Accelerated Learning Series

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Modules in Home Construction

Building your own Home

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Revision History

- 1.0 (June 2021) - Initial Draft
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Prerequisites

- Project Management skills
- Basic understanding of structures
- Engineering Drawing skills
- Basic Handyman skills
- Camping skills

Preface

Food, clothing and shelter are the proverbial essentials for human survival and yet in this modern age where societies have advanced technologically, many spend a lifetime securing a shelter for their families. It doesn't have to be this way.

In this set of notes on Home Construction, we will walk you through the steps to build your own 'Stick-home" - the most common type of construction in North America. While the construction method used here is applicable to "Stick-homes", a substantial portion of these notes will apply irrespective of the construction method employed.

There are two independent aspects that add to the cost of housing. The first is the cost of land and that is always dictated by location. Densely populated regions often have a limited supply of land and consequently demand higher prices for building lots. The only way around this is to move further away from the cities where land costs are exorbitant or succumb to the temptation to buy coordinates in space (a.k.a apartments) and forever sacrifice freedoms and become slaves to the "strata".

The other aspect that adds to the cost of ownership is the actual cost of construction. This is where you can save as much as seventy percent if you are willing to put in some time and effort. For some, the same time and effort invested in other areas may be more profitable, but for most of the population, a seventy percent savings in construction cost will be the difference between assets or debt in the inheritance they offer the next generation. If you fall in the latter category, you will find these notes beneficial.

These notes are based on the hands-on experiences of two individuals who decided to build a couple of homes from scratch. It is our hope that these notes will convey our learnings to future aspiring Builders.

1.0 Understanding the Process

Every endeavor in life starts with a dream. Owning a home is a dream shared by every generation in every society. As this dream takes root in your mind, you will undoubtedly form a picture of what you consider practical in serving the comforts that you desire. This picture will evolve over time as you get more exposed to existing Designs and will eventually lead to a full-fledged Design that will form the genesis of what is referred to as the “Architectural Drawing”. The location of where you will eventually build will substantially influence your Design but let that not stop you from constantly thinking about what you consider essential features of your home. This natural evolution of thought will inform the final Design profoundly.

While your Design is evolving in the background, spend some time searching for a building lot in different areas where you will be comfortable living and where the price is within reach. A preliminary understanding of the construction process and local municipality by-laws will serve you well in picking the right building lot. **Your choice of lot will be highly consequential in terms of the risk and cost associated with your project**. **Hence make sure you are as fully aware of the permitting requirements and local construction practices as possible before putting an offer on a lot.**

Once you purchase a building lot, you can start tweaking your design to fit naturally into the terrain of your lot. At this stage it is worth investing some time in learning one of many Engineering Drawing tools available online and start drafting your design. Rest assured this design will go through several iterations. Having a Computer Aided Design (CAD) tool will make it easy to modify your drawings.

In this section, we will offer an overview of the entire process along with the relevant technical knowledge so you can make informed assumptions and be more prepared for what lies ahead.

1.1 The Basics

1.1.1 Building Codes

In Canada, every province is responsible for their own best practices in construction. While most of these practices are rooted in a common Canadian standard, each province makes alterations to accommodate geographical and climate nuances that apply to their individual provinces. These best practices are published by each province and are referred to as "The Building Code". The Building code is sometimes sold for a fee and is almost always available for free in the public library.

While the Code is a substantial document that attempts to cover a myriad of situations, the items relevant to a "Single Family Dwelling" is rather limited and only consumes a few sections of the code. The challenge however is in identifying the applicable sections and deciphering the often less than articulate language used in the code. At the outset, a general perusal is all that is required to identify the relevant sections. As you encounter specific issues during construction, you can dwell in more detail at the applicable sections.

Note that the Electrical, Plumbing and Heating/Cooling codes are often separate from the Building code.

1.1.2 Municipal By-laws

In addition to complying with the edicts of the Building Code, you will have to comply with the By-laws of the municipality where your lot is located. These By-laws will impact things like how many parking spaces you need, where those parking spaces should be, how high your building can be, what setbacks need to be allowed from the property lines and other such rules that fall under the jurisdiction of the Municipality.

1.1.3 Surveys

A professional survey of your lot is one of the first things you will do after (or before) you purchase your lot. This will tell you exactly where the corners of the lot are located and allow you to complete your site layout as part of your architectural drawing.

1.1.4 Architectural and Structural Drawings

After getting your survey, you can complete your **Architectural Drawing**. This drawing will give enough detail on the exact location and layout of your house to allow a qualified structural engineer to provide a **Structural Drawing** that identifies load bearing and other structural integrity items of the design. The most basic measurement used by a Structural Engineer is known as the "**Bearing capacity**" of the grade where the house is to be constructed. This measurement determines the load allowed on the structure. While a structural engineer can decipher the bearing capacity, the municipality where you are located might insist on a more substantial Geological report that addresses additional issues such as landslide risks. Most municipalities will allow the owner builder to complete their own Architectural Drawings. However, the Structural Drawing (and Geological report if required) will have to be completed by licensed professionals (P.Eng. & P.Geo. respectively in Canada).

1.1.5 Permits

The permits required to begin construction will vary by province and municipality. In our case we had to have the following permits in BC.

