North Ridge CO_2 Analysis Report

Comparison between Modular and On-Site Construction

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Introduction

The residential construction practice of on-site wood framing has been widely applied in North America and has been considered to be a reliable, efficient, low-cost construction method for housing. However, the reality today is that technological innovation, higher costs, and the need for sustainable construction are challenging this method. In particular, there has been a significant increase in greenhouse gas emissions due to construction-related activities, and an alternative to on-site construction thus needs to be considered. In particular, the purpose of this report is to compare through a case study on-site with modular construction practices in terms of their respective effects on CO_2 emissions.

Background

Nearly $6 billion (CAD) was spent in 2008 in the construction sector in Canada (Statistics Canada 2009, "Capital expenditures"). Furthermore, the construction industry uses more than 50% of the world's natural resources, 70% of which is wood materials (Edwards and Hyett 2001). For example, in Canada, more than 57 billion m^3 of sawn lumber was used for construction purposes during 2008 (Statistics Canada 2009, "Production"). When considered in relation to CO_2 emissions, these statistics demonstrate the economic and environmental impact of building construction. Previous research on CO_2 emissions (Gonzalez and Navarro 2006) has found that the construction of a conventional single-family dwelling (125 m^2) generates more than 45 tonnes of CO_2. To put this statistic in perspective, during 2008, almost 30,000 residential units (houses, low-rise and high-rise buildings) were constructed in Alberta alone (Statistics Canada 2009, "Residential construction"), which, based on the existing research mentioned above, corresponds to CO_2 emissions in excess of 1.3 million tonnes.

Industrialized housing is a term that describes various factory approaches to wood-framed house construction, such as modular and panelized. Industrialized homes are assembled from elements (i.e., modules, panels) which are constructed in a controlled environment and are then transported to the job site for assembly. Industrialized housing is sometimes referred to as "system-built", because dwellings are built using an efficient and cost-effective approach. Instead of the old-fashioned on-site, stick-built construction method, most of the work is pre-fabricated at an off-site climate-controlled factory, as mentioned. As each sub-section or modular component is finished, it is transported to the building site on a flat-bed truck. *Panelized construction* is the process of making wall and floor sections in a factory rather than at the construction site. In this approach depending upon the size of the panels, a crane may set the panels in place on-site after delivery.

Project Description

The North Ridge Project is located at 21 Mont Claire Place, St. Albert, Alberta, Canada. North Ridge is a 42-suite, four-storey, multi-unit, low-rise residential building that will serve mainly as an affordable seniors' residence. As shown in the figures below, there are three types of exterior finishes for the building: horizontal and vertical cementitious siding, and stucco (smooth sand). Depending on the type of material used and the application process, there will be differing rates of CO_2 emissions.

Figure 1: Exterior vertical siding and horizontal siding finishing

Figure 2: Exterior stucco (smooth sand) finishing

Among the 48 suites, 40 have one bedroom and the remaining 8 have two bedrooms. A single-bedroom suite typically has an area of 594.60 s.f., while a two-bedroom suite has an area of 929.21 s.f.

Figure 3: Main entrance at northeast corner of building

Objective

As mentioned, the central aim of this report is to provide an analysis of the CO_2 emissions incurred from traditional on-site residential construction and compare them with those from modular factory construction processes. In particular, this involves identifying on-site construction activities and quantifying their corresponding CO_2 emissions in terms of material delivery trips, crew trips, and equipment usage.

General Scope and Limitations

The study's scope is limited to the residential construction industry, specifically multi-unit, low-rise dwellings. Regarding the quantification of CO_2 emissions, this investigation is also limited to on-site construction activities—embodied energy CO_2 quantification from building materials is not included in the analysis. The report will not only compare on-site and modular factory construction, but will also address the benefits of the modular construction process.

Assumptions:
This research is built based on the following assumptions:

- On-Site Construction:
    - Round trip for material delivery and crew transportation is assumed to be 40 km (City limits).
    - Emission rates by equipment/vehicle type are generalized values (see Tables 1 and 2).

Analysis of CO_2 Emissions for On-site and Modular Construction

In order to determine the amount of CO_2 emissions due to on-site construction and modular construction, it is necessary to identify the types of equipment that are typically used for both construction methods, as well as the emission rates produced per unit of work. The same procedure is followed for the installation of construction materials for both construction processes.

On-Site Construction Calculations

Tables 1 and 2 provide a summary of the equipment used on-site; Table 1 lists the vehicle types used for material delivery and crew mobilization to the site:

Table 1: CO_2 emission rates per vehicle type

Vehicle	kg/km
Concrete Pump	0.98
Five-Ton Concrete Truck	1.16
Five-Ton Truck	1.02
Half-ton Truck	0.34
One-Ton Truck	0.7
Ten-Ton Truck	1.26
Three axle dump Truck (9m3)	1.9
Three-Ton Truck	0.82
Two-Ton Truck	0.76
Van/Car	0.23

The vehicle types listed above have a direct impact on the total CO_2 emissions per building. As can be seen, a van/car emits 0.23 kg/km, while a one-ton truck emits 0.70 kg/km. The nature of vehicle usage is also taken into account in this analysis in order to provide more accurate results, differentiating between material transportation and manpower mobilization.

