a building or structure before complete plans for the whole building or structure have been submitted or approved, provided adequate information and detailed statements have been filed complying with all pertinent requirements of this Code. Holders of such permits may proceed at their own risk without assurance that the permit for the entire building or structure will be granted."
- Inspections at the L&I and DPD end need to satisfy 80.54 Inspections which means:
 "(1)The authority having jurisdiction is authorized to conduct cover inspections when all of the following work has been completed:

(a) All piping, ducts, plumbing and like installations of other trades which are liable to interfere or run in close proximity to the electrical installation are permanently in place and inspected, but prior to any work to cover or conceal any installation of electrical equipment, and;

(b) Electrical equipment grounding (boxes, equipment, conductors and provisions for grounding receptacles, etc.) for all systems shall be completely made-up.

(c) For conduit systems, after all conduit has been installed and properly secured to the structure.

(2) Final Inspection. The authority having jurisdiction is authorized to conduct a final inspection after all wiring has been completed and all permanent fixtures such as switches, outlet receptacles, plates, electric hot-water tanks, lighting fixtures and all other equipment has been properly installed. The permit holder shall call for a final inspection when the work described on the permit has been completed."

• Persons, firms, partnerships, corporations, or other entities making electrical installations shall obtain inspection and approval from an authorized representative of the department as required by this chapter before requesting the electric utility to connect to the installations.

2.5.3. Plumbing

In Washington, the 2008 Universal Plumbing Code (UPC) edition is adopted; except for any provisions of such codes affecting sewers or fuel gas piping. L&I and DPD enforce exactly the same requirements as above. Here are some main considerations:

- A permit is required for plumbing work (under 103.1); except for repairs of stoppages, leaks, etc.
- Plumbing requires that contractors must be licensed plumbers or registered plumbing contractors (Chapter 18.106 RCW PLUMBERS).
- Plans need to be provided with engineering calculations, diagrams, specs reviewed and approved.
- Inspections need to occur before the system is covered (see further below)
- Testing of Systems is required. Plumbing systems need to be tested and approved by the Authority having jurisdiction.

Some of inspection requirements for moved buildings which might be applicable to modular housing too are as below:

- 103.5.1.1 Inspection. No water supply system or portion thereof shall be covered or concealed until it first has been tested, inspected, and approved.
- 103.5.1.2 Scope. New plumbing work and such portions of existing systems as may be affected by new work, or any changes, shall be inspected by the Authority Having Jurisdiction to ensure compliance with the requirements of this code and to ensure that the installation and construction of the plumbing system is in accordance with approved plans.
- 103.5.1.3 Covering or Using. No plumbing or drainage system, building sewer, Private sewer disposal system, or part thereof, shall be covered, concealed, or put into use until it has been tested, inspected, and accepted as prescribed in this code.

2.6. Permitting and Inspections

This section summarizes the process for permitting and inspections of mid-rise modular apartment development in Seattle, WA. The section outlines the steps that are needed in order to obtain approval from both the State Department of Labor and Industries and the Seattle Department of Planning and Development. In the appendix B of this report, there are two tables which compare different types of factory-constructed structures and the requirements for each type. Lastly, the diagram at the end is an attempt to understand the process as a streamlined system.

2.6.1. Permitting

Before installing a "factory-installed" structure on-site you have to apply for a building permit from the Seattle Department of Planning and Development's Applicants Service Center (located on the 20th floor of Seattle Municipal Tower). Along with the application you must supply **two sets of plans and specifications for the factory-constructed structure and provide verification of design and construction approval from the Department of Labor and Industries**. You also need to include any foundation details and a site plan of the site showing the location of the factory-constructed structure in relation to setbacks and yard requirements that should be noted on the document in order to guarantee compliance with the Seattle Land Use Code.

It is important to note that only the building plans, and not the factory in which the modules are built, have to be certified. In addition, the installation permit does not cover any additions or extra structures constructed on-site (i.e. porch, deck or garage) unless specifically included in the L&I initial approvals. In order to gain permitting you either have to include these in initial application to the Seattle DPD or in an additional building permit application.

Other permits are issued through different agencies:

- Curb cuts for the creation of new driveways an additional permit must be acquired from the Seattle Department of Planning and Development.
- Gas-powered appliances require a separate permit for gas piping must be acquired from the Seattle-King County Department of Public Health.
- Plumbing permit is granted by the Seattle-King County Department of Public Health.
- Service connections are issued by Seattle City Lights. Furthermore, if there is any excavation, then a DPD Construction Stormwater Control Plan and/or a Drainage Plan is required.
- Sewer hookup a side sewer permit from the DPD is required.
- In the case of an Environmentally Critical Area (ECA), then a plan review is required and the foundation plan is required to be designed by a licensed structural engineer and approved by geotechnical engineer that is licensed in the State of Washington. Also, a soil report must be prepared by the geotechnical engineer.

2.6.2. Inspections

Factory-built buildings will generally need inspections and approval by 2 layers of authorities – the Department of Labor & Industries (L&I) and secondly, at the local government level (Department of Planning and Development (DPD), for Seattle) (figure 4).



Figure 4. Factory (by L&I) and on-site (by DPD) inspection procedure

Inspection in Factory by L&I

Modular construction for residential and non-residential use is approved by the Department of Labor and Industries (L&I) with issuance of serial number and a gold seal insignia certifying that the project meets the standards of the Washington State Building Code. These structures are regulated by state standards for housing body and frame construction as determined by state law. As mentioned in the previous section, standards are outlined in the Washington Administrative Code 296.150B and the structure must comply with Washington State Building, the Mechanical, the Plumbing, and the Energy codes and must be placed on a permanent foundation conforming to Seattle Building Code (SBC). The gold insignia must be placed on or near the meter base or where electrical service enters the structure. Further, any alterations made before occupancy must be approved by the L&I. After occupancy, it is up to the local jurisdiction to approve any alterations.

In order to get approval from the Department of Labor and Industries, you have to submit two sets of plans and specifications for the factory-constructed structure. Once everything is submitted, assuming there are no revisions, the approximate time for approval is 5 to 6 weeks. This approximation is based off of what it may take for a 5 story structure. There have not been enough, if any, reviews of mid-rise modular apartment building for more specific estimates for a review of taller structures.

According to the Washington State Legislature of factory-built housing/commercial structures¹⁴, the inspection and approval process at the L&I level can be summarized as below:

- There is no statutory requirement for plans to be approved prior to construction in the factory, however it makes practical sense that the plans are complete as possible and approved, as these are what the inspection is based off and no insignia is provided without sighting approved plans in the factory (see http://apps.leg.wa.gov/WAC/default.aspx?cite=296-150F-0500
- 2. Construction occurs in line with the code complying plans.
- 3. Inspection consists of Design Approval and Physical Inspection.
- 4. DESIGN APPROVAL of the plan is required PRIOR to the final inspection. Design approval consists of:
 - A completed approval request form
 - Payment of fees filing fee + design plan fee (see fee discussion)
 - Two complete sets of design plans, specs and engineering analysis. One of the sets needs to have the original wet stamp from the Professional Engineer or Architect licensed in WA – the stamped set will be retained by the L&I. Engineering analysis needs to show the structural design meets the code.
 - A key drawing showing arrangement of the modules if there are 3 or more.
 - For specific building types (Hospitals, institutional, health care) electrical plans showing review electrical plan review is part of the inspection process.
 - Other items.
- 5. The L&I inspection will be at the factory (and may require multiple inspections) and occurs prior to occupation, whereas the local government inspects on-site following occupation. This includes:
 - a. Checks of insulation and vapor barrier
 - b. Other required code inspections.
 - c. L&I inspection of the unit needs to occur BEFORE the walls are covered this ensures mechanical, electrical, plumbing, structural systems are checked.
- 6. After plans are finally approved, a final inspection is carried out
- 7. The L&I inspector has authority to approve/deny the insignia.
- 8. Inspection by the L&I needs to occur on site if the module/component is damaged in transit.

Inspection on Site

After placing the factory-constructed structure on site, you have to schedule an on-site inspection with the Seattle Department of Planning and Development. They must ensure that the structure is properly sited and that it meets all applicable code requirements. Manufacturer instructions must be on site for the inspector to review and reference during inspection.

¹⁴ <u>http://apps.leg.wa.gov/WAC/default.aspx?cite=296-150F</u>
Requirements for Inspection on Site

The Department of Planning and Development (DPD) is in charge of inspecting: yard and setback requirements, the permanent foundation, electrical hookup, site grading, side sewer, storm water control used during construction and installation, and any required infiltration pit or commercial parking lot drainage.

The Seattle Transportation Department inspects any driveway or curb cuts. Public Utilities inspect the water hookup. And the Seattle-King County Department of Public Health inspects plumbing and gas piping.

The inspection process at DPD level can be summarized as below:

- 1. The relevant developer/contractor engages a design professional who can design to the required code– design is developed to the codes
- 2. Applications for the land use/planning permit as per the DPD website procedures. The land-use needs to go through the Design Review panel.
- 3. Land use permit provided
- 4. Building Permit issued
- 5. After approval, construction commences on site and in factory
- 6. Modular components shipped to site
- 7. DPD (the local government agency) receives a notification from the L&I which:
 - a. Specifies what connections, standards, and incomplete items the local enforcement agency must check when the unit is installed; and/or
 - b. Estimates the expected time of arrival of the factory-built house or commercial structure to the site.
- 8. L&I may need to inspect the unit if it is damaged in transit.
- 9. DPD may refer items to other departments –e.g. Fire Code compliance is monitored by the Seattle Fire Department, whereas the Uniform Plumbing Code is enforced by Seattle King County Public Health. For some elements, e.g. Fire Code, the codes nominate the relevant agency which will be the approving authority, and in other cases it is simply mentioned as the Approving Authority.
- 10. DPD cannot open up the walls to inspect the module i.e. concealed construction of the unit cannot be compromised if the insignia is attached.

2.6.3. Costs/Fees

At the DPD stage, costs and fees include permitting, development and construction permits for on-site work. At the L&I stage, the costs are delineated by WAC¹⁵. Typically the cost is based on a standard formula and does not take into account more expensive or less expensive construction methods. It will be:

1. Building Permit Fees:

¹⁵ <u>http://apps.leg.wa.gov/WAC/default.aspx?cite=296-150F-3000</u>

- a. Determined by a table of square footage rate of construction costs and standard tiers
- b. For \$1,000,000, this is \$5,608.75 for the first \$1,000,000 plus \$3.65 for each additional \$1,000.00, or fraction thereof;
 - i. Hence approximately 0.5% of the standard project cost and lower.