1. Owner Builder (OB) Permit (Obtained after completing an OB exam in BC)
2. Development Permit (Obtained after submitting a Professional Geologist report)
3. Building Permit (Obtained after submitting a Survey and an Architectural and Structural Drawing)
4. Electrical Permit (Obtained from Technical Safety BC)

If you are using a Septic system, you will likely have to submit a filing with the Ministry of Health on the type of septic that meets the soil conditions. This will have to be done by a licensed septic specialist prior to obtaining a Building permit.

In areas where a Development Permit (DP) is mandatory, you can’t clear a lot until you have gotten a DP.

In general, you can’t start excavation until you have obtained a Building Permit.

1.1.6 Inspections

Inspections are designed to catch potential problems and code/By-law violations in a timely manner so that remedies are easier to implement. In most municipalities, you can expect the following inspections…

Inspection Number	Inspection	Comments
1	Excavation	Conducted by Geologist or structural engineer to verify bearing capacity before footing foams are prepared.
2	Set-backs	Conducted by Municipality after footing foams are prepared but prior to the pouring of the footing. Generally a 2nd survey is required to identify the corners of the structure such that it meets the set-back requirements.
3	Footing	Conducted by a structural Engineer to verify re-bar and concrete thickness recommendations are satisfied. This inspection is done prior to the pouring.

4	Foundation wall	Conducted by a structural Engineer to verify re-bar and concrete thickness recommendations are satisfied. This inspection is done prior to the pouring.
5	Drain Tile	Conducted by the Municipality prior to Backfill to ensure the Drain tiles are in conformance to code.
6	Backfill	Conducted by Geologist to verify the backfill meets the recommendations of the earlier report.
7	Rock-pit Drain	This is required in areas without a storm water drain system and is designed and inspected by a licensed Engineer.
8	Sheathing	Conducted by the Engineer after the structure is completed, but prior to covering the exterior with waterproof paper. Engineer confirms structural integrity.
9	Under-slab plumbing	Also known as the Drain-Waste-Vent (DWV) inspection. This is often done by the city before the floor slab is poured in slab-on-grade construction.
10	Under-slab poly insulation	Most codes have protection against Radon gas. The remedy usually involves a layer of 6mil Poly under the floor slab. This is inspected by the city before the pouring of the floor slab.
11	Plumbing Rough-in	Conducted by the city to confirm pipe dimensions, gradients, p-traps and venting.
12	Ducting	In BC, there is a new body known as TECA who are now the only people licensed to sign off on Ducting.
13	Electrical Rough-in	In BC, the Technical Safety body is responsible for the issuance of Electrical Permits and associated inspections.
14	Structural	The Engineer who provided you with the Structural Drawings will have to inspect the structure prior to any coverings.
15	Framing	Done by the city prior to any coverings. There is substantial overlap between the Framing inspection and the Structural inspection.
16	Insulation	Done by the city to ensure insulation meets code.
17	Final Electrical	Technical Safety BC responsible for final Electrical Inspection.
18	Final Occupancy	The city inspects hand rails and other such

		safety issues prior to issuing an occupancy permit.

1.1.7 Structures

The term “Structure” refers to everything that contributes to the bearing and transmission of the load along with the tolerances for external forces (such as wind) on a building.

It starts with a footing, over which the foundation wall rests. Anchored to the foundation wall is a sill plate and nailed to the sill plate are all load bearing walls. If the floor spans exceed the specifications for your chosen floor joists, you will need additional concrete pads, posts and beams between your foundation walls to support sections of the floor joists. In “Stick-home” construction, load bearing exterior walls are usually made of 2x6 studs (to be decided by P.Eng) 16” apart that are tied together with ½” plywood sheathing. Floor joists sizes will be determined by their spans and are tied together with ¾” plywood sheathing. The roof is made of engineered trusses that are tied together with ½” sheathing. These trusses are attached to the walls with nails and hurricane ties, and they act as the binding force that holds the walls vertical, allowing them to take the transferred loads from the floor joists and pass them down to the foundation wall.

The general idea behind a structure is rather simple – every load placed on the building must have a way to get passed to the foundation. The foundation in turn relies on the bearing capacity of the grade. If any part involved in the bearing and transmission of load is compromised, the overall structural integrity is compromised. In addition to loads placed on the building, the structure should also account for lateral forces generated by wind and other such external contributors.

While the Professional Engineer is responsible for the design that addresses the overall structural integrity, as an owner builder you are responsible for ensuring that you are conforming to the Engineer’s specifications. Understanding the engineering principles behind the recommended design will give you greater appreciation for the need for strict compliance.

Once your structure is up, you can call for a Sheathing inspection. The inspector will examine compliance with the structural specifications by the engineer. Shear wall reinforcements, type and length of nails used, depth of nails into plywood and all other externally visible items will be inspected at this stage. Once you pass this inspection, you can cover the exterior of your structure with waterproof paper. Typar is the preferred material used on external walls and QuickStart is used on the roof sheathing. This is done to keep your structure dry as soon as practical.