Table 2 provides a summary of some of the equipment/tools used by trades involved during the construction process on-site and their related CO_2 emissions per hour of work:-

Table 2: CO_2 Emission rates per equipment type

Equipment	kg/hr
Bobcat	28.63
Compactor	35
Compressor	2.68
Concrete Finisher	9.65
Concrete Pump	22.36
Excavator	40
Generator	2.68
Lift	16

Table 3 shows a sample of on-site construction activities and their corresponding CO_2 impacts. If we take framing material delivery as an example, we find that this activity accounts for 3,536 kg of CO_2 emissions per floor. This amount is based on the number of delivery trips, the type of vehicle used, and the type of equipment used to hoist the material to the various floors. The quantification for on-site construction is divided into two distinct stages: Stage 1 includes work from excavation to gypcrete, while Stage 2, also known as unit finishing, includes work from gypcrete to possession. The detailed breakdown of activities in both stages is provided in the appendix.

Table 3: Emissions from framing activity

Activity - Excavation to Gypcrete	Duration	Material Trips		Crew trips		Equipment		CO_2
	(days)	Qty (trips)	Vehicle	Qty (trips)	Vehicle	Qty (hrs)	Type	(Kg)
FRAMING MATERIAL DELIVERY (PER FLOOR)	3	15	Ten-Ton Truck			8	Lift	3536
FRAMING (PER FLOOR) WALLS and FLOOR ABOVE	14			112	Van/Car	224	Compressor	6523

The construction activities listed in the appending spreadsheets are categorized according to material trips, crew trips, and equipment usage. The accumulated emissions of these activities for both stages equal 106 tonnes of CO_2. With respect to Stage 1, from excavation to gypcrete, the first six activities generate half of the CO_2 emissions—41 tonnes of the 82 tonnes for this stage. Excavation, in particular, contributes 24% of Stage 1 emissions. The second stage, gypcrete to possession (finishing), accounts for another 19 tonnes of CO_2 emissions. In total, on-site construction activities generate **98.9 tonnes** of CO_2 emissions.

Modular Construction Calculations

The calculation of CO_2 emissions from modular construction was tabulated in a similar approach as for on-site construction process. The installation of materials, equipment used, and trips for labour and materials for modular construction varied significantly from on-site construction, primarily due to the mass production techniques employed (see appendix).

Crew Trips

Crew trips for conventional on-site construction (10.75 months from main floor framing to turn-over/possession—basement pouring not included) result in 69.8 tonnes of CO_2 emissions. Crew trips for modular construction (6.75 months with a total of 4.98 days of total cycle time per cube) result in 69.8*6.75/10.75 = 43.82 tonnes of CO_2. The difference is 26 tonnes of CO_2. Hence, modular construction process savings, based on the reduced crew trips, amounts to **26 tonnes** in CO_2 emissions. It should be noted that material procurement varies depending on the construction method; for instance, in modular construction, materials are delivered to the factory in bulk, not in packages as is often the case for on-site construction.

Scheduling

A line-of-balance schedule of all construction activities is included in the appendix. This schedule is based on a summer construction start. For both construction methods, the duration from excavation to foundation walls is 3.5 months. For modular construction, 8 cubes are manufactured per week (2 suites per cube). It takes 4.75 months to build 42 apartments/suites in the factory. After shipping the modules to site, 2 months more are needed to finalize the connections and finish the building. In comparison, on-site construction takes 9 months to complete the first stage and 2.75 months for the finishing stage. Overall, the project lasts 6.75 months using modular construction, compared to 10.75 months for the traditional on-site construction process.

It should also be mentioned that scheduling of the project start during a different season could drastically impact CO_2 emissions. The effect of season on construction activities and emissions is thus outlined in the following section.

Winter Heat

On-site construction during the winter has a dramatic impact on CO_2 emissions. Typically, two 400,000-BTU heating units are used per floor for space heating to support construction activities, with the emission rate generally being 62.7 kg of CO_2/million BTU/hour. Hence, ten units operating at 10 hours per day for 22 working days per month, and one unit operating at half-capacity during non-working time, will result in **431 tonnes** of CO_2 emissions over the course of 5 months.

The factory space required for manufacturing the North Ridge project is assumed to be 120,000 s.f. For the purpose of comparison, the factory facility's heating results in 74.7 tonnes of CO_2 emissions for the same 5-month period. It is important to note that two months of propane heating are required when installing and connecting the modules on-site (172.5 tonnes of CO_2). Still, this results in significant savings of **184 tonnes** of CO_2 emissions if the construction process is moved to a factory environment during the worst-case scenario for modular construction, i.e., winter construction (see Table 4).

Table 4: Comparison of CO_2 emissions between on-site and modular construction

Item	Construction Methodology: Conventional	Construction Methodology: Modular	Difference	Difference (%)
Construction Time (Months)	10.8	6.8	4.0	37%
CO_2 emissions - construction process (Tonnes of CO_2)	98.9	56.3	42.5	43%
CO_2 emissions - Winter Heating (Tonnes of CO_2)	431.3	247.2	184.0	43%
Total (CO_2)	**530.1**	**303.6**	**226.6**	**43%**

Construction Material Waste Minimization

In Alberta, approximately 22% of the materials required for new construction and renovations become waste in landfills—approximately 650 thousand tonnes in 2006. Alberta Environment's aim to reduce waste by 500 kg/capita by 2010, meanwhile, accounts for 50% of the province's current material waste (C&D Waste Reduction Advisory 2006). In terms of new construction for the homebuilding industry, 4.38 pounds of material waste are produced per square-foot (California Integrated Waste Management Board 2007). A study conducted by the Hole School of Construction Engineering at the University of Alberta found that, on average, almost 1400 kg of waste are generated during the construction of a single residential facility, 89% of which is wood waste. Furthermore, the variation in material waste was almost 600 kg for the same house model between different framing contractors (Mah 2007).