2. Additive to miscellaneous fees for design review:

- a. Structural Plan Review fee
 - i. One year design: 35% of building permit fee
 - ii. Master Plan Review: 50% of building permit fee (min 2.5hrs @ \$85.50/hr)
- b. Fire and Life safety review (required for all structures > 4000 sqft)
 - i. One year design: 15% of building permit fee
 - ii. Master Plan Design 25% of building permit fee
- c. Plumbing plan review fee (\$18 + \$6/fixture)
- d. Electrical Plan inspection and review¹⁶
 - i. For Commercial/Industrial: Determined by feeders/service first one @ \$100 + 50 per extra feeder/service
 - ii. For multi-family: first one @ \$60 + \$6 per extra per circuit
 - iii. Progress inspections: \$45/half hour
 - iv. Electrical plan review: 35% of work permit fee + \$74 (submission fee)
- e. Design renewal or submission: both charged for @ 10% bldg. permit + \$85.50
- 3. Notification fee to Local Agency (e.g. to DPD; \$37)
- 4. Insignia fee: \$273.40

As a rough guide, these fees can add up to 1-2% of the total construction cost. It should be investigated whether DPD-level inspection would result in a double up on the fees or whether the DPD fees will cover the value of substructure construction only.

¹⁶ <u>http://apps.leg.wa.gov/WAC/default.aspx?cite=296-46B-906</u>

2.7. Labor, Skills and Unions

Selection of the right project team is of significant importance for the successful delivery of modular buildings. In addition, hiring union versus non-union labors is associated with cost and quality implications.

2.7.1. Project Teaming

The consultant selection process can be more difficult with modular construction than with traditional on-site construction in many markets (Cameron and Di Carlo, 2007). It is important to work with consultants familiar with modular construction. With on-site construction, it is relatively simple to visit a completed project to gain an understanding of quality. With modular construction, it can be more challenging, primarily because there are not as many completed projects. The Pacific Northwest does not have the same experience level with modular construction as Europe or even the east coast, and therefore finding firms with the necessary experience and expertise can be a challenge in this region. In particular, structural and MEP engineering requires specialized knowledge (Garrison and Tweedie, 2011), and should be vetted.

2.7.2. Skilled Labor

With most traditional on-site construction, the contractor is able to select which subcontractors it will use, either based on cost, qualifications, or both. With modular construction, however, it is typical for the contractor to not have control over which teams are used in the factory. Paetra Orueta, project manager for Blazer Industries Inc., a manufacturing company, explains that in their employees are full-time, rather than seasonal or employed on a per project basis. Some employees specialize in certain construction techniques, and some are general construction laborers. Orueta also states that specialty work can be subcontracted if it is extensive, or highly time sensitive. In Blazer's experience, they have found that some of these extensive components can be completed at lower costs, and often more efficiently, by specialty subcontractors. Costs and quality are weighed when decided between using staff labor or subcontractors.

One significant benefit to using skilled labor in an open-shop factory setting is that each worker has the potential to work on multiple trades. Multi-trade labor helps reduce crew size since a worker can, for example, finish and paint drywall.

2.7.3. Unions

To understand union constraints, it is worthwhile to study how the issue is handled at the Atlantic Yards project in New York. The union agreement for Atlantic Yards is consider to be one of the most exciting innovations of the project.

The Atlantic Yards is a 6.5 million square foot development in Brooklyn, New York. The B2 portion of the project is a residential high rise poised to be the world's largest modular building. For unions and union activists, the project equates to the promise of jobs for members.

However, estimates have placed job creation around 190 if work can be prefabricated. The potential loss of union jobs and wages had an effect on project financing, which has caused construction delays. Mary Anne Gilmartin, director of commercial and residential development for Forest City Ratner Cos., the site's developer, stated, "*We need an agreement with labor before we can get a bank loan, and [we] are working on both*" (Post, 2011). Currently, it is reported that union labor will be used in the prefabrication factory, to a significant cost savings.

Union and Open Shop Labor

Union work ensures a quality end product; however, it is more expensive than open shop labor. In 2012, after fringes and taxes, union rates for electricians and carpenters in Seattle are close to \$60 an hour. A union ironworker is close to \$70.

Eric Franklin, of Carpenters Local 131, states that if non-union labor is used in a factory, to remain mindful of the following:

- Ensure the factories are using licensed workers to perform technical trades (MEP trades)
- Ensure that an actual, licensed supervisor is signing off on the work.
- Ensure that workers are documented.
- Ensure safety is a priority. Modular construction is often touted as a safer construction option, which can precipitate lax safety attitudes and practices. Franklin reiterated that a factory is still a dangerous setting, with dangerous tools and situations.

Franklin also went on to state that due to the nature of factory work versus on-site construction work, pay scales for union workers would be adjusted and ultimately cost less. This is similar to Atlantic Yards' estimates and finding, where a union carpenter who earns \$85 an hour on site might only earn \$35 an hour in a factory (Chaban, 2011). Tommy Key, of the National Electrical Contractors Association, however, states that at the moment electricians' base rate is not lower in a factory setting, but since fewer overall hours are worked, costs tend to be lower.

For contractors that are signatory to union labor, agreements need to be honored and implemented during factory work if the contractor or one of its entities owns the factory. However, when purchasing materials, in this case a module, from a vendor, the vendor is responsible for the decision to use a union or non-labor workforce. For the on-site portion of modular construction, such as stitch-up and finishing mate lines, union contracts need to be honored by signatory contractors.

This is a sensitive issue, and one that is likely to be clarified further as modular construction gains in popularity.

2.8. Architectural Design and Delivery

This section is a list of constraints on the innovation and progress of modular construction from an architectural design and delivery perspective. This review includes constraints outlined in previous sections and here we articulate how and in what ways these constraints impact the design process.

An analysis of case studies demonstrated some of the process constraints associated with use of modular construction methods, which are discussed in more detail in the following subsection, and are as follows:

- The amount of planning needed in the upfront design process, may be increased if the architect is not familiar with modular construction constraints.
- As compared to typical construction, there is an increased need for project coordination between architect and manufacturer and general contractor.
- Design is constrained by and has to account for the methods of shipping the modules from factory to the site.
- The module size and shape are fairly inflexible.

2.8.1. Pre-planning

First, the amount of pre-planning associated with modular construction is much greater than the development of on-site construction. According to conversations with John Harvey, IPIA Administrator and FAS Plan Review Supervisor for the Washington State Department of Labor and Industries, by the time documents are submitted to the state they should at least be in Construction Document phase. (An argument will be made later on in this report suggesting that architect and manufacturer collaborate to produce a single set of shop drawing to enlist the manufacturer in optimizing the design for fabrication and construction).

2.8.2. Procurement Methods

There are four standard routes that the client may take when going through the process of construction procurement for modular construction: design-bid-build, negotiate bid, designbuild, and strategic partnering (Garrison and Tweedie 2011). The first method known as designbid-build is the most conventional method in which the project is designed by the architect and then bid among competing builders. While this is the standard method used, it does not take advantage of the collaboration process between the architect and the manufacturer. Next, in negotiate bid, the architect and client team work with a modular manufacturer from the beginning of design and ideally a great amount of collaboration occurs in which manufacturer's standards are used as known constraints in the design process. In design-build the client and the modular manufacturer enter into a single contract where the modular manufacturer can either undergo the design process in house or involve an outside architect who completes documents created by the modular manufacturer in-house. Finally strategic partnering is when a client procures a modular manufacturer for an extended period of time to complete multiple projects.

There is a vital need for collaboration of architect and manufacturer in the design process of modular buildings. The benefits of this collaboration include:

- 1. Estimates in the early stages of the design process can provide more accurate pricing than in typical building.
- 2. Greater transparency and understanding of means and methods of construction results in ability to monitor work quality more efficiently.
- 3. Collaboration on Construction Documents provides integration of manufacturers methods into design and eliminates some of the drawing redundancy associated with construction methods. Combination of construction documents with shop drawings further streamlines process.

There are three different ways in which collaboration between the architect and the manufacturer may occur. In the first method the architect produces the set of construction drawings and then from this set the manufacturer will produce the shop drawings. This method does not take full advantage of the collaboration discussed earlier in this paper. Next, the manufacturer may be involved from the beginning in an advising role and then will begin to produce drawings at a stage in between final design development and construction documents. Finally, if using a design-build method the architect may produce bridging documents that are given to the manufacturer to complete in house.

While collaboration from the start is the preferred method for modular construction, often times the decision to use modular construction is only made after the design process is finished. In this case the general contractor or owner decides that they would like to use modular construction methods. Accordingly, the completed design drawings are translated into modular construction that maintains the plan layout and the look of the facade. This is mentioned in order to demonstrate that the constraints associated with modular housing construction are not always considered in early design development but can still be worked into the project.

2.8.3. Some Issues to Be Considered in the Design Process

Shipping Methods

As previously mentioned in the transportation section of this report, physical constraints that should be taken into account during the initial design process include the limitations of modular size and weight that are in accordance with designated shipping method and path of procurement. By deciding methods of construction early on in the design process, overall dimensions of modular size and structural methods can be established. One of the most limiting factors is the height of the shipping container in which the module is transported. As a result, ceiling heights are almost consistently limited to 12 feet high. Width and length are also subject to transportation constraints.

Inflexibility of Modular Unit and Design Implications

Also, the inflexibility of the modular unit has to be considered. While modules can be combined in order to create larger spaces, the shape is governed by the standard module size and shape. Also, the module designs tend to create structural redundancy. The goal of optimization of the system should be taken into account and perhaps leverage for acoustics in the design process.

Interior Openings

The size of a typical module structure results in a typical opening dimension of 8'-0". However, openings as wide as 9'-6" are possible without any modifications. If a clear span opening is desired, there are a couple choices of ways in which to modify the module in order to create the desired effect. Clear span openings can be achieved by: increasing beam depth, incorporating of interstitial truss modules, or welding frames across mate line.

Mechanical, Electrical and Plumbing Systems

Because of the nature of modular construction, a decentralized MEP system is the most common form of distribution. One reason for a decentralized system is because of the limitations on the ceiling height of modules which does not allow enough room for these system to be placed within the ceiling. Also, by decentralizing the system and treating each module as more or less self-contained, the architect can play with alternative design choices of component interaction. Thirdly, decentralization also allows for a higher quality of environmental control within each module (Garrison and Tweedie, 2011).

It is important for the architect to note that hookups are connected after the module is placed on site, requiring field access. This can be accomodated by the removal of floor or wall panels and should be integrated into the design of interior and exterior finishes.

2.9. Regional manufacturing

As part of our investigation, we examined the capabilities required for a regional manufacturer of modules and idenified some of the major regional players.