1.1.8 Sewage

Wastewater is a health hazard and a substantial amount of science is involved in how we ensure that waste generated in a home is treated safely. In general, there are two methods of dealing with wastewater – a city sewage system or a Septic system. If your lot is in a region that has a city sewage system, you just need to hook the waste plumbing to this system. If your lot does not have access to a city sewage system, then you will have to have a septic system. There are many kinds of Septic systems and the one applicable to you will be determined by a Septic Engineer based on the soil conditions. The cost of the septic system will be based on the type that is required for your lot.

1.1.9 Electrical

Unless you plan on living off-grid, you will have to rely on power from your local Electric company. You will likely need power during construction as well. Power connections are expensive and considering your options early can allow for savings.

Warning – Extreme caution must be employed when dealing with live power connections. If you are not eligible to take a permit to work on your own house, you must employ a qualified electrician. Any error in dealing with live power connections can be extremely dangerous and even fatal!

You only need a basic high school physics background to understand how a house is wired. Most homes in North America get two feeds of 110-Volts that are phase shifted by 180 degrees along with a Neutral line. The 180-degree phase shift allows for a 240-Volt differential between the two powered lines. This higher voltage is handy when you want greater power (Note: Power = Volts x Amperes) at a lower amperage (thinner wiring). Most common cases where higher power is required is in Stoves, Dryers and Water Heaters. In these cases, you will use a double pole breaker to tap the two live wires coming into your home. In all other cases, you will tap between any one of the live wires and the neutral with a regular breaker.

All three wires coming into the house will first go through a meter and then go into a main Breaker panel where every adjacent Breaker will be configured to tap from alternate live lines. This is to allow Double Pole Breakers to tap from the two phase shifted lines. Most modern homes have a 200 Amp connection, but that does not mean you are limited to having a total of 200Amp in appliances. The assumption is that you will not always have all appliances active. You don't want to be too far from the 200Amp mark either to avoid tripping your main panel breaker.

1.1.10 Plumbing

There are two distinct parts to plumbing a house – Inlet and Drain.

The Inlet is often a high-pressure potable water connection from the city or an overhead tank. Where the inlet gets into the house, you want a back-flow preventer and a pressure reducing valve and a main shutoff. Subsequent to this, you need to run this line to every faucet in your house as the cold line as well as your hot water tank. The output of the hot water tank must be routed to every faucet in your house as the hot water line. There are a few considerations that influence the size of the pipes, but as a rule the size reduces as you get closer to your faucet to maintain pressure. Most modern homes will have a 1" line coming into the house that is reduced to ¾" on the trunk lines and ½" lines to the faucets.

The challenges with the Drain lines are very different from the Inlet lines. There is hardly any pressure in Drain lines, but you must prevent sewage gases from coming into the houses. Every fixture/drain must have a p-trap for this purpose. Another challenge with Drain lines is to ensure adequate venting is provided to prevent flow blockages. The size of drain pipes will generally increase from about 1½" at a faucet to 2" to 3" and finally to 4" at the exit from the house. A single-family dwelling will seldom need a drain size greater than 4". Since drain lines hardly have any pressure, you must provide adequate sloping. The larger the pipe, the less the required slope. Finally, most codes will disallow sharp bends on drain lines. Hence a 90-degree bend would have to be achieved by two 45-degree bends.

1.1.11 Heating/Cooling

Depending on your location, Heating/Cooling may be essential and should be accounted for very early in the construction process. If you plan on a centralized Heating/Cooling system, you will need a Ducting system that extends to all living areas of the house. The fuel sources available in your area such as gas, propane or electricity will also influence the system you purchase. Code in your area may also dictate external fresh air intake and this will also influence your ducting system.

In the most simplistic form, a Heating/Cooling system involves sucking air from central areas of your home such as hallways and pushing this air though a heating or cooling coil (also known as an exchanger) and pumping the heated or cooled air to the extremities of living space. Separate ducting systems are required for the intake and the distribution of the heated or cooled air. To avoid losses (frictional and convection), ducting systems must allow for smooth flow and be insulated.

1.1.12 Insulation

Once you have completed your structure and made allowances for your Plumbing, Heating/Cooling and Electrical rough-in, you are ready to call for a structural and framing inspection since all the openings in the structure are already made. On completion of these two inspections, you will be granted the "ready-to-cover" authorization. At this point you can start insulating your home. Your building code will dictate the level of insulation required in your region. In the pacific NW, most codes require R-40 in Attics, R-28 for flat roofs (and decks), R-20 for external walls, and R-12 for exposed foundation walls (up to 2 feet below grade). After placing the insulation batts, you can cover the insulation with a 6-mil poly vapor barrier. Code will usually dictate an acoustic seal between the poly and the top and bottom plates of your wall. Once this is completed, you can call for an insulation inspection.

1.1.13 Drywall

The finishing of the interior is accomplished with a gypsum board known as Drywall. Drywall is screwed to the studs with openings for electrical outlets and gaps between boards sealed and finished to give a clean wall ready to be painted.

1.1.14 Flooring

Once the Drywall is installed and painted, you can start your flooring since there is less risk of spillage into your new floor at this stage.

1.1.15 Finishing

What is left at this stage is the finishing work. This is the stage where you hook up your lights, switches and sockets to the electrical rough-in done previously. Similarly for the plumbing, you can now hookup your faucets, drains, showers and toilets. For ducting, you can put your register covers. The windows and doors can have trims put on, and the walls can have skirting. You can also install your appliances.