The causes of the excessive waste produced lie in the nature of the building process. The conventional building of a home is conventionally-managed in the manner of a small-scale project. The home developer orders materials, such as lumber, OSB sheets, and shingles from suppliers who package and ship them to the site. Trades contract only for the labour involved. This practice leads to remarkable material waste for a number of reasons. First, considering the potential cost of schedule delays due to material shortage, the builder is willing to absorb the cost of consequential material waste from overbuying in order to circumvent schedule delays. Moreover, construction methods are not standardized—different trades companies offer the same services using different methods and material quantities. Therefore, estimators often issue purchase orders (POs) of material packages with a 10%–15% safety factor. In consideration of high labour costs, suppliers usually include in material POs commercially-available dimensional material instead of the exact lengths and amounts needed, leading to an additional 5%–10% waste. Subcontractors also have little motivation to save material, since every job comes with its own material package provided. For home developers, it is not worthwhile economically to collect leftovers from job sites and reassemble them into new packages. Consequently, extra material is generally left on the site and eventually is discarded.

Research data indicates that 9% of materials by weight delivered to a construction site end up as waste (Bossink and Brouwers 1996). Mechanisms that may reduce construction material waste include build green programs, componentization methodologies, and landfill levies (C&D Waste Reduction Advisory 2006). Most of the waste recycling programs provide incentives to construction companies and contractors to look after material leftovers (Kelleher Environmental 2006), but little has been done to maximize material usage. The manufacture of building components and use of automated building designs, on the other hand, serve to minimize material waste and better utilize primary materials for construction.

The utilization of a controlled environment, such as a manufacturing shop, addresses waste reduction prior to construction disposal. The process of building components in a plant results in continuous flow production, where material inventory is managed based on consumption instead of project-based estimates. Theoretically, there should be no material left. The example of floor joists demonstrates this concept. Figure 4 shows a floor joist package delivered to the site of a duplex house, which consists of three types of joists: 40'-long 11-7/8" Ni-40x, 30'-long 11-7/8" Ni-40x, and 24'-long 11-7/8" Ni-80x. Every joist is cut to a required length, as shown in Figure 5, resulting in leftovers that are too short to be applied elsewhere. In contrast, Figure 6 shows the situation in a pilot pre-fabrication plant. Using 60'-joists from the shop inventory, the workers cut the required length of the material, optimizing the cutting sequence to minimize leftovers. Based on data collected for 16 jobs completed in June, 2008, the average lumber cost was reduced by 8%-10% (actual lumber cost compared to PO amount for conventional building) for typical single-family homes (1900 s.f.) and 12% for small dwellings (≤ 1500 s.f.).

Figure 4: Floor joist package

Figure 5: Joist being cut to correct length

Figure 6: Floor joist inventory in pre-fab plant

The use of mathematical algorithms and application of the obtained results to build components for stick-built residential construction is a technique to minimize material waste. The investigation is limited, however, by the current practice regarding material handling and storage, as well as by the logistics required to apply cutting patterns and scenarios at the manufacturing shop.

The Hole School of Construction Engineering at the University of Alberta has developed a system based on information, innovation, and applied intelligence for stick-built residential facilities. Research in this area has focused on 3D modeling and material optimization techniques in order to provide automated construction drawings for panelized framing in the home building industry. Take-off lists of materials and cutting patterns are extracted from the drawings for nominal lumber, sheathing, and drywall. With regard to material waste, the current model uses combinatorial analyses to generate the optimum number of cuts and leftovers for the given materials. For example, a material waste rate of less than 1% can be achieved for nominal lumber by utilizing diffent combinations with 8-, 9-, and 12-foot components in a detached single-family home (Manrique et al. 2008). Implementing this research in the current practice can improve the quality of manufactured building components in the home building industry by prefabricating them within a controlled environment for subsequent assembly on-site.

Another aspect of waste reduction is materials innovation. However, innovation of materials is often constrained by factors ranging from social to economic (Goverse et al. 2001). Nonetheless, new products and materials have been successfully introduced into the marketplace. The selection of construction materials with a low-environmental impact has resulted in a 27% reduction in CO_2 emissions (Gonzalez and Navarro 2006).

Still, there are opportunities for further innovations in materials in the interest of sustainability. Previous research in residential construction has shown, for instance, that wood waste accounts for 60% (by volume) of all waste. As Figure 7 shows, wood accounts for the vast majority of material waste particularly at the first of the three waste pick-ups for a typical home (Mah 2007), and thus wood is an appropriate resource to be targeting in terms of sustainability enhancements.