2.9.1. Inside Factory

The Factory Environment

There are two typical types of manufacturing processes, an assembly line and static production. In an assembly line, the product moves through different stations while fabrication is complete. In static production, the workers move to the module. A benefit to the static assembly option is that it mimics a typical jobsite. A benefit to an assembly line process is that any mistakes are identified earlier than in the static production process (Cameron and Di Carlo, 2007).

Capabilities

Manufacturers' output capabilities depend on the size of the facility and the overall design of the modules. Production varies between 100 single-family homes a year at smaller fabrication warehouses, to 12,000 square feet a day at some of the larger facilities (Cameron and Di Carlo, 2007). At the Marysville, Washington location of Whitley Manufacturing, they typically employ 35 to 70 skilled workers, depending on the project. Another factor to consider when assessing a factory's capabilities is whether they specialize in wood or steel construction. Many manufacturers in the Pacific Northwest use wood framing, and transportation costs may increase if a factory in a different geographical region is selected.

It is also possible for larger developers and contractors to start and run their own factory. Gene Rega, preconstruction director at Skanska, states that the manufacturing facility used at Atlantic Yards B2 will be a Skanska-owned facility.

Finishes and Stitch-Up

The goal of modular construction is to complete as much as possible in the factory setting. Units are typically shipped at 60% - 80% finished. There will still be, however, requirements for on-site construction trades, to attach and seam the units when put in place, especially depending on the level of finish completed in manufacturing. In addition to site preparation and foundation work, there are common components that would not typically be completed in the factory. There is a higher probability for damage to these areas if they were completed early, but more importantly, it is difficult to design these components with the necessary matching seams and lines needed for stitch-up. These areas commonly include:

- Flooring Finishes
- Ceiling Finishes
- Casework
- Exterior Cladding

Given that it is sometimes difficult to align factory installed finishes once on-site, consideration can be made whether to completely install them on-site, or to partially install them in the factory. Manufacturers are able to finish a majority of the module, leaving mate-lines unfinished so they can be completed and aligned in the field. On-site workers will be needed to stitch-up the modules. Jessica Fabro, at OneBuild in Seattle, states that a good estimate to use for conceptual cost estimates is approximately \$1,500 per module.

2.9.2. Manufacturers

Part of the study involved canvassing the current market for regional manufacturers involved in the prefabricated modular scene. We have specifically avoided looking at manufactured home builders as these specialize predominantly in single-family homes, which is a rather well established market and not the main focus of this study.

To determine the main modular manufacturers within the industry we relied on several resources including the main body representing the interests of the industry, the Modular Building Institute (MBI), informal networks with parties involved in the construction industry, and internet searching. We found that in the local Seattle region the industry is very much in its infancy. The players headquartered in Seattle are mainly new companies (started within the last 5 years). Such names include OneBuild (est. 2010), Sustainable Living Innovations (est. 2008) and Method Homes (est. 2007). Whilst Seattle does not have any large home-grown modular manufacturers, that is not to say that modular projects are not happening in Seattle. Rather, it seems to be that the established operators that are active in Seattle are based in other states within the Pacific Northwest such as Idaho, Oregon and across the border in British Columbia.

Some of the companies operating within the Pacific Northwest in the multi-family market include:

- 1. Guerdon (Idaho-based)
- 2. Whitley Industries (Indiana-based but with a factory in Washington formerly Evergreen
- 3. Blazer Industries (Oregon-based)
- 4. Sustainable Living Innovations (Seattle-based)
- 5. One Build (Seattle-based)
- 6. Method Homes (Seattle-based)
- 7. Britco (based in British Columbia)
- 8. Shelter Industries (based in British Columbia)

We have provided company profiles on 6 of these players. The manufacturers specifically addressed are those doing/those have previously done multi-family projects within the Seattle region. The manufacturing profile detail manufacturing capabilities, project history and construction methods.

Table 4. Major Regional Modular Manufacturers

	Distance from Seattle (Mile)	Production Cost per sqft	No. of Modules per month	First module Manufacturing time	Typical Module size	Construction Material
Guerdon	510	N/A	100	7 days	N/A	Wood frame
Whitley	40	65-500	12-16	N/A	14' x 60-66'	All
Blazer	230	N/A	60	N/A	14' x 64'	All
SLI	0	N/A	N/A	N/A	N/A	Steel frame
One Build	450	75-150	30	12 days	15' x 60-68'	Wood, Steel and SIPs
Method Homes	100	150	~3-4	1.5 months	16' x 65'	Wood frame

National players which have performed significant projects outside of the northwest but which have held discussions with local players include modular companies such as Warrior Group of Texas. Both Hensel Phelps and Absher Construction have held discussions with Warrior Group of Texas, who is a significant player nationally. Hensel Phelps was the GC on a major 1.6 million square foot multi-family project (in Texas) involving Warrior Group as the modular supplier.

In addition, the Canadian companies are well developed in the prefab modular industry. A strong reason for this may be the fact that initially the oil and mining industry in remote regions of Canada have driven prefab modular demand, and this form of construction technology has flowed onto less remote regions of Canada. As a result, both Shelter and Britco seem to be established players in their respective fields – exporting to the USA and Asia.

General Contractors do not equate to Modular Manufacturers:

A majority of these contractors specialize in only the manufacturing side of projects. They are not the main developers nor are they the general contractor. Hence on any given project, they are usually subcontracted to the General Contractor.

We informally interviewed the representatives of a number of general contractors in Seattle to confirm industry opinions on prefab modular. The companies included:

- Absher Construction
- Lease Crutcher Lewis
- Walsh Construction Company (Seattle)
- Howard S Wright/Balfour Beatty
- Hensel Phelps
- Rushforth Construction

Of the above names, Walsh, Absher, Howard S Wright and Hensel Phelps have recently completed or are in the midst of construction for modular prefab projects; usually with a modular manufacturer as a partner. An interesting question is why the general contractor has

not generally been the same company as the prefab modular manufacturer. Several dominant reasons exist for this in Seattle which have been informed with discussions with modular manufacturers and general contractors:

- 1. Newer smaller companies, such as One Build, do not have sufficient bonding capacity (which can be 5-10% of the project value) and hence, cannot post a bond for the purposes of a large project in its entirety.
- 2. General Contractors have much more on-site expertise and hence lower costs in doing the site works than the modular manufacturers, hence the modular manufacturers do not generally perform site work.
- Small to mid-size general contractors seem unwilling to take the risk of new technology and construction systems such as modular prefab unless there is significant proven benefits and demand for the modular construction type – a 'wait and see' approach. Hence, subcontracting allows the shifting of risk to those who have the most expertise.
- 4. Inherently developers being the financiers and hence owners of projects have driven the process of the project design. They have decision-making ability and often drive the decisions to use modular manufacturing. General contractors are generally risk averse. Developers in adopting modular are led by market demand for modular apartments, but the flipside is perhaps that lack of understanding of the process has held back modular adoption by developers.
- 5. Designers have been the drivers for construction innovation, and play a critical role in specifying the modular construction methods for a project.

Whilst we have found that the general contractor side has been somewhat reluctant to embrace prefab modular in its entirety we do note that prefabrication has been utilized it to some extent in a smaller capacity, e.g. precast panels, or panelized/assembly based systems, prefab of MEP.

Manufacturel: One bunu					
City/State/Country	Experience (yrs)	Capacity (module/yr)			
Seattle, WA	2 (previously operated as Transform	1/day (after the first 12 days lead up			
	and IBS) –established 2010	time)			
	Extent of completion	Project type:			
	85%	Multi-family, Hotels			
Total no. of completed projects	Module dimensions	Structural type:			
1 (senior housing in Vancouver)	68ft length x 15ft wide x12ft high	Wood frame modules, Light Gauge			
		and SIPs also possible			
Address:		Tel:			
1326 Fifth Ave, Suite 459		(206) 801 1675			
Seattle, WA 98101					
For information and photos, click <u>here</u> .					
Overview One Build is a new company (2 year	s old) that was formed by Dale Sperling fr	nmerly the CEO of LINICO properties			

The company is mainly interested in multi-family and hotel projects, and is interested in mainly higher quality projects. One Build consists of the assets of Transform – a modular builder from Mt Vernon and Bellingham, WA, and the production facility of One Build is that of Integrated Building Solutions (IBS) which was a manufacturer of light steel gauge panels, SIP panels and also acted as a modular builder.

Methods:

- Modules are built in the factory and transported to site by a semi-trailer.
- Typically modules are 85% complete in the factory, finished on the inside and wrapped in Tyvek.
- The system is a fully automated assembly line and involves computerized cutting machines
- One Build's system is approx. 30-50% faster than on site and production takes approx. 12 days
- Almost 1 module can be produced per day after that.

Modules:

- Longest 68ft length x 15ft wide x12ft high
- Up to 16ft
- Base: \$3700 per module transport from factory to site from OR to Seattle
- Setting with crane: \$1500 per module
- Material Cost: material about the same
- Cost: \$75 psf (inc overhead and margin) up to \$120 psf

Skills/Labor/Capabilities:

- Onebuild Framing is automated
- Specialist trades subcontracted
- 20 factory staff as at 2011.
- Cost: can be between \$80-250psf (depends on level of finishes)
- Factory located in Klamath Falls, Oregon

Targeted Area:

• Seattle at present, OR, WA, ID there is reciprocity.

Timeframe:

- 12-14 months vs. 22 months for a conventional project
- 4-5 weeks site work, 8 crane picks per day, Button up required for marriage line between modules

Manufacturer: Whitley Manufacturing				
City/State/Country	Experience (yrs)	Capacity (module/yr)		
Indiana, USA	Since WW2 – veterans housing	Ramp up – 3 to 4 Modules per		
		week in WA factory		
	Extent of completion	Project type:		
	80-90%	Commercial and Educational		
Total no. of completed projects	Module dimensions	Structural type:		
40,000 units	14 x 60-66ft long – optimal	All		
Address:		Tel:		
Based in Indiana – 3 factories.		+1 (360) 653-5790		
Washington factory located at:		+1 (360) 659-7735 fax		
Whitley Evergreen, 14219 Smokey Point				
For information and photos, click <u>here</u> .				