1.2 Task Sequence and Cost estimates

One helpful piece of information for an owner-builder is to know the sequence of tasks and approximate costs. The following table summarizes the tasks involved and their order along with approximate costs. The wide variance in cost is to reflect the varying home sizes, product quality and how much external labor is involved.

One issue to be aware of is that most financial institutions will not fund construction of homes by owner builders. So other options like Line-of-Credit should be explored early in the planning phases.

Task #	Task	Cost Estimate	Comments
1	Understanding the Process	$0	
2	Purchasing the Lot	Variable	
3	Getting the Permits	$10K – $25K	
4	Lot clearing	$10K - $25K	
5	Excavation	$2K - $20K	
6	Footing	$10K - $15K	
7	Foundation wall	$15K - $25K	
8	Framing	$20K – $40K	
9	Roofing	$10K - $30K	
10	Typar and QuickStart wrap	$1K - $2K	
11	Windows and Doors	$10K - $40K	
12	Septic	$10K - $40K	
13	Basement under slab plumbing (For slab on grade)	$1K - $2K	
14	Basement concrete floor slab	$5K – $20K	
15	Internal walls	$3k - $10K	
16	Staircase	$1K - $2K	
17	Plumbing	$5K - $25K	
18	Ducting	$5K - $25K	
19	Electrical	$5K - $25K	
20	Siding	$5K - $25K	
21	Furnace	$2K - $20K	
22	Insulation and vapor barrier	$5K - $25K	
23	Drywall	$15K - $30K	

24	Flooring and Painting	$5K - $25K	
25	Electrical final	$5K - $10K	
26	Washroom Fixtures	$2K- $25K	
27	Kitchen counter and cabinets	$3K - $25K	

2.0 Purchasing the lot

Purchasing the lot will be the first of many consequential decisions of your project. We will discuss some of the key considerations here.

2.1 Size of lot

The obvious consideration when purchasing a lot is the size of the lot. You want to make sure that you have the adequate room for your dream home after you allow for setbacks and other infrastructure needs like parking and septic fields. Also you want to give consideration to where the house will be located relative to the septic field to ensure you can accommodate gravity feed into the field to avoid the cost of pumps (assuming a septic system).

2.2 Slope of lot

A gradient higher than 20% (2' drop for every 10') can be problematic and may incur additional permit and construction costs.

2.2 Bearing Capacity

The ability of the grade to withstand load will also impact permitting and construction costs

2.3 Underground water

While it is hard to make judgments on underground water paths, you can come up with educated opinions based on the flow observed in nearby gutters. The amount of gravel in the lot will inform if pooling can be avoided. Ideally a lot with no underground water paths at least up to the excavation depth is desired.

2.4 Soil type

The soil type will influence the type and size of your septic field (assuming septic system).

2.5 Cost of lot

Once all the above factors are considered, you can make an informed decision on what you are willing to pay for the lot.

3.0 Getting the Permits

Understanding the permit requirements will generally involve a visit to the Building Department of your municipality. Unless you are fortunate enough to have an efficient local government, you will likely face several bureaucratic hurdles. The interfacing with the government was in our experience the most unpalatable part of the project. The staff at the municipality were less concerned about technical details and more concerned about delaying and stalling the process. It was a very painful experience. With the exception of a couple of knowledgeable and efficient individuals, the majority of interactions left much to be desired. You must be prepared to deal with individuals who have neither completed a project of the scale you are about to embark on nor have the aptitude to do so, yet have been entrusted with the power to destroy your enthusiasm. The majority of these government officials will use that power, without hesitation, to your detriment.

In the end, you will find that the government will take zero responsibility for any risk, provide you with no useful information and continually ask for assurances from licensed professionals in the form of "Schedules". In cases where certain schedules are not applicable to you, the onus will be on you to prove that those are not needed. When you point out that some of these requirements are redundant and add unnecessary cost, they will promptly let you know that the cost and torture you incur is no concern to them. Finally, if you believe that the government is taking these steps to give you an assurance that they will come to your rescue if there is a mishap, you are due for a rude awakening.

In a conversation with a General Contractor where we questioned his high quote for construction, the contractor was quick to acknowledge that we could certainly do it cheaper if we were willing to deal with the government to get our own permits. Without a doubt, a substantial reason for the high cost of construction is our incompetant government and how lobby groups influence building codes.

Sadly society continues to count on the government to provide affordable housing when it is the government that is largely responsible for inflating the cost of housing in the first place. The government is not the solution. The government is the problem!

In our case, we were required to get an "Owner Builder Permit", "Development Permit" and a "Building Permit". We also needed to get a separate Electrical Permit from a different agency.

3.1 Owner Builder License

This is a relatively new requirement in BC with the express intent of discouraging owner builders. Of course, it is not advertised that way. Instead, you are made to believe that the exam you are forced to take is designed to make you a more competent Owner Builder. The exam does little to help you with the actual construction, and more to test you on the bureaucratic requirements. I would argue that this document will prove far more useful to you than your preparation of the OB exam. There was no concise preparation material and there were several "Industry leaders" providing training courses to prepare for this exam for a substantial fee. You will be asked questions like what gas is used in double pane windows. This would certainly be a relevant question if you intend to build double pane windows. Ultimately if you get 70% in the exam, you will be granted an Owner Builder Permit.