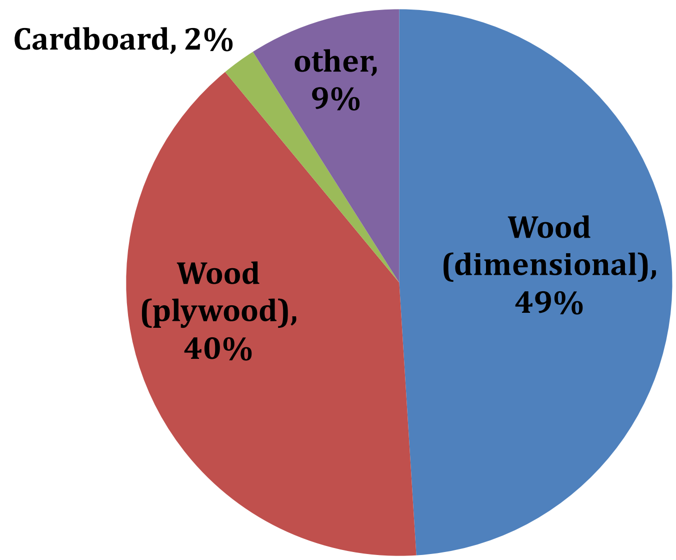

Figure 7: Material waste from framing pick-up (by volume)

Reuse is another avenue of waste minimization. Asphalt shingles, for instance, are thrown away at a rate of 1.25 million tonnes per year in Canada. Leftovers of these products can easily be stored and reused if construction takes place within a controlled environment (manufacturing shop), thus minimizing landfilling of these usable materials (Alberta Construction Magazine 2007). The implementation and control of waste management procedures at manufacturing shops are easier to achieve with bulk storage of material waste.

Another consideration in waste generation is demand. Because labour costs typically exceed material costs, the pace of construction is increased during times of high demand and, consequently, material is used less effectively. Primary materials are misused, generating high volumes of waste and decrementing vital resources such as wood and gypsum board.

Benefits of Modular Construction

Considering the opportunities outlined above for waste minimization, utilization of a modular construction approach can facilitate waste minimization in a number of respects.

Environmental

Consolidating work at a factory reduces the CO_2 emissions resulting from the transport of materials and labour as well as from construction operations. Waste materials are minimized, and the waste generated is easily reused and recycled in the factory. Generally, there is no need for large dumpsters to remain on-site for an extended period of time. With a compressed site schedule, fewer workers are on-site, and for less time, and fewer materials are stored on-site. Furthermore, tightening the building envelope lowers the consumer's energy bill due to the smaller heating/cooling system. LEED certification and NetZero programs can also be considered under this approach, since factory-based construction allows for better quality control in regard to such aspects as house sealing.

Scheduling

In modular building, factory construction of a home and site preparation work can proceed simultaneously, allowing projects to be completed in a much shorter time-span.
Modular homes are assembled in a factory while earthwork, foundation, and utilities service are prepared on-site. When properly scheduled, the modular sections or panels can be installed on-site immediately upon delivery. Complete hook-up, final grading, and landscaping can usually be completed within one month, and often sooner. With a shorter construction time, the homeowner benefits from an earlier move-in date.

Economic

Since houses are built by a stable work force under controlled factory conditions with predictable raw material inventory and supply, assembly is much more efficient, resulting in a cost reduction compared to conventional construction by 10%-30% (Goverse et al. 2001). Through industrialization, the operating costs per house will also be reduced due to building tightness. These savings could be passed on to buyers under affordable housing initiatives.

It is important to note that material storage and double-handling are unnecessary costs that are absorbed by the final customer. Utility costs such as heating, power and water supply are incurred due to mid-point material handling between main suppliers and construction sites. Table 5 shows approximated costs of material storage and handling, based on an annual cost for material storage, handling, utilities, and other operations of approximately CAD $1.8 million for a 40,000 s.f. warehouse (Napolitano 2003):

Table 5: Warehouse costs per year (Canadian dollars per square foot)

YEAR	Storage (CAD $ / s.f.)	Handling (CAD $ / s.f.)	Utilities (CAD $ / s.f.)	Operating + Adm. Expenses (CAD $ / s.f.)	Total (CAD $ / s.f.)
2008	12.05	22.49	2.35	6.26	43.14

Safety

Safety on the job site is a significant issue for contractors. During a shortage of skilled labour, many young and inexperienced workers enter this field without adequate training. Consequently, the rates of on-site accidents with these young workers are higher than with older, more experienced workers. In addition, site conditions such as inclement weather (temperature, wind, moisture) lead to higher accident rates (WCB BC 2009). With the shift towards a controlled factory environment, these weather conditions are mitigated. Likewise, factory construction better lends itself to safe material handling and assembly than do conventional methods. For example, safety risks are significantly decreased when the need to work on elevated platforms or walls is reduced.

Among safety issues for on-site construction, the risk of falling is of paramount concern. Moving towards a factory setting will reduce claims from injuries due to falls in floor openings and wall-lifting activities. Use of scaffolds and ladders, which are high contributors to injuries, is eliminated since assembly of panels and modular components is performed at the ground level in factories. For conventional on-site construction, conversely, statistics indicate that more than 50% of all injury claim costs are due to falls, with an average of approximately $32,000 and 71 days lost per claim for the period, 2003-2005. As shown in the distribution in Figure 8 based on WCB statistics (WCB BC 2009), injuries due to falls can be significantly mitigated through utilization of a factory construction approach which eliminates the need for tasks to be performed from a ladder or scaffold. Hence, factory construction's potential safety benefits and cost savings (well over $16 million) would be substantial.