Overview

- Commercial aspect mainly, offices and educational, up to full campuses
- Not much in multifamily
- Completed almost 40,000 units in its almost 70 year history

Modules:

- Typically for multifamily
- Typically: 14ft wide, up 16ft (any larger it gets called a superload), 72ft long– DOT restrictions
- If the width is over 8-10 ft in Seattle it may need to be hauled at night
- Height under 13ft 2' (bottom to top of highest projection) this allows you to put a trailer under it
- \$100sf factory costs (range: \$65-500/sf)

Extent of Completion - Protection

- Custom projects so may vary drywall typically in and painted and finished, as much as possible
- Temporary heat may be used while modules are being stored
- Protection: tarps and membrane roofing, walls covered with plastic

All Structural types:

• Container box (20'x 8' or 40' x 8'), wood frame, steel frame, clear-span, slab on grade

Timeframe:

• Varies – A 21,000 sqft dormitory (accommodates 68 in 4 stories) was finished in 90 days

Transport:

• Varies: \$3000-5500up to 300 miles

Examples of multifamily:

- Frank & Anne Oropeza Hall, Indiana Institute of Technology 21,000 sqft dorm facility, 4 stories, 68 beds
- Evans Kimmel Hall, Indiana Institute of Techniology 4 stories, approx. 72 beds
- Rogers-Yergens Hall (3-Story Dormitory) 18,000 sqft dorm, 3 stories, 45 beds

Manufacturer: Sustainable Living Innovations (SLI)				
City/State/Country	Experience (yrs)	Capacity (module/yr)		
Seattle, WA	Founded in 2008; Offshoot of	N/A		
CollinsWoerman, DCI, McKinstr				
	and Lydig construction			
	Extent of completion	Project type:		
		Hotels, Housing, Resorts		
Total no. of completed projects	Module dimensions	Structural type:		
Prototype only	Panelized system	All		
Address:		Tel:		
710 Second Avenue Suite 1400, Seattle, Washington 98104-1710		Rick Osterhout: (206) 245-2100		
For information and photos, click <u>here</u> .				

Overview

SLI is a new company set up to provide a scalable form of construction of medium rise structures. It is particularly tailored to efficient construction of housing, in terms of time and product waste by using prefabricated off-site components and a standardized system of construction. The SLI product is particularly tailored to multi-family housing/accommodation.

Method of Construction/Modules:

- The system is not modular per-se but is built out of componentized/panelized parts and assemblies which are assembled on site.
- After substructure work, post tensioned concrete floor slabs are poured on site. 2. A structural steel frame is erected. This is generally externally located similar to an exoskeleton.
- The wall and internal assemblies are brought onto site and installed. These may include panelized floors with the ceiling substrate already in place.
- Individual floor is then hoisted to the highest floor. Working from the top floor downwards, hence the next highest floor is brought in etc.
- The glass wall façade of the building is installed.
- SLI teams up with the GC, and hence SLI is a supply chain management organization as such.
- Structural steel assembly is done by the steel sub. Site work and substructure is done by the GC.

Positive design features

- More usable space a saving of 20% space overall 10% less common space required, 10% less wasted space in each unit
- No internal point is less than 20ft from a window
- Floor to ceiling glass walls
- Heat recovery from the grey water system
- The targeted level of quality is higher than that of the market. Hence the system is not intended to be 'cheaper' but rather better value.

Structural types:

• Steel braced frame structure

Timeframe:

• Delivery for a standard building supposed to be 6-9 months (commencement to end)

Targeted areas:

• Seattle, San Francisco, New York

Manufacturer: Method Homes					
City/State/Country	Experience (yrs)	Capacity (module/yr)			
Seattle, WA	5 years (since 2007)	20,000 sqft/year			
		Approx 15-20 projects per year			
	Extent of completion	Project type:			
	85-90%	Housing, Resorts			
Total no. of completed projects	Module dimensions	Structural type:			
Not confirmed	Up to 16 x 65 ft	Wood frame			
20 cabins completed; 18 projects in					
2011; 10 homes in 2010; 2 homes in					
2009; 1 home in 2008					

Address:	Reference:	Tel:		
2921 Eastlake Ave. E.	Senior Project Manager	206.789.5553		
Seattle, WA 98102	Bec Chapin			
For information and photos, click here				

For information and photos, click here.

Overview

Method Homes is an organically grown company setup by Mark Rylant (a builder) and Brian Abramson (a commercial real estate broker). In an interview with the Puget Sound Business Journal (Oct 12-18 2012), the founders stated that the company was first started to provide prefab vacation homes to people in the northwest - in particular to remote sites where weather was poor and skilled labor hard to find. As a result the company first started focusing on vacation homes and in particular cabins.

Method of Construction/Modules:

Method homes projects are designed for modular but traditionally built inside the factory in Ferndale. There is no overhead cranes, no assembly line as such. The main construction typology is a wood frame system. Method Homes can also act as the general contractor through their sister company Method Contracting. However it is essentially up to the owner to decide which general contractor they wish to use. If several modules are combined for one unit (3 units may be combined together) the tie in system/detailing may be as follows:

- Use of special timberlocks/steel hold-downs and in those areas no drywall will be used
- Leaving one side unclad so as not to be over-width
- Leaving off drywall at structural connections
- Finishes left off to 2 feet either side of the connection point (marriage line) e.g the wood paneling may be setup

Construction Typology:

- A standard construction type may be: 2x6 wood-frame construction with strengthening around openings by use of aluminum frames/steel members; Batt insulation; Drywall – structural mod board; 50/50 rigid wrap for the exterior Window walls may make use of a steel column/beam
- Typical sizes quoted are 14-16 x 65ft. Maximal dimensions are 22ft width and 72ft long
- It was noted that much wider units add to transportation costs, and longer/wider units get too heavy with resulting drywall cracks

Extent of Completion/Design:

- 85-90% complete prior to being brought to site
- Method Homes tends to have 2 types of modular buildings:
 - a. Modular built according to a standardized design; i.e. off the shelf plans which encompasses those on their website for instance their Cabin Series, M Series, HOMB Series, Option Series, Paradigm Series
 - b. Non-modular designs which are 'converted' to modular these include one off projects such as ski resorts/cabins
- There is a notable architecture fee saving with standardized designs, as the design fee is limited to a small royalty for the plans, and to any significant design changes (some minor changes included in the pricing).

Structural types:

• Wood frame construction

Costs:

• Typically \$150/sqft and site costs on top. A range of \$130-220 sqft for the prefab construction cost (excluding soft costs – design, engineering, permitting and excluding site costs)

• Standardized units can cost from \$80,000 upwards for a 565sqft unit (1BR,1Bath) with 123sqft deck

Timeframe

- Typically this may be 1-3 months for a unit (one unit sighted in the factory took 2 months due to waiting for MEP equipment). For a new build the company typically takes 3 months.
- On-site work usually takes 2 weeks 2 months

Transport:

A typical module to transport will cost \$1000 to Seattle (from Ferndale); \$14,000 to LA

Targeted areas/markets:

The company specializes in high end commercial/residential, and markets itself as a green/sustainable builder. A particular market segment that Method homes is looking at includes cabins/remote location properties. Method is looking to grow in California and the East Coast, but is taking an organic approach to growth.

Examples of multi-family:

According to the Puget Sound article, Method Homes is planning to build:

- A modular motel in BC, Canada
- An apartment complex in Portland
- An apartment complex in Bellingham

Manufacturer: Blazer Industries				
City/State/Country	Experience (yrs)	Capacity (module/yr)		
Aumsville, OR	36	\$39 million/year		
	Founded in 1976	Average over last 7 yrs:		
		454,000 sf		
		750 modules/year		
	Extent of completion	Project type:		
	90-95%	Education, Commercial – Office &		
		Retail mainly, Specialty,		
		Residential (least)		
Total no. of completed projects	Module dimensions	Structural type:		
17,000 units	14' x 64'	Wood-frame, light gauge and SIPs		
		also possible		
Address:		Tel:		
945 Olney Street, P.O. Box 489, Aumsville, OR 97325		Paetra Orueta: 503-749-1900		
For information and photos, click <u>here</u> .				

Overview

Blazer Industries is a company setup in 1976 to provide mobile restroom buildings. This later changed to include mobile office trailers and commercial buildings. In the 2000s the company started on concrete block buildings like restrooms, and specialty products like Starbucks drive-throughs, Fast Lube buildings and custom houses. They are particularly experienced in the northwest.

Method of Construction/Modules:

Blazer produces a large range of module designs - usually wood frame construction inside a factory but also do concrete block buildings and have capability with light gauge steel and SIP panels.

Framing in one area, level and bolt together in another area, then completed as much as possible inside the

factory. It is then disassembled thereafter for transportation. Module size is typically 14' x 64', but can go up to 16' x 70'

Non-union labor is used, on site work (if required) is paid at the prevailing wage rates

Extent of Completion/Design:

Varies across projects.

Timeframe:

Typically 550 hours per month for a basic 2 module classroom. Can produce 60+ modules per month.

Manufacturing Facilities:

Aumsville, OR - commercial Stayton, OR – residential Total: 155,000 sqft, 24,000 sqft warehouse space Over last 7 years Blazer has done an average of 454,000 sqft of modules adding up to 750 modules, 450 buildings and \$25 million of work per annum

Transport:

Dealers handle transport and usually use trucking companies that specialize in moving modular buildings. Modular units are up to 63,000 lbs.

Transport can be anywhere from \$800 to \$12,000. This can be reduced by splitting modules into 2 smaller pieces.

Transport to further areas- Hawaii/Alaska are shipped to Seattle and then by barge.

Craning costs: Typically \$3500 crane mobilisation (in/out) fees, \$150 p/h craning cost

Targeted areas/segments:

Pacific Northwest, and Hawaii, Alaska and California.

Educational projects are generally cost driven – especially the portable classroom market. Blazers product is one of higher quality (also potentially higher prices) and hence the company is targeting more commercial builds.

Past work:

STEM school in Redmond. 161 modular units, 63,000 sqft Blazer supplied modular units for Absher Construction (the GC) on this project (http://www.absherco.com/portfolio/in-progress/stem-secondary-school/)

Manufacturer: Guerdon Enterprises				
City/State/Country	Experience (yrs)	Capacity (module/yr)		
Boise, ID	11	1,200 modules per year		
	Extent of	Project type:		
	completion	Multi-family (majority of projects),		
	90-95%	Single-family, Commercial		
		(office/hotels), Government housing		
Total no. of completed projects		Structural type: Wood-frame		
Address:		Phone: 800-473-3586		
556 South Federal Way		Fax: 208-336-9269		
Boise, ID 83716		info@guerdon.com		
For information and photos, click <u>here</u> .				

Overview

Guerdon is a leading modular manufacturer and one of the main modular manufacturers in the western USA.

Extent of Completion/Design:

Varies across projects. In-house engineering and drafting staff with experience in MEP, Structural, green building and code compliance.