3.2 Development Permit

The prerequisites for a Development permit involved a detailed Geological Report provided by a licensed Geologist along with several assurances in the form of "Schedules". These reports, assurances and site visits cost us approximately $7000 and it represented almost 50% of the permitting costs. On our lots, the slopes were mostly under 20% and such stringent Geological requirements were uncalled for, technically speaking. However, there is no room for such nuanced interpretation when dealing with the government. In addition to the Geological reports, we were asked to provide drawings detailing the location, size and height of the proposed structure, along with perspective views showing that the new structure would not unduly impact neighboring properties.

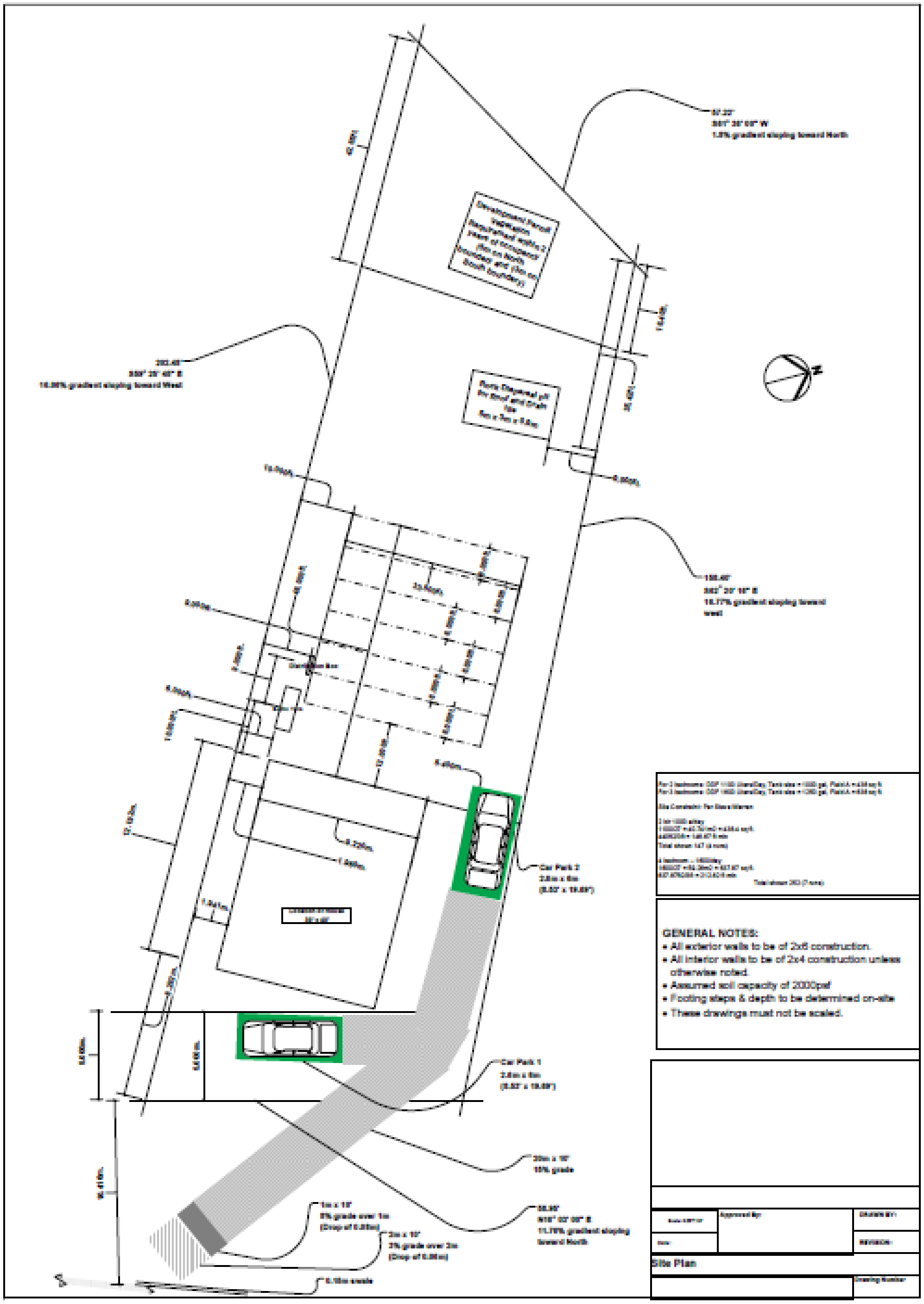
3.3 Building Permit

The Building Permit was relatively more straightforward because we had an excellent structural engineer and the government officials in this department were more reasonable. The prerequisites for the Building Permit involved an Architectural drawing (which we were able to do on our own), a Structural drawing provided by our Engineer and Septic filings with the Ministry of Health by a licensed Septic Engineer.