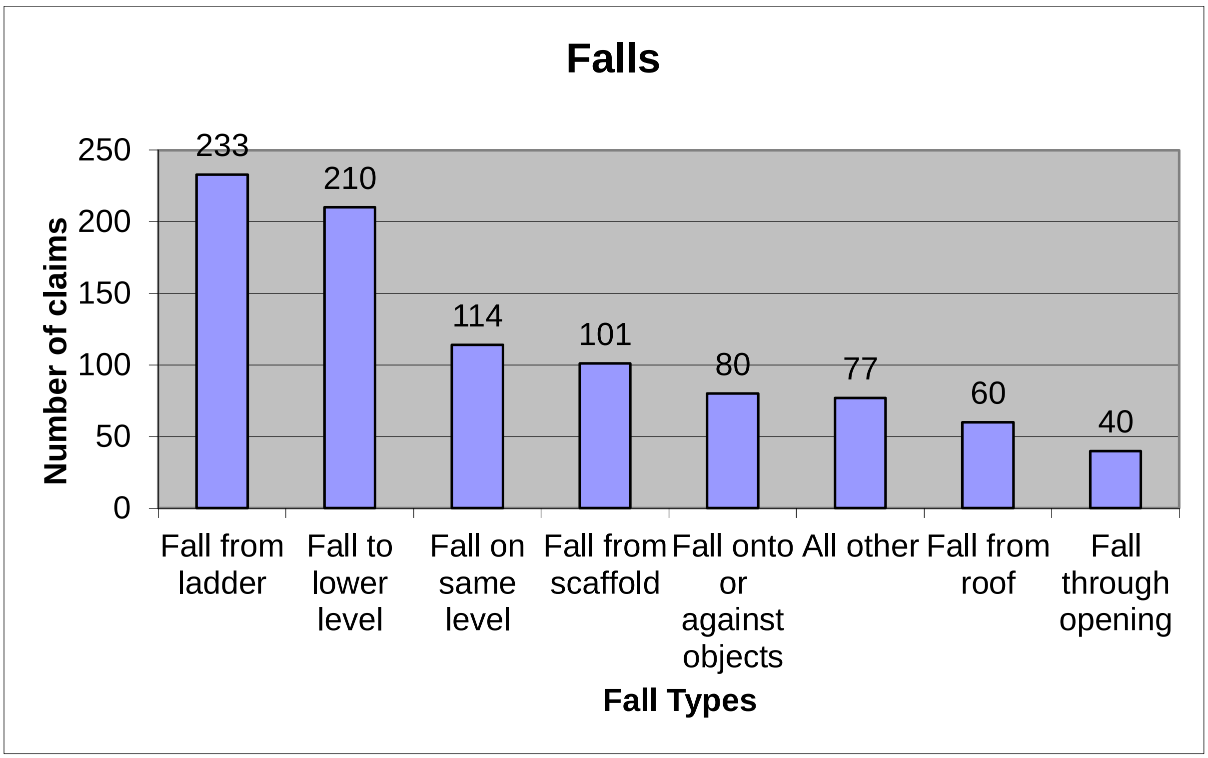

Figure 8: Claims due to injury, 2003-2005

Quality
Modular and panelized construction is tighter and stronger than stick-built or traditional methods because of the high level of quality control possible in a controlled indoor environment with an experienced labour force. Furthermore, workers familiar with their product can easily integrate materials and techniques into the process when working side-by-side with individuals of other trades backgrounds.

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Appendix A: Comparison of CO_2 between on-site and modular construction (breakdown)

Construction CO_2 emissions - Conventional	
	(Tonnes CO_2)
Excavation to Gypcrete	81.8
Finishing stage	17.1
Total	**98.9**

Construction time - Conventional	
	(Months)
Excavation to Gypcrete	8
Finishing stage (42 suites)	2.75
Total	**10.75**

Winter heating (5 months) - Conventional	
	(Tonnes CO_2)
*Heaters running at half-capacity	225.0
**Heaters during working hrs	206.25
Total	**431.25**

Running 24hr/day, 30 days/month, 5 months/year, one heater/floor (5 in total)
Running 10hrs/day, 22 days/month, 1.5 heaters/floor (7.5 in total)

Construction time - Modular	
*Total cycle time per cube (days)	4.98
Total cubes	21
Installation & final connections/finishing @ construction site (months)	2
Total (Months)	**6.75**

*1 cube = 2 suites

CO_2 emissions - Modular	
	(Tonnes CO_2)
Excavation to foundation walls	32.5
Manufacturing shop - suite assembly	36.4
Total	**68.9**

Assuming that crew trips are 62% of the current crew trips to the construction site (10.75 months conventional compared to 6.75 months - modular).

Winter heating (2 months) - Modular (120,000 sf Assembly line)	
	(Tonnes CO_2)
Natural gas	74.7
Total	**247.23**

Assembly line - 120,000 sf. For this analysis, the following worst-case scenario was assumed: construction starts during January, using propane heaters during 2 months at the construction site during final installation and connections

Utility Spending ($) - 120,000 sf shop	
	Jan-09
Gas	$8,139
Electricity	$4,056
GJ - Natural gas (price /GJ = $5.99)	1,358.8
Kg of CO_2 per GJ = 55	74,732.1
Total (Tonnes CO_2)	74.7

Appendix B: Durations and trips (crews, materials) for conventional construction activities (finishing stage)