Timeframe:

Typically the first module can be churned out in 1 week. Delivery can be done in 3 months. 2/3 of the time taken off of the construction process. 70% of the work done in the factory, 30% done on site

Manufacturing Facilities:

• Primary 20-acre site; 125,000 square feet of production area; Additional plant with 30,000 square feet facility for steel fabrication and overflow production capacity; Assembly line process with 24 line stations; Annual capacity of 1200+ modules/year

Transport:

Organized and arranged for by Guerdon. – in storage in Boise, insurance protection, delivery, staging and storage near the site and transportation to the crane. Guerdon owns 200+ special purpose trailers for use in bringing the modules to site until craning occurs and these are reused. Typically transported 600 miles away.

Targeted areas/segments:

• 10 western USA states, Canada and Alaska

Examples of multifamily:

- Cahill Park in San Jose 160 units, townhouses (3 stories), \$28 M project value, 13 months
- Harbour Landing in Regina, Saskatchewan 314 rental apartments, \$30 million, approx. 6-7 months (site work until C of O)
- Fort Lewis Town Center in Fort Lewis, WA 220 units (350,000 sqft), 17 months

3. OPPORTUNITIES

The main opportunities associated with modular prefab buildings can be categorized into three groups of schedule, cost and quality opportunities.

3.1. Schedule

Modular construction allows for compression of the building schedule, due to the ability to overlap module construction with site work similar to fast-track design-build construction.

Some questions remain as to whether the permitting and design process will have the same duration as site-built construction or if it will take longer due to the unfamiliarity of the building department with modular construction.

A McGraw-Hill study found that in 66% of modular and prefabricated construction projects the schedule was positively affected with time savings of 4 weeks or more in 35% of projects. For the 34% of projects not reporting time savings, 6% said that prefabrication/modularization increased the project's duration while the other 28% noted that prefabrication/modularization made no difference to the project's schedule. The schedule was measured from the beginning of design through project completion. Time savings are achieved through concurrent factory and on-site work, fewer weather delays, and less on-site material staging. For modular projects, design is often more time intensive due to the added degree of coordination necessary to allow for module fabrication (McGraw Hill Construction, 2011).

Due to the highly customized nature of modular fabrication, it is difficult to find metrics for average production rates. This is also due to the small number of manufacturers currently building large-scale projects in the United States as well as the propriety nature of the industry.

In factory schedule for module assembly varies substantially from project to project depending on the complexity of each module and the degree to which modules within the building are alike. One manufacturer noted that a standard two-module classroom could be completed in 550 man-hours in factory. Other manufacturer's cited times ranging from 12 days to 3 months for the manufacture of single units. Other quotes we received include: 4 modules/day, 20,000 sf/yr, 1-3 months/unit, 21000 sf/3 mo, 3-4 modules/ week, and 1/day.

Large manufacturers interviewed cited production rates of up to four modules per day. For smaller manufacturers the production rate can be much slower producing less than one module per day and at the slowest producing one module every few months. This rate is subject to a high degree of variability depending on the project and module complexity. Once completed, modules can be stored until they are ready for site delivery assuming adequate storage space exists at the factory.

The degree to which modules are complete when sent to the site also varies substantially from project to project. Many manufacturers recommend completing the modules to the greatest

extent possible to minimize on-site construction time. For multi-module buildings, finishing around connection points on site is recommended to allow for greater installation tolerances.

3.2. Costs

A recent McGraw-Hill survey indicated that 65% of firms currently using prefabrication or modular construction reported reductions in their project budgets (McGraw-Hill, 2011). A majority of these costs are due to secondary items, such as a shorter construction schedule, the reduction of expensive labor, less waste, and increased quality control.

The previous section outlined specific scheduling opportunities, but it is also worth briefly mentioning here. According to Jeff Brink, structural engineer at DCI, the shortened construction schedule is the biggest cost opportunity on a modular project. Reducing the time that large expenses, such as cranes and hoists, are needed on site is a reduction in the overall project budget. An accelerated construction schedule also means that owners can carry their financing costs for shorter periods (Pickerell, 2012). Simply put, time is money.

Labor Rates

Work in a factory can be done quicker than work on-site, due to the controlled climate, ergonomic factory organization, and optimized repetition. Eric Franklin, from Carpenters Local 131, states that based on commuting distance and scheduling consistencies, base wages for union carpenters would be lower in a factory setting than they would be on a typical construction site. Franklin did not give specific examples for what that reduced pay rate might be, but estimates at Atlantic Yards B2, in Brooklyn, New York, state that workers who might typically earn \$85 in the field, would earn \$35 in a factory (Chaban, 2011).

Franklin also mentioned that the carpenters' union realizes that modular construction is the wave of the future, and accordingly does not see an adversarial relationship with it, especially if contractors keep the door of communication open on projects. Tommy Key, of the National Electrical Contractors Association, echoes this general premise. Key states that the electrical unions may not be in total favor, but realize this is the only way to work and maintain a share in certain markets.

Even within open-shop conditions, there is an opportunity for cost savings depending on the factory's location. Shipping costs would need to be weighed against labor cost savings, but a factory in a more rural setting may have lower overhead than an urban factory.

Crew Size

Because of the condensed setting in a manufacturing facility, and because of the speed of construction, crew sizes in a factory are smaller than they would be on site. The University of Washington Medical Center Expansion project, a \$130 million project in Seattle, had roughly 300 subcontractors and field workers on site. Meanwhile, estimates for the Atlantic Yards B2 building, a 32-story apartment tower slated to be the world's largest modular construction project, is estimated to take 190 factory workers (Bagli, 2011). Construction crews operating in a factory setting might not always get a lower hourly base rate, but with a smaller crew size and reduced schedule, cost opportunities are present.

Materials

McGraw-Hill reports that 47% of survey respondents cited reduced materials and installation prices on modular construction. There is debate on whether modular construction uses more or less materials, so this statistic is particularly interesting. McGraw-Hill mentions that owner interviews suggest that many find prefabrication's overall quality much higher, so even if materials costs are more expensive, it is worth the premium. Jeff Brink, of DCI Engineers, mentions that a majority of the projects he has worked with have broken even with, or spent a bit more on, materials costs when compared to on-site construction.

One possible way to save on materials costs is when the manufacturer purchases the items in bulk at the beginning of the execution of the contract (Cameron and Di Carlo, 2007), thereby reducing the potential for price escalations and repeated delivery fees.

3.3. Quality Opportunities

Opportunities associated with modular construction are not limited to schedule and costs. This section is a discussion of the opportunities for higher quality in modular construction. Modular projects report lower errors and defects, higher worker productivity and safety, improved material quality, building performance, and improved sustainability.

Lower defects and rework

Because components of modular units are constructed in a factory setting, the overall process can result in a higher quality product. In the factory, workers can mock up an entire module and work out many of the design defects before the rest of production begins. This process can reduce the amount of unseen defects associated with typical on-site stick built construction. Also, building within a factory allows for a greater consistency of parts and makes it much easier to reproduce the module quickly and accurately (this is a typical characteristic of a factory assembly line). The assembly line technique allow for close tolerance, standardization, predictability and consistency among parts.

Also, before modular units are placed and stitched-up, supervisors and workers alike have a unique advantage to inspect work from both, or all, sides. The occurrence of defects is decreased when the process is so visible (Garrison and Tweedie, 2011). Monitoring assemblies as they are installed, as well as the unit's construction as a whole, can help ensure lower incidents of error or defect, which in turn could help speed up the overall schedule and keep costs down.

Worker Productivity and Safety

Modular factories provide the opportunity to work within a controlled environment, away from the elements of on-site construction. For instance, many moisture issues are eliminated simply by moving construction indoors.

The factory setting also allows for easier access to technology. Computers with the latest construction documents, or 3-D modeling information, can be provided and readily accessible. This helps cut down on assumptions and communication errors, and ensure employees are working from the most current set of plans and specifications.

The factory setting also offers improved physical access to workstations, as well as a faster flow of work. Improved ergonomics, and working on a ground level rather than multiple stories above the ground, helps keep workers safe and focused. Additionally, tools and materials are centrally located. Rather than lugging equipment from floor to floor, factory workers are able to move from module to module, or even have the module come to them. This helps create a production flow, and enables the overall schedule decrease.

Building Performance

Performance and quality of acoustics, insulation, air infiltration and structural capacities are all increased in modular construction when compared to quality of on-site stick built construction.

First, acoustics in modular building are usually better as a result of the inherent qualities of multi-unit construction. Because each module is framed independently, there is no chance for direct sound transfer allowing for a more isolated environment (Garrison and Tweedie, 2011). This is an important aspect to consider in apartment complexes with many units. Furthermore, additional acoustical barriers can easily be added and integrated in each module increasing the isolation.

Attaching the insulation and vapor barrier in the factory lends to a much higher quality installation than what can typically be achieved by on-site construction crews (Garrison and Tweedie, 2011). As a result of the higher degree of quality installation and workmanship the air infiltration can be expected to be much less in a modular building. According to an essay by Ed Zdon on Permanent Modular Construction, testing by the U.S. Army Corps of Engineers determined that air infiltration for permanent modular buildings was as much as 49% less than the Corps' stringent guidelines for building tightness and low air infiltration (Zdon, 2012). This results in a higher thermal performance as well as an increased quality in indoor air.

While conventional buildings are often prone to leaks in walls around windows, roofs, and floor joints this is not a problem in modular buildings because everything is carefully sealed in the factory setting. Walls are built with electrical and plumbing included and sealed before they are fully constructed. Further, insulation comes from the air barriers between modules, which are sealed when the permanent roofing system is attached. The enhanced building performance is important when considering sustainable aspects of modular construction (Zdon, 2012).

Sustainability

Inherent to modular construction are aspects that provide an increase in the sustainability of a modular project. According to a report published in the Journal of Industrial Ecology, modular construction has fewer impacts, on average, than on site construction for all environmental impact categories studied (Quale *et al* 2012). The factory assembly of modular construction lends itself to an increase in sustainability opportunities associated with LEED. First, off-site modular construction provides a factory setting in which to test and utilize technological advancements. This is a result of the ability for a factory to mock-up entire modules before production as well as the ability to take advantage of reproduction of a single or few different types of modules. Second, there is not a lot of on-site construction that typically produces significant particle matter, run off and pollutants. Associated with pollutants from on-site construction other less quantifiable disturbances to adjacent sites such as noise and traffic congestion are also greatly reduced as a result of decreased on-site construction. Along with decreased pollutants, air infiltration and air quality are greatly increased in modular construction and are associated with improvements in the energy performance of modular apartments.