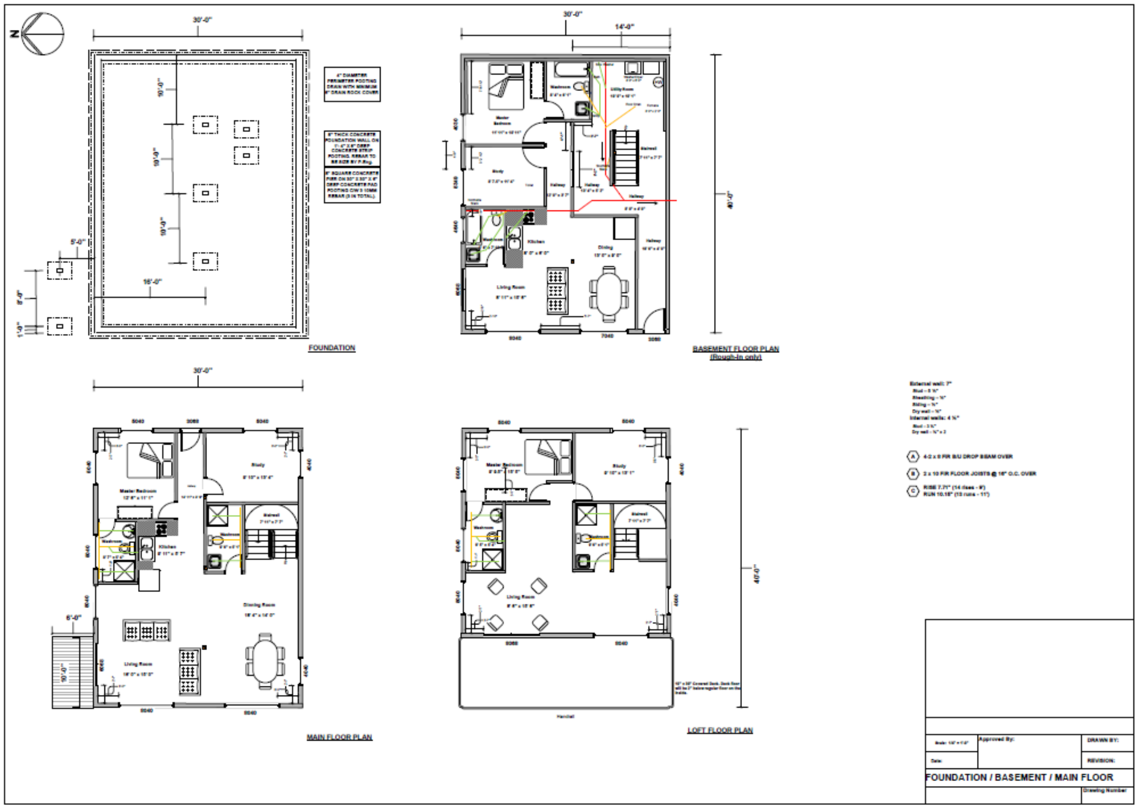
The Architectural drawing should be fairly detailed and should account for all the constraints in the Building Code including limitations on the number and size of windows (fire related restrictions), types of soffits, waterproof coverings, furring strips, type of siding, roofing material etc. Setbacks from property lines must also be clearly shown, along with location of car parks, Septic fields etc.

The following are samples of the Architectural details required.