	Conventional Construction					
Activity - Finishing stage (Suites)	**Duration (days)**	**Material Trips Qty (trips)**	**Material Trips Vehicle**	**Crew trips Qty (trips)**	**Crew trips Vehicle**	**CO_2 (Kg)**
Paint Walls- 1st coat	42	11	Half-ton truck	84	Van/Car	922
Finishing Stage 1 (Interior doors, baseboard trim and casing)	21	21	Two-ton truck	42	Van/Car	1025
Paint Doors & Trim	21	7	Half-ton truck	84	Van/Car	868
Tile Tub Surrounds	11	11	One-ton truck	11	Van/Car	409
Grout Tile tub surrounds	11			11	Van/Car	101
Kitchen+Bath Cabinets	42	11	Five-ton truck	84	Van/Car	1222
Boot & Duct OTR & Fan Covers	7	7	One-ton truck			196
Measure P.Lam Countertops	42			42	Van/Car	386
Sweep & Shop Vac	42			42	Van/Car	386
Lino	42	4	One-ton truck	42	Van/Car	498
Finishing Stage 2 (Baseboards in bathrooms, closets & laundry rms)	42			42	Van/Car	386
Measure & Drill Wire Shelves	7			7	Van/Car	64
Install Laminate Countertops	42	42	Half-ton truck			571
Paint Final (bath+clos+laund)	42	11	Half-ton truck	84	Van/Car	922
Mechanical Final	42	42	One-ton truck			1176
Carpet	42	42	One-ton truck			1176
Construction Clean Stage 1	42			42	Van/Car	386
Wash Windows	7			7	Van/Car	64
Window+Door Lockout	4			7	Van/Car	64
Final Paint (Kitchen+Bed+Liv)	42	11	Half-ton truck	84	Van/Car	922
Wire Shelves Install	4	4	One-ton truck			112
Electrical Final	21	21	Half-ton truck			286
Final Finish (bifolds)	42			84	Van/Car	773
Shower Doors+Mirror Install	7	15	Half-ton truck	15	Van/Car	342
Window Coverings	7	7	Half-ton truck	7	Van/Car	160
OTR & Dishwasher Delivery	7	7	Five-ton truck			286
Install Dishwashers	4			4	Van/Car	37
Install OTRs	11			11	Van/Car	101
Appliance Delivery & Install	7	7	Five-ton truck	7	Van/Car	350
Washer & Dryer Install	7			7	Van/Car	64
Initial Inspection	21			21	Van/Car	193
Deficiencies	38			114	Van/Car	1049
Pre-Occ Clean	14			14	Van/Car	129
Pre-Occ Orientation	14			14	Van/Car	129
Correct Deficiencies	38			114	Van/Car	1049
Final Clean - Possession	14			14	Van/Car	129
Possession	14			14	Van/Car	129
						17064

Appendix C: Material trips for modular construction activities (finishing stage)

Activity - Finishing stage (Suites)	Modular Construction		
	Material Trips		Modular
	Qty (trips)	Vehicle	CO_2 (Kg)
Paint Walls- 1st coat	2	Two-ton truck	60.8
Finishing Stage 1 (Interior doors, baseboard trim and casing)	4	Two-ton truck	121.6
Paint Doors & Trim	2	One-ton truck	56
Tile Tub Surrounds	3	Two-ton truck	91.2
Grout Tile tub surrounds			0
Kitchen+Bath Cabinets	11	Five-ton truck	448.8
Boot & Duct OTR & Fan Covers	2	One-ton truck	56
Measure P.Lam Countertops			0
Sweep & Shop Vac			0
Lino	1	Two-ton truck	30.4
Finishing Stage 2 (Baseboards in bathrooms, closets & laundry rms)			0
Measure & Drill Wire Shelves			0
Install Laminate Countertops	4	Two-ton truck	121.6
Paint Final (bath+clos+laund)	2	Two-ton truck	60.8
Mechanical Final	5	Two-ton truck	152
Carpet	5	Two-ton truck	152
Construction Clean Stage 1			0
Wash Windows			0
Window+Door Lockout			0
Final Paint (Kitchen+Bed+Liv)	2	Two-ton truck	60.8
Wire Shelves Install	3	One-ton truck	84
Electrical Final	1	One-ton truck	28
Final Finish (bifolds)			0
Shower Doors+Mirror Install	5	One-ton truck	140
Window Coverings	2	Two-ton truck	60.8
OTR & Dishwasher Delivery	7	Five-ton truck	285.6
Install Dishwashers			0
Install OTRs			0
Appliance Delivery & Install	7	Five-ton truck	285.6
Washer & Dryer Install			0
Initial Inspection			0
Deficiencies			0
Pre-Occ Clean			0
Pre-Occ Orientation			0
Correct Deficiencies			0
Final Clean - Possession			0
Possession			0
			2296

Appendix D: Detailed breakdown of activities for conventional construction (excavation to gypcrete)