Next, the issue of recycling and waste is potentially more manageable in modular building. As discussed earlier in the section on quality in factories, the assembly line techniques associated with off-site factory construction allow predictability and consistency among parts; this significantly reduces building waste of modular constructed projects. The use of steel is also

beneficial because the recyclability is much higher than other building materials. Finally, the modularity increases the ease associated with the disassembling of parts required in order to recycle building materials after the building is no longer used.

The life of the building plays a key part in determining sustainability. The factory setting makes it possible for a higher quality in construction and in turn increases the expected longevity of the life of the structure. Many projects such as The Modules at Templetown are also taking advantage of technologically advanced green features. This student housing project located in Philadelphia, incorporates a water source heating and cooling system along with a highly insulated building façade for a major reduction in the building's year round energy consumption. Additionally, The Modules at Templetown incorporate a storm water management system, green roof and pervious paving which results in a major reduction of water runoff (Meinhold, 2012). While these aspects of sustainability mentioned above are possible in any form of construction type, modular building seems to present an easier setting in which to employ these methods.

4. CASE-STUDIES

Location Brooklyn, NY Construction cor Skanska USA Buil Project value (\$) 130,000,000 Number of unit 1 363	npany Iding	Owner Forest City Ratner Manufacturer XSite Modular & Forest City Ratner Project size (sf) 340,000		
Brooklyn, NY Construction cor Skanska USA Buil Project value (\$) 130,000,000 Number of unit t 363	npany ding types	Forest City Ratner Manufacturer XSite Modular & Forest City Ratner Project size (sf) 340,000		
Skanska USA Buil Project value (\$) 130,000,000 Number of unit t 363	npany Iding	XSite Modular & Forest City Ratner Project size (sf) 340,000		
Project value (\$) 130,000,000 Number of unit t 363	types	Project size (sf) 340,000		
130,000,000 Number of unit 1 363	types	340,000		
Number of unit t 363	types			
363		Unit size(s) (sf)		
		Avg. 940		
Project overview B2 is the first of three new residential towers envisioned to cradle the Barclays Center arena, and is part of a \$49 billion, 22-acre Atlantic Yards project in Brooklyn. The 3 new residential buildings will contain a total of approximately 1500 units of residential housing. B2 will be the first of the residential buildings to break ground, and at 32 stories and 363 units, will be the tallest modular building in the world.				
		Potential Cons		
 Reduced schedule up to 4-6 months Reduced labor to approx. 190 factory workers Reduced costs by up to 25% Ease of construction Innovation and trendsetting 		nts IM during design		
Additional Information Additional Information Approximately 150 studios, 165 one-bedrooms, and 48 two-bedrooms. Approximately 4,000sf of retail on the ground floor, and 20,000sf of arena storage in the cellar and base of B2. Expected to achieve LEED Silver As designed, only 17 of the 930 modules are exactly the same. Potential to be world's tallest modular building Used 25-story dorm in England as its model Prefabrication can reduce the construction schedule by 4-6 months Forest City Ratner is in talks with the City regarding permits and unions. If labor agreements cannot be reached, B2 will be constructed without modules. Forest City and XSite are setting up a prefabrication factory a few miles from the site High use and coordination of VDC-BIM during design phase Each module will have a tubular-steel chassis, and a single point of electrical connection (units will be wired in the factory) Scheduled to break ground in December 2012 For further reading, click here and here.				
	63 Itial towers en tic Yards proje 500 units of re nd, and at 32 s Is Dry workers s, 165 one-bec retail on the gr Silver e 930 modules lest modular b gland as its mo the constructi ks with the City I be constructe etting up a pre of VDC-BIM d ubular-steel ch factory) ember 2012 d here.	63 Itial towers envisioned to cradle tic Yards project in Brooklyn. Th 500 units of residential housing. nd, and at 32 stories and 363 ur Is 1. Labor agreeme Is 1. Labor agreeme Ory workers 2. Permits 3. Heavy use of Bl 4. 5. s, 165 one-bedrooms, and 48 tw retail on the ground floor, and 2 Silver 930 modules are exactly the salest modular building gland as its model the construction schedule by 4- ks with the City regarding permited be constructed without module etting up a prefabrication factor of VDC-BIM during design phase ubular-steel chassis, and a single factory) ember 2012 d here.		

Case Study 2 - SOMA Studios, US					
Project name	Location	Owner			
SOMA Studios	San Francisco, CA	Panoramic Interests (Berkeley, CA)			
Architecture firm	Construction company	Manufacturer			
Lowney (Construction) and					
Trachtenberg (Façade)	Pankow	ZETA			
Construction year	Project value (\$)	Project size (sf)			
2012	\$4.5 - \$5M	~15,000			
Number of floors	Number of unit types	Unit size(s) (sf)			
4	23	300			

SOMA Studios, or 38 Harriet St., is a 4-story LEED Platinum residential project. The building will include 5 or 6 units per floor, an elevator, lobby, and 1,000 sf backyard. Units are 300 sf which is a design that fits with the growing demand for MicroHousing within dense urban communities such as San Francisco. The cost for the project comes in around \$200,000 per unit, and each apartment will rent for around \$6/sf.

Units are 12' x 29' and come pre-furnished. To make the design less claustrophobic, ceilings are 9' high and windows are 7' high.

Pros	Cons
1. Factory located within 100 miles of site	1. Outside of target demographic, not
2. Micro Housing design catered toward existing	marketable
and growing demographic	2. Urban setting limits size of project
3. Factory control allows for superior product	
(sound insulation, LEED)	

Additional Information

- Factory is owned by ZETA, which is 91,000 sf, and can produce 300-400 homes annually
- Modules for SOMA Studios trucked over Bay Bridge from ZETA's Sacramento factory
- Estimated construction time for traditional construction of this project was 13 months
- Modular building process took 3 months
- Modular erection of all 4 floors took 4 days
- Green features incorporated into design LEED Platinum achieved
- 50-90% less waste used on project due to controlled factory setting and procurement

For further reading, click <u>here</u>, <u>here</u> and <u>here</u>.

Case Study 3 – The Modules, US				
Location	Owner			
Philadelphia, Pennsylvania	Carlisle Street Partners, LLC			
Construction company	Manufacturer			
Equinox Management &	Equinox Management &			
Construction, LLC	Construction, LLC			
Project value (\$)	Project size (sf)			
	8,000 sf			
Number of unit types	Unit size(s) (sf)			
72				
	Se Study 3 – The Modules, Location Philadelphia, Pennsylvania Construction company Equinox Management & Construction, LLC Project value (\$) Number of unit types 72			

The Modules at Templetown is a five-story student housing development expected to earn a LEED silver certification. The layout takes the shape of a double H giving access to views and light from each apartment. It is expected to be the largest modular LEED-certified building in the country. The whole process took a total of 1 year, 3 months for design and then 9 months for construction.

Pros	Cons
1. Pre-fabrication generated less waste and	1.
contributed to LEED certification.	2.
2. Modular is construction process not particular	3.
product.	4.
3. Fighter construction and better indoor air quality	5.

Additional Information

- The cost is approximately \$135 per square foot
- Timber frame components came from modular manufacturer IDBS
- Floors of residential accommodations top a single story steel and concrete parking structure
- Modular size 15' X 35' or 55' x 10'
- The modules were fabricated in Harrisburg and trucked in to the site in less than 6 weeks.
- The modules arrived with plumbing and wiring installed and interiors almost completely finished.
- Pre-fab units are wrapped in a rainscreen made up of fiber cement panels.

Generously sized operable windows, light-filled common spaces and a green roof terrace that assists in the facilitation a 50 percent-reduction water runoff.

Case Study 4 – Victoria Hall, UK		
Project name	Location	Owner
Victoria Hall, University of	Wolverhampton, England	Victoria Hall Ltd.
Wolverhampton		
Architecture firm	Construction company	Manufacturer
O'Connell East Architects	Flemming Group	Vision Modular Structures
Structural Engineer	M&E Consultant	Construction Duration
Bailey Johnson Hayes, Barrett Mahoney	Martin Buckley Associates	27 weeks
Construction year	Project value (\$)	Project size (sf)
9/2009	\$34 M	
Number of floors	Number of unit types	Unit size(s) (sf)
25	2 (Primarily multi-bedroom	
	suites)	

Victoria Hall, Wolverhampton, was constructed by Victoria Hall Ltd. to address a shortage of student housing near universities in the UK. The 25-story tower consists of a bottom site built floor with 24 modular floors constructed atop it. The upper stories are constructed of 383 modular units which tie into site built concrete cores.

Each module has a structural steel frame with a concrete floor. Modules were shipped complete with drywall, plumbing, fixtures, finishes, cabinets, and furniture. Each module weighed between 21 and 29 tons and were welded into place.

The modular manufacturer, Vision Modular Structures, is a unit of the greater construction company (Flemming Group) that built the project. The decision to use modular construction was arrived at after the initial design phase; therefore, the modular type of construction did not influence the architectural design.

Pros	Potential Cons	
1. Faster construction times.	1.	
2. More predictable costs.	2.	
3. Safer, fewer on site hazards.	3.	
4. More predictable schedule and completion date.	4.	
5. Better quality assurance.	5.	
For further reading, click <u>here</u> , <u>here</u> , <u>here</u> and <u>here</u> .		

Case Study 5 – Wilmslow Park, UK		
Project name	Location	Owner
Wilmslow Park	Manchester, UK	University of Manchester
Architecture firm	Contracting company	Manufacturer
Odgen Associates	Watkins Jones Construction	Rollalong
Engineering Company	M&E Consultant	Construction Duration
Veryards Ltd.		
Construction year	Project value (\$)	Project size (sf)
2002		
Number of floors	Number of unit types	Unit size(s) (sf)
7	3 (three, four and five bedroom)	

- The project is a mixed-use residential commercial development; used for student residence, worker accommodation and retail premises.
- 1425 Modules = 945 study bedrooms+130 worker apartments+6 rooms for people with disabilities.
- Completed in 4 months
- Main structure is steel modules, constructed on a steel-composite podium structure at first floor.
- Modules were self-supported. Corridors were integrated in them to reduce site-work and increase weather tightness.
- Width of modules ranged from 2.4 to 3.6 meters and modules arranges in 3, 4 and 5 bedroom clusters.
- A rain-screen cladding system was attached to the building after modules were installed.

Case Study 6 - Neapo, Finland		
Project name	Location	Owner
Neapo	Helsinki, Finland	Housing Finance and
		Development Centre of Finland
Architecture firm	Construction company	Manufacturer
Hedman & Matomäki Architects		
Structural Engineer	M&E Consultant	Construction Duration
Construction year	Project value (\$)	Project size (sf)
2012		25,000 sq. ft.
Number of floors	Number of unit types	Unit size(s) (sf)
5	38	730 sq.ft.