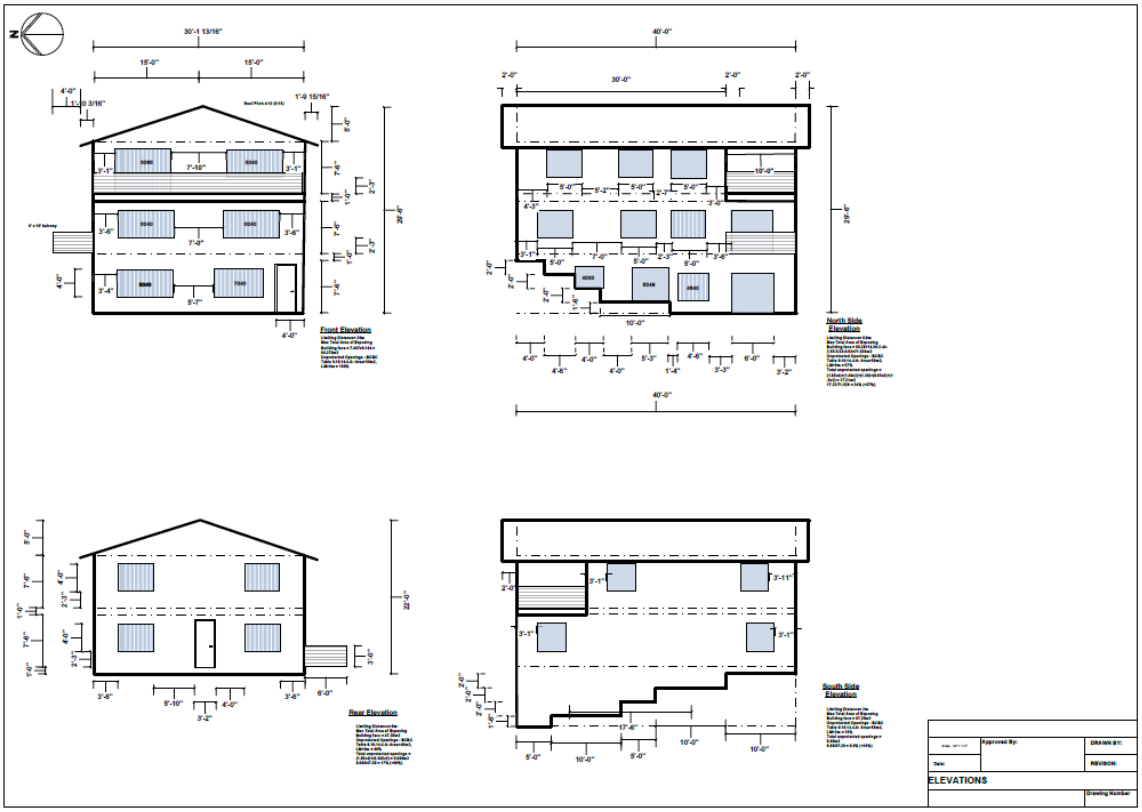
3.3.1 Site Plan



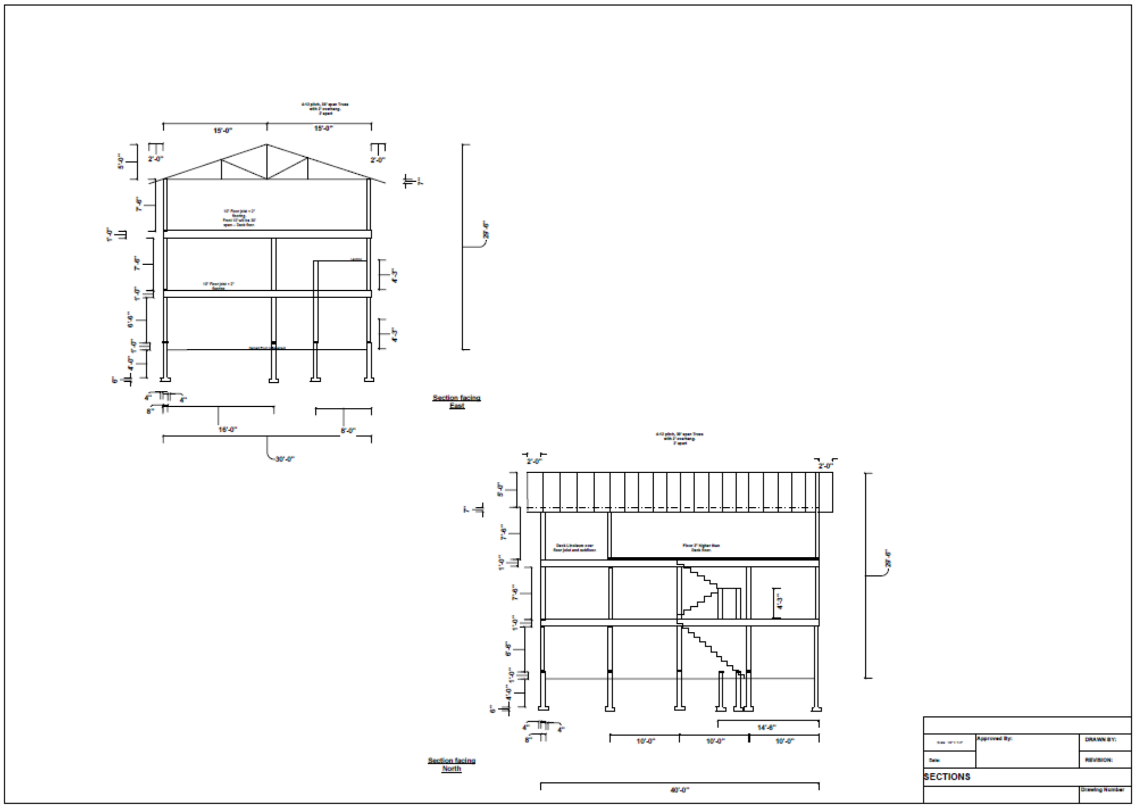
3.3.2 Floor Plans



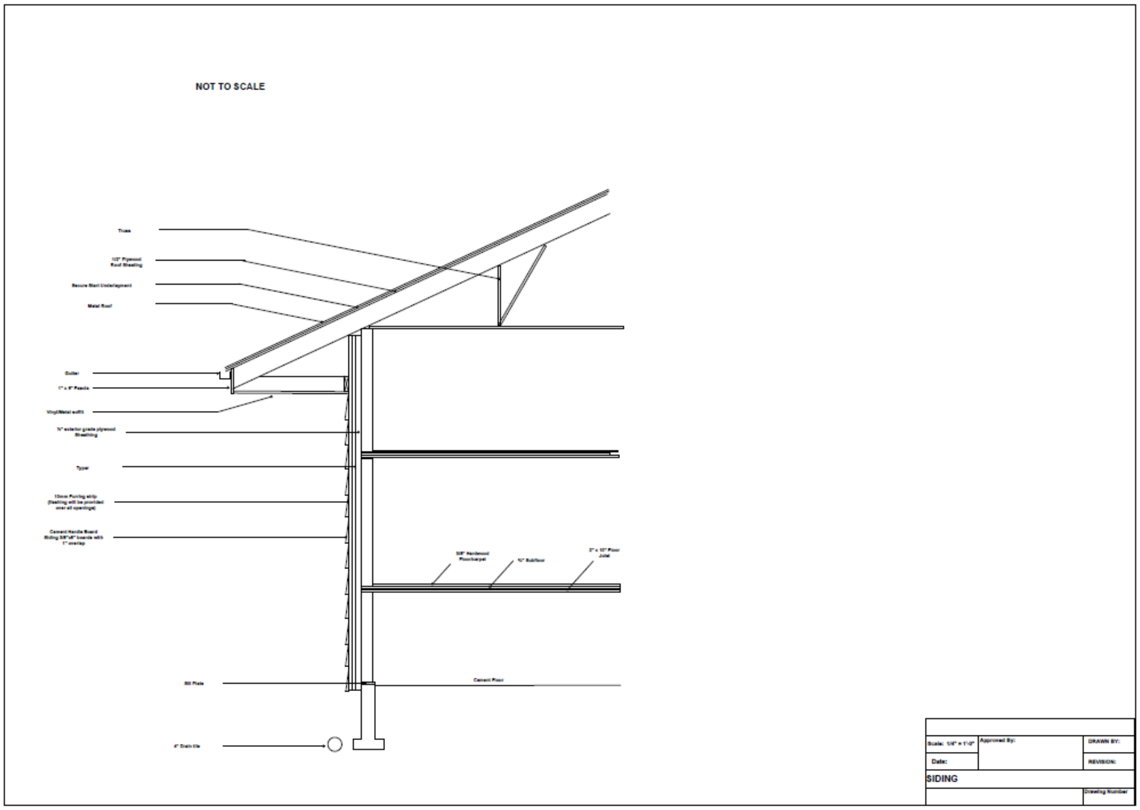
3.3.3 Elevations



3.3.4 Sections



3.3.5 Siding Details



4.0 Lot Clearing

Once you get the necessary permits, the fun can begin! If you ended up with a wooded lot, your first task would be to get a tree feller to bring the trees down followed by getting a machine to get the roots out and prepare for excavation. Depending on the size of your lot and the number of trees, this may take 3 to 6 days, but you must budget a month in time to line up all the resources involved. Tree fellers generally charge anywhere from $600 - $1200 per day and a machine with an operator would cost about $1000/day.

You must allocate an area of the lot to store the tree trunks if you don't plan to give them away. The branches and leaves would need to be sent to disposal since fire restrictions would prevent you from getting rid of this on site. The cost for this would involve the transportation cost and the cost at the disposal facility (usually charged per ton in weight). This cost can add up quickly and depending on the amount of waste, you will have to budget anywhere from $1000 to $10,000.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5.0 Excavation

Once the lot is cleared, you get to be less dependent on external resources. If you can hire a small machine (usually they go for about $500/day) and a rotating self-leveling laser, you have all the tools necessary for excavation. It is a good idea to get a surveyor to help mark the exact corners of your proposed structure before you start excavation.

First you need to scrape the top garden soil and organic material in the area when you plan to construct.

You can then set up your laser at a convenient spot on the lot to guide you as you use the machine to get the excavation started. The laser will help ensure you are as close to level across the entire excavation.

The cross section of the excavation will tell if you have gone past the organic material and reached the region where maximum sustained bearing capacity is possible. You want to determine the ideal floor level for your basement and use that level as a guide for how deep you wish to excavate once you are past the organic level. You want to avoid going deeper than you need to so that you are less dependent on external structural fill.