Activity - Excavation to Gypcrete	Duration	Material Trips		Crew trips		Equipment		CO_2
	(days)	Qty (trips)	Vehicle	Qty (trips)	Vehicle	Qty (hrs)	Type	(Kg)
SURVEY SITE UTILITY SERVICES	2			4	Van/Car			37
TEMP ELECT. PANEL	2			4	Van/Car			37
INSTALL SITE MECH UTILITY SERVICES	10	2	Three-Ton Truck	20	Van/Car	16	Excavator	890
BACKFILL VAULT & INSTALL TRANSF. RAILING	1	1	Two-Ton Truck	2	Van/Car	4	Excavator	209
ELEC TRANS VAULT & PRIMARY+SECONDARY PIPES	4	1	Two-Ton Truck	8	Van/Car	8	Excavator	424
EXCAVATION SURVEY	3			3	Half-ton Truck			41
EXCAVATE U/G PARKADE	8	227	Three axle dump Truck (9m3)	16	Van/Car	64	Excavator	19934
SOIL TEST	1			1	Half-ton Truck			14
PER FTGS - FORM+POUR+STRIP (1st section)	2	2	Three-Ton Truck	4	Van/Car	8	Concrete Pump	281
		3	Five-Ton Concrete Truck					139
		1	Concrete Pump					39
PER FTGS - FORM+POUR+STRIP (2nd Section)	2	3	Five-Ton Concrete Truck	4	Van/Car	8	Concrete Pump	355
DETAILED EXCAV+PAD FTGS+MECH RM+ELEV PIT	2	1	Concrete Pump			16	Excavator	679
PADS+ELEV FTGS REBAR + POUR	4	9	Five-Ton Concrete Truck	12	Van/Car	8	Concrete Pump	707
		1	Concrete Pump					39
SHAFTS & WALLS (FORM+ELEC+POUR)	16	20	Five-Ton Concrete Truck	48	Van/Car	16	Concrete Pump	1727
		2	Three-Ton Truck					66
		1	Concrete Pump					39
STORM LINES	3	2	Two-Ton Truck	6	Van/Car			116
SANITARY LINES	4	3	Two-Ton Truck	8	Van/Car			165
STRIP+CLEAN UP	3	2	Three-Ton Truck	6	Van/Car			121
INSPECT FOUNDATION	1			1	Van/Car			9
D.P. + W.T. + PLATON TO 4FT (1ST SECTION)	3	2	Five-Ton Truck	12	Van/Car			192
ELECTRICAL RI (U/G)	5			5	Van/Car			46
CITY INSPECTION FOR FOUNDATION	1			1	Van/Car			9
SOG - GRADE + COMPACT + GRANULAR FILL	5	26	Five-Ton Truck	20	Van/Car	16	Compactor	1805
						24	Bobcat	687
MECH RISER CONN	2	1	Three-Ton Truck	4	Van/Car			70
SOG - POLY + REBAR + ELECTRICAL	2	5	Five-Ton Truck	8	Van/Car			278
		1	Half-ton Truck	1	Van/Car			23
POUR SOG	1	23	Five-Ton Concrete Truck	5	Van/Car	8	Concrete Pump	1292
		1	Concrete Pump			8	Concrete Finisher	116
SEAL SLAB	1			1	Half-ton Truck			14
BACKFILL EXTERIOR WALL TO 4FT	2			4	Van/Car	16	Compactor	597
						16	Bobcat	458
SAWCUT SOG	1			1	Van/Car			9
SETUP COLUMNS & BEAMS BASEMENT	15	4	Three-Ton Truck	60	Van/Car			683
MECH + ELEC SLEEVES + LAYOUT (SURVEYOR+FRAMER)	3			8	Van/Car			74
ELEC CORELINES+BOXES	2	2	Two-Ton Truck	4	Van/Car			98
FRAMING MATERIAL DELIVERY (PER FLOOR)	3	15	Ten-Ton Truck			8	Lift	3536
FRAMING (PER FLOOR) WALLS and FLOOR ABOVE	14			112	Van/Car	224	Compressor	6523
						112	Generator	300
REMOVE INTERIOR SHORING/SCAFFOLDING	8	4	Three-Ton Truck	16	Van/Car			278
FINAL D.P.+ PLATON + INSULATION	5	2	Five-Ton Truck	15	Van/Car			220
BACKFILL EXTERIOR TO TOP OF SLAB	3			6	Van/Car	24	Compactor	895
						24	Bobcat	687
CONCRETE STAIRS - BASEMENT	4	2	Five-Ton Truck			8	Lift	210
NO-BURN - PER FLOOR	1			1	Half-ton Truck			54
STAGE 1 DRYWALL (SHAFTS & TUBS) - PER FLOOR	2	1	Five-Ton Truck	8	Van/Car			458
ROUGH-IN HVAC (PER FLOOR)	2	2	Two-Ton Truck	4	Van/Car			390
MAIN STACKS - MECH (PER FLOOR)	5	2	Two-Ton Truck	10	Van/Car			611
HEATING RISERS (PER FLOOR)	10	3	Two-Ton Truck	20	Van/Car			1101
DOMESTIC WATER RISERS (PER FLOOR)	5	2	Three-Ton Truck	20	Van/Car			998
ELECT RI'S CORRIDORS + COMMON AREAS + MAIN FEEDERS (PER FLOO	10	1	Two-Ton Truck	40	Van/Car			1594
FIRE ALARM SYSTEM - CORRIDORS + SUITES (PER FLOOR)	5	1	Half-ton Truck	10	Van/Car			422
MARK OUT & DRILL HOLES - HVAC (PER FLOOR)	1			2	Van/Car			74
ROOFING + ROOF INSULATION	15	15	Two-Ton Truck	30	Van/Car	16	Lift	988

Appendix D (cont'd)