Case Study 7 – Little Hero, Australia		
Project name	Location	Owner
Little Hero	Melbourne CBD, Australia	
Architecture firm	Construction company	Manufacturer
Fender Katsalidis	Unitised Building/Hickory	Unitised Building/Hickory
Construction year	Project value (\$)	Project size (sf)
2010	\$12 M	
Number of floors	Number of unit types	Unit size(s) (sf)
8 (7 residential levels)	3	

- 63 one and two bedroom city apartments and duplex penthouse residences.
- Built as pods similar to steel shipping containers- and shipped to site.
- Priced from \$369,500, which around market price for a 1BR apartment at the time.

In factory:

- Factory built in Brooklyn, Victoria, which is approx. 20km west.
- Using linear assembly line techniques and robotics, then stationary for fitout.
- 20 modules/week, floor space for 120 modules.
- Set out by laser projector onto the floor
- Fitout time 30 days (reduced from 95-105 days)
- Integrated project teams important for services (esp. hydraulics) and cores

On site:

- Excavation, concrete foundations and podium level constructed while pods factory built.
- 10 day on-site delivery 'within that time there were strict controls over traffic management, with mandatory deliveries before peak traffic flows, control of pedestrians and on-lookers and closure of the adjoining street for pod lifting.

Pros	Potential Cons
1. Difficult site	1. Limited floor plans
2. 6 months lower construction time vs conventional	2. Capital appreciation minimal (pricing issue?)
build	3.
3. High quality finishes	4.
4. Stable rental product (5.6% gross yield, based on	5.
\$369,500 purchase price, \$400pw rent)	
5. High market demand	

Additional Information

Structurally, the initial steel pods are made from roll-formed sheet and purlins, spot welded to form a monocoque structure or outer shell. Four columns with a patented locking mechanism absorb line loads, whilst tortion and sheer loads are absorbed by the box shell. Sheet bracing is added to the end of the pod, and the structure typically braces against the core. The pods are manufactured in a jig, which is calibrated to ensure levels are within a one millimeter tolerance. The fixed column design, which is essentially a tapered plug, is designed in consideration of the installation sequence, and allows a point of relativity to ensure facades meet on installation.

Case Study 8 - T30 Hotel, Xiangyin, China		
Project name	Location	Owner
T30 – Hotel	Xiangyin, Hunan Province, China (2	Broad Group
	hrs southwest of Shanghai)	
Architecture firm	Construction company	Manufacturer
	Broad Group	Broad Group
Structural Engineer	M&E Consultant	Construction Duration
Broad Group	Broad Group	15 days (not inc substructure
		work)
Construction year	Project value (\$)	Project size (sf)
2011	\$17 million	17,000 sqm (183,000 sqft)
	\$1000 per sqm (\$93 per sqft)	
Number of floors	Number of unit types	Unit size(s) (sf)
30	N/A	N/A

Broad was founded in 1988 as an A/C manufacturer. Building large absorption chiller units.

Approx 10 years ago, Broad started its subsidiary – Broad Sustainable Building, and is a design build contractor/modular manufacturer in particular office and multi-family projects.

There are 2 factories 90 mins drive from Changsha, there are also another 8 factories being built to meet the demand. Employees live in dorms in Broadtown and eat all their meals on campus. The company values and work culture is deeply in-house workforce is deeply indoctrinated.

Pros	Potential Cons
1. 30% lower cost	1. Standardised look – aesthetics generally
 Accelerated schedule – 2 floors per day typical 	plain
3. High standards of quality – assembly method ensures quality	2. Difficulty integrating non standard design –
checks and standardised processes	e.g larger lobbies/irregular shapes etc
4. High standard of safety – no accidents on the T30 project	3. 'mistrust' of made in china product – may
5. High market demand – franchisees around the world are	not be suitable for application to the USA
adopting the product	immediately
6. Low embodied energy	4. Undefined acoustic rating
7. High energy efficiency	

Additional Information

The project:

- 358 Hotel rooms, 30 stories
- Structural steel frame, curtain walls
- 90% built in the factory
- Particularly energy efficient/low carbon due to low emission manufacturing and efficient products within the project such as quad pane glass, efficient A/C units
- Several smaller story prototypes exist
- Built to withstand a 9.0 Richter scale earthquake
- Finished in 15 days (on site work)
- Quality is high, except on-site workmanship not so good according to observers
- Unclear how long factory fabrication and site work took
- \$1000 per sqm (almost 30% less than comparables in China, much lower than the western world approx. 80-90% cheaper)

Construction Process:

On site:

- Excavation, concrete foundations constructed while work occurs in the factory.
- 15 day on-site delivery for 30 stories- including internal fitout
- Floor platforms are craned into place, and connections are made by bolting.
- All vertical elements--columns, internal walls, facade modules--laid flat on the finished floor surface and located where it needs to be (i.e preloaded)
- Internal walls are steel frames panelized and plasterboard is installed on top of this wall framing.
- Curtain wall installed conventionally while this occurs
- \$1000 per sqm vs \$1,400 for conventionally built commercial buildings

In factory:

- Structure is made from braced steel frames with a proprietary design, and with curtain wall exterior.
- Proprietary panelized system for floors/ceilings, panelized systems are assembled in the factory, these are steel framed with MEP rough in already complete, and plastering done.
- The basic building block of the system is a steel-framed floor platform, measuring 3.9 meters in width, 15.6 meters in length and 450 millimeters in depth. This module weighs 12 tons. MEP is roughed in, then the ceiling grid is installed, concrete topping and floor tiles installed.
- Elevator systems base, rails and machine room installed in the factory.

Broad Group's next project:

BSB – Sky City

- 220 stories, 838m residential, office and retail tower
- 1,000,000 sqm of floor space
- 104 elevators
- 7 months (factory and on-site time), 90 days timeframe modular framing, due to commence in 2013
- Location: Xinjiang River in Changsha, \$628 million, 95% complete from the factory
- 6x more efficient with material (i.e. less construction material needed per occupant)
- Energy Efficiency in embodied energy: Each sqm produces 20kg of carbon emissions per sqm vs 2000-5000kg of carbon emissions of comparable buildings
- Energy Efficiency in Operation: every sqm -uses 5kW of primary energy same as 16kg of carbon per sqm 1/7 to 1/10 of existing bldgs.

Sky City has been designed to house 31,400 people in its luxury and low-income communities. Residential area will occupy 83% of the tower, all serviced by schools, hospitals, offices, shops and restaurants within the building.

The structure will be constructed using approximately 200,000 tonnes of steel, and will be built to withstand earthquakes of a magnitude of up to 9.0 on the Richter scale, and to resist fire for up to three hours.

Environmentally radical, Sky City will also be equipped with 15cm thermal insulators, four-paned windows, fresh air heat-recovery systems, and a host of other equally eco-friendly features. Use 1/5 of the energy of a conventional bldg.

Perhaps the boldest claim is that the cost of the construction of Sky City will come at less than 1,500 per m2 – a tenth of the cost of the Burj Khalifa with its 15,000 per m2 price tag.

For further reading, click <u>here</u>, <u>here</u>, <u>here</u> and <u>here</u>.

5. INTEGRATED AEC STUDIO

As part of the Skanska's innovation grant, the students and faculty members at the University of Washington's Departments of Architecture and Construction Management worked on three mid-rise residential modular building designs in a hypothetic site in Seattle.

This Integrated Studio was a project-based architecture/construction management studio where students from the two disciplines and allied fields worked in a collaborative environment to develop and deliver design proposals using a working process modeled on the practice of Integrated Project Delivery (IPD). IPD is a design approach that integrates people, systems, business structures and practices for harnessing the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction. Professionals from the design and construction industry worked regularly with our three student teams to provide instruction advice, and critique. Building Information Modeling (BIM) and other computational tools were applied to the analysis, design, project management and communication of the conceptual designs. Students applied skills acquired in previous coursework and as a team they worked through collaboration exercises. In addition to a fully developed architectural design proposal, each team developed a conceptual cost estimate, a construction plan and a schedule. The outcome of three student teams are presented below.

5.1. Team 1

Alena Birillo (Dual¹⁷), Richardson Maneze (Dual), Kylie Yamamoto (Arch), Marc David James (Arch), Keri Woltz (Arch), Jacob Jacobski (CM¹⁸), Eli Lemanski (CM)

Team 1 started with exploring the opportunities and challenges presented when designing with narrow and wide modules for a mid-rise modular residential building. They realized they could obtain more rentable square footage using the narrow modules. However, the unit layout brought out the difficulty of designing within small spaces.

The students continued with site analysis and several iterations to achieve the final design. In design iterations, sustainability performance, aesthetics, community-oriented design, structure, cost and schedule were the main considerations that the students tried to optimize for the final solution. The outcome the first team's proposal is presented in the following figures.

¹⁷ Dual Degree in Construction Management and Architecture

¹⁸ Construction Management



Figure 5. Final design proposal (Team 1).



Figure 6. The layout of modules (Team 1).


Figure 7. Manufacturing detail of modules (Team 1).



Figure 8. Proposed delivery schedule (Team 1).



Figure 9. Cost analysis of the proposed design (Team 1).

5.2. Team 2

Chris Tritt (Dual¹⁹), Mariam Hovhannisyan (Dual), Flynn Wienker (Arch), Katherine Sistek (Arch), U Cheong (Leo) Lei (CM²⁰), Mamadou Leigh (CEP²¹)

The second team used the same procedure as team 1 to optimizing design with respect to modular design, sustainability, transportation and logistics, structural design, cost and schedule. The outcome of their work is presented below.

¹⁹ Dual Degree in Architecture and Construction Management

²⁰ Construction Management

²¹ Community, Environment and Planning



Figure 10. Exterior view of the proposed design (Team 2).



Figure 11. Layout of the proposed design (Team 2).



Figure 12. Lighting analysis of interior spaces of the proposed design (Team 2).



Figure 13. Logistics of the proposed modular design (Team 2).



Figure 14. Proposed schedule for the modular design (Team 2).



Figure 15. Cost analysis for the proposed design (Team 2).

5.3. Team 3

Evan Dunagun (Dual), Yushang (Michelle) Deng (Dual), Jason Duckowitz (Arch), Chen-ann Fu (Arch), Alan Montufar (Arch), Mark Kinsman (CM), Cory Hartwigsen (CM)

The third team considered many building massing options, and their final design encompassed elements from every iteration. Their design's core concepts included maximizing daylight, simplifying circulation, and creating movement by stepping volumes.



Figure 16. Various iterations to achieve final design (Team 3).



Figure 17. Exterior view of the proposed design (Team 3).