Activity - Excavation to Gypcrete	Duration (days)	Material Trips Qty (trips)	Material Trips Vehicle	Crew trips Qty (trips)	Crew trips Vehicle	Equipment Qty (hrs)	Equipment Type	CO_2 (Kg)
ROOF TOP PLUMBING VENTS	2	1	Two-Ton Truck	4	Van/Car			67
ROOF FLASHING	6	2	Two-Ton Truck	12	Van/Car	42	Lift	843
WATERPROOF STRIPPING - MAIN FLOOR	2	2	One-Ton Truck	4	Van/Car			93
BUILDING WRAP - (PER FLOOR)	2	2	Two-Ton Truck			14	Lift	1139
GAS LINES (PER FLOOR)	10	3	Two-Ton Truck	18	Van/Car			1027
WIRING SUITES (PER FLOOR)	5	2	Two-Ton Truck	18	Van/Car			906
SUPPLY & EXHAUST AIR DUCTS - SHAFTS (PER FLOOR)	1	1	Two-Ton Truck	2	Van/Car			195
WINDOWS (PER FLOOR)	1	3	Five-Ton Truck	4	Van/Car			637
DRYWALL - ELEVATOR SHAFT (PER FLOOR)	1	2	Two-Ton Truck	2	Van/Car			317
DRYWALL+TAPE CORRIDOR CEILINGS (PER FLOOR)	2	2	Five-Ton Truck	8	Van/Car			621
SOFFITS & FASCIA (PER FLOOR)	2	2	Two-Ton Truck	4	Van/Car	4	Lift	646
ELEC DIST & PANEL DIST	8			16	Van/Car			147
INSTALL ELEVATOR	30	2	Five-Ton Truck	26	Van/Car			321
BASEMENT MASONRY	8	2	Five-Ton Truck	16	Van/Car			229
MECH EQUIPMENT/PIPPING/FLUE	30	2	Two-Ton Truck	54	Van/Car			558
SPRINKLER RI'S - SUITES (PER FLOOR)	1.5	2	Two-Ton Truck	4	Van/Car			390
STUCCO AND HARDIPLANK SIDING (PER FLOOR)	20	3	Two-Ton Truck	40	Van/Car	72	Lift	6445
SUITE WATER PEX (PER FLOOR)	7	1	Three-Ton Truck	28	Van/Car			1162
PIPING INSULATION (PER FLOOR)	1	2	Two-Ton Truck	2	Van/Car			317
INSTALL TUBS (PER FLOOR)	5	3	Three-Ton Truck	10	Van/Car			762
FORM ELEVATOR DOORS+BOARD+TAPE+FIRE CAULK (PER FLOOR)	10	1	Two-Ton Truck	20	Van/Car			858
WALL INSULATION + VAPOR BARRIER (PER FLOOR)	8	3	Three-Ton Truck	16	Van/Car	4	Lift	1238
SOUND BARS + BOARDING (PER FLOOR)	8	6	Five-Ton Truck	32	Van/Car	8	Lift	2669
TAPING (PER FLOOR)	10	2	Two-Ton Truck	36	Van/Car			1568
CEILING SOUND BARS (PER FLOOR)	2	1	Two-Ton Truck	4	Van/Car			269
CEILING INSULATION (PER FLOOR)	3	6	Three-Ton Truck					787
PRIME + 1 (PER FLOOR)	3	1	Half-ton Truck	12	Van/Car			496
TEXTURE CEILINGS (PER FLOOR)	2	1	Half-ton Truck	4	Van/Car			202
GYPCRETE PREP (PER FLOOR)	1.5			4	Van/Car			147
GYPCRETE (PER FLOOR)	1	3	Five-Ton Truck	6	Van/Car			710
GYPCRETE CLEAN+REPAIR (PER FLOOR)	1	1	Half-ton Truck	4	Van/Car			202
LIGHT CHECK - DRYWALL (PER FLOOR)	1			2	Van/Car			74
CORRIDOR DUCT DIST. (PER FLOOR)	2	1	Two-Ton Truck	2	Van/Car			195
CORRIDOR CEILING FRAMING (PER FLOOR)	10	2	One-Ton Truck	20	Van/Car			960
SPRINKLER - CORRIDOR (PER FLOOR)	1	1	Half-ton Truck	2	Van/Car			128
PRESSURIZATION - STAIRWELLS	5			10	Van/Car			92
EXHAUST SYSTEMS - ELEV+ELECT+STOR. RMS	3			3	Van/Car			28
MAKE-UP AIR DUCTS + BREECHING	5	1	Two-Ton Truck	10	Van/Car			122
CEILING DIFFUSERS -CORRIDORS (PER FLOOR)	1	2	Two-Ton Truck					243
ELECT. BOILER CONN	4			4	Van/Car			37
PREFINAL - ELECTRICAL (PLUGS+SWITCHS+LIGHTS (PER SUITE)	5	1	One-Ton Truck	10	Van/Car			480
CPU'S	3	1	Three-Ton Truck	6	Van/Car	8	Lift	216
MECH ROOM INSULATION + PIPING INSULATION	10	1	One-Ton Truck	18	Van/Car			194
BASEBOARD HEATERS (PER FLOOR)	5	2	Three-Ton Truck	10	Van/Car			630
BOILER START-UP	5			10	Van/Car			92
TESTING FOR WATERLINES (PER FLOOR)	2			4	Van/Car			147
MECH FIRECAULKING (PER FLOOR)	1			1	Half-ton Truck			54
BOILERS - TERMINATION	1			1	Van/Car			9
CHEMICAL TREATMENT	2			2	Van/Car			18
BOILERS+HW TANK - FINAL ELEC	5			5	Van/Car			46
CORRIDOR FINISHING - ELEC (PER FLOOR)	2			2	Van/Car			74
ELEVATOR DEFICIENCIES	10			10	Half-ton Truck			136
LOBBY FINISHING - ELEC.	2.5			3	Van/Car			28
							Total	**81826**