Figure 18. Logistics in construction of the proposed design (Team 3).



Figure 19. Breakdown of construction cost areas for the proposed design (Team 3).

6. CONCLUSION

The main conclusions of this study are summarized as below:

Market: In this market study we performed a supply and demand analysis. The market demand for prefab modular multi-family is essentially that of multi-family housing. This demand is highly dependent on several important factors: employment growth, household formation, population increases, and housing preferences among others. On the market supply side, factors such as housing affordability, renting vs. buying, shortfalls/oversupplies of housing units and future releases of new projects/units/land should be considered. We found is that there is a strong demand for multi-family housing in the tri-county region, however there is also potentially an oversupply of multi-family units coming onto the market in the medium term. We can however suggest that any construction method that promises to deliver high quality housing, and which is fast and simple to build as prefabricated modular construction aims to be, holds potential for the future.

Transportation: Transportation is likely to be a primary constraining factor for the module size and manufacturing location. Transportation by truck is likely to be the most economical mode of transport, so long as the modules are manufactured less than 200 miles from the site. The optimal module size should balance the overall number of modules needed for the building with the escort requirements and other transport limitations such as weight. Typical module sizes, as reported by modular manufacturers, are 11 feet high, 12 to 16 feet wide, and 55 to 65 feet long.

Logistics: In most regards, logistical considerations for modular construction mirror that of traditional construction. However, there are differences that contractors and developers should be aware of. Modules can easily weigh up to 22 tons, and span over 50 feet, which affects crane options. Additionally, the speed of construction and the potential lack of areas for tie-offs can present challenges with transporting materials and crews. The team who developed the logistics plan at Atlantic Yards B2 has decided on using a tower crane, and will jump the on-site materials hoist frequently as modules are placed. It is estimate that 10-12 modules can be placed each day at Atlantic Yards, and in general a good practice is to ensure the availability of a staging area that would allow modules to be unwrapped and rigged in an effort to increase the crane's picking efficiency.

Labor and Unions: Deciding on a fabrication facility is one of the largest components in modular construction. From location to assembly style, selecting a manufacturer affects the final outcome of the project. Some factories will employ union labor, which carries wage premiums but often produces a higher quality product; other factories might have non-union labor, but cost savings might not be fully realized due to potential quality issues, or even shipping costs depending on delivery proximity. Some contractors, such as Skanska's New York office, which is overseeing construction on the Atlantic Yards B2, opt to own their own manufacturing facility. Since the manufacturer is responsible for assembling, shipping, and

delivering the modules, finding a factory that is capable of meeting the project's needs is a critical component to success.

Costs: Modular construction is not as popular as traditional, on-site construction, especially in the Pacific Northwest. Because of the unknowns, many firms are reluctant to enter the market or take on the associated risks. However, many firms that have built using prefabricated modular construction have done so successfully, despite the somewhat different financial considerations. Higher start-up costs, levels of management and oversight, coordination and sequencing, as well as increased logistical considerations such as transportation, and staging, all play an important role in determining the overall feasibility of the project.

The biggest area for cost opportunities stems from an accelerated schedule, both during fabrication and stitch-up. Although it is typical to expect the design phase to carry a somewhat longer schedule depending on the project's complexity, the repetitive nature of modular construction shortens the construction schedule. This allows for cost savings with crane and material rentals, General Conditions and General Requirements such as flagging and on-site offices, as well as a reduction in labor wages. Other areas for cost reductions include reduced crew sizes in the factory, the overall quality control and safety benefits of working in a controlled environment, and the potential to buy bulk materials.

Codes: Factory-built housing and commercial structures should meet the requirements of the codes defined by the Washington State legislature – Washington Administrative Code (WAC) and Revised Code of Washington (RCW). These codes include State Building Code, Seattle Energy Code, National Electrical Code and Universal Plumbing Code.

Permitting and Inspection: All factory-constructed structures must have the Department of Labor and Industries insignia plate (gold seal insignia) for modular structures. All alterations occurring prior to occupancy must be approved by the Department of Labor & Industries while alterations post-occupancy should be submitted to the Department of Planning and Development. If a module is damaged en-route to the site, the issue must be brought to the attention of L&I and someone from the department will come out to the site and re-inspect the module after it is repaired. Lastly, the site should be tested for adequate drainage and loadbearing capacity and a foundation system designed for factory-installed structures. Finally, if planning to install a solid-fuel burning appliance of any kind, then you must have a UL-listed appliance that is specifically for use in manufactured housing.

Architectural design and delivery: High levels of collaboration and planning are needed in early design process of modular buildings. Shipping methods, inflexibility of modules, interior opening, and MEP systems are some of the issues that should be considered in design of these buildings. Integrated delivery methods are beneficial for modular construction.

Regional Manufacturing: The Puget Sound market seems ripe for an influx of modular manufacturers. Current competitors based in Seattle are of smaller scale, hence local competition is limited at this point. For large future projects it would be particularly pertinent

for a general contractor to approach a larger regional manufacturing partner with intentions for an alliance, leveraging off their significant manufacturing capabilities whilst providing on-site expertise.

Schedule: Modular prefabrication is expected to result in schedule savings for most projects with more pronounced benefits for projects that are designed and planned as modular construction from the early stages. This allows for the maximum overlap between site-work and fabrication. Module fabrication varies greatly by project and manufacturer. Given the controlled nature of fabrication, rates could likely be increased as required by adjusting the number of laborers at the factory.

Quality: Modular buildings in general have the potential to benefit from higher quality with respect to improved material quality, improved building performance, sustainability, etc. In addition, production in factory environment results in higher worker productivity and a safer and healthier environment in modular construction compared with on-site construction.

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Codes:

- Chapter 18.106 RCW; Plumbers: <u>http://apps.leg.wa.gov/RCW/default.aspx?cite=18.106</u>
- DPD Codes: <u>http://www.seattle.gov/dpd/codes/</u>
- Local Governmental Amendments: <u>https://fortress.wa.gov/ga/apps/sbcc/Page.aspx?nid=61</u>
- Plumbing and Gas Piping Code: <u>http://www.kingcounty.gov/healthservices/health/ehs/plumbing/code.aspx</u>
- Revised Code of Washington (RCW): <u>http://apps.leg.wa.gov/RCW/default.aspx</u>
- Seattle Mechanical Code: <u>http://ecodes.biz/ecodes_support/free_resources/Seattle2009/09seattle_mechanical/09seattle_m</u> <u>echanical_main.htm</u>
- Washington Administrative Code: <u>http://apps.leg.wa.gov/WAC/default.aspx</u>
- Washington State Building Code: <u>https://fortress.wa.gov/ga/apps/sbcc/Page.aspx?nid=14</u>
- UPC (2009): Uniform Plumbing Code (January 1, 2009): <u>http://archive.org/details/gov.law.iapmo.upc.2009</u>

Appendix A: Transportation - Application for Transportation Permits

A & W Permits Permits Po Box 34996 ~Seattle, WA 98124-4996 Telephone: (206) 684-5086 ~ Fax: (206) 684-5085	A & W Permits	A & W Permits	MENT OF TRANSPORTATION / th Π~ 700 5 th Ave, Suite 3768 ~Seattle, WA 98124-4996 84-5086 ~ Fax: (206) 684-5085	
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Application for Oversize/Over weight Vehicle Permit Same Day Service Not Guaranteed if Received after 12:00 p.m. (noon)

1 day (\$18 ea*) _____ 30 days (\$60 ea*) ____ Annual Fee ____ (\$290 ea*)
*separate fee scale for vehicles that are both over-sized & over-weight

Company Name		C	Contact Name (please print)				
Street Address		P	Phone (with area code)		Fax (With Area Code)		
City	State	Zip Code	Р	Permit Start Date		Truck number (Annual Permits)	
License Number	Power U1	nit#ofAxles	Traili	railing Unit # of Axles Gross W		ght	Licensed Weight
Width	Height		Overa	all Length	Front O/H		Rear O/H
Load Description							
Origin				Destination			
Purposed Route:							
	•	•	1.0			6 1	
number of tires per axl	ve axie spa e.	icing measur	rea mo	m center of axie	to center o	oi axie	in ieet & inches and
Hours of Operation: 9:00 a.m. to 3:00 p.m or 7:00 p.m. to 6:00 a.m							
NO REFUNDS. OBSERVE ANY PEAK HOUR RESTRICTIONS							
I understand that if I know revocation of this permit. I	ingly make a J ly signing this	false statement o application I aş	r represe gree to p	en tation in this applica ay all fees invol ved an	ttion, I may b d to abide by	e punishe requiren	ed by a cīvīl fin e or by sents set forth herein.
Date:		Signature:					
Pager, Cell Phone, or email:							

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Appendix B: Inspection Requirements

Insignia Required	Use	Construction Code Requirements	Construction Location	Who Inspects Construction in Factory?	Who Inspects the On-Site Structure?
Red Seal (Manufactured Housing)	Residence	Federal Housing and Urban Development (HUD)	Factory	State Labor and Industries (L&I) for HUD	City of Seattle
Gold Seal (Modular Construction)	Residence or Non-Residence	Washington State Building Code	Factory	L&I	City of Seattle
Black Seal (Commercial Coaches)	Non- Residence (Temporary Only)	Washington Administrative Code - Commercial	Factory	L&I	City of Seattle

Table B.1: Comparison of the Three Types of Factory-Constructed Structures

Table B.2: Installation Requirements for Factory-Constructed Structures

City Permits and	Types of Factory-Constructed Structures				
Information Required	Red Seal Insignia	Gold Seal Insignia	Black Seal Insignia		
Type of Building Permit Required from DPD	Expedited review (ER), with installation certification per L&I requirements	ER, but more extensive plan review may be required for difficult sites or complex foundation plans	ER		
Site Plan (see DPD CAM #103 and #103A)	Yes	Yes	Yes		
Site Drainage Plan	Yes	Yes	Yes		
Site Grading Permit (Excavation Plan)	If exceeding grading threshold, or if located in an ECA	If exceeding grading threshold, or if located in an ECA	If exceeding grading threshold, or if located in an ECA		
Structure Foundation Plan	Yes	Yes	Yes		

Copy of L&I Approved Factory Constructed Structure Plans	Yes	Yes	Yes
Electrical Permit from DPD	Yes	Yes	Yes
Certificate of Water Availability from Seattle Public Utilities	Yes	Yes	Yes
Plumbing Permit from KC Public Health Dept.	Yes	Yes	Yes
Site Inspection by DPD Inspector	Yes	Yes	Yes
Foundation Inspection by DPD Inspector	Yes, except special inspections required for HUD foundations	Yes	Yes



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