Once you are at the level you want to be at, make sure you use a scraping bucket (as opposed to a fork bucket - see pic above) on the machine to avoid disturbing the soil at the location of the footing.

If your lot is not level, it is best to go down in steps of 2 feet and follow the natural terrain of the lot. Structural Engineers will usually only allow 2 feet drops on the footing at a time. There is no need to disturb the soil in regions where the footing is not located.

As an added safety, you can hire a 5 ton tamper and tamp the entire region where the footing will be located.

Now you can be confident that you have the maximum Bearing Capacity of the grade at your disposal for your structure.

If you are in a region where a Development Permit is required, you will likely need a GeoTech engineer to come and certify your work. While there are instruments to get accurate readings of Bearing Capacity, most GeoTech engineers will manually poke a few spots and sign off. They are usually happy once they see that you have got a tamper on-site.

6.0 Footing

After excavation, you must get your surveyor to put pins on the corners of your proposed structure. The width and depth of your footing will be determined by your structural engineer. Generally, if the foundation wall is 8", your footing will be about 18" wide to have a 5" overhang on either side of the wall. You want to build your footing forms such that the survey pins are located exactly where the corners of the foundation wall will be located.

A self-leveling laser will prove very useful as you build your footing forms. You can see one on top of the 2x6 at the bottom left corner in the pic below. The pink ribbon in the pic below is tied to the survey pin which is hidden by the peg.

Using a fluorescent taut string between your survey pins is a helpful guide for the form construction.

You will find the 1x2 cross pieces add strength to the form work and will later double as ties for the rebar dowels, so space them at the dowel spacing recommended by the Engineer.

A preliminary inspection by the local wildlife is always gratifying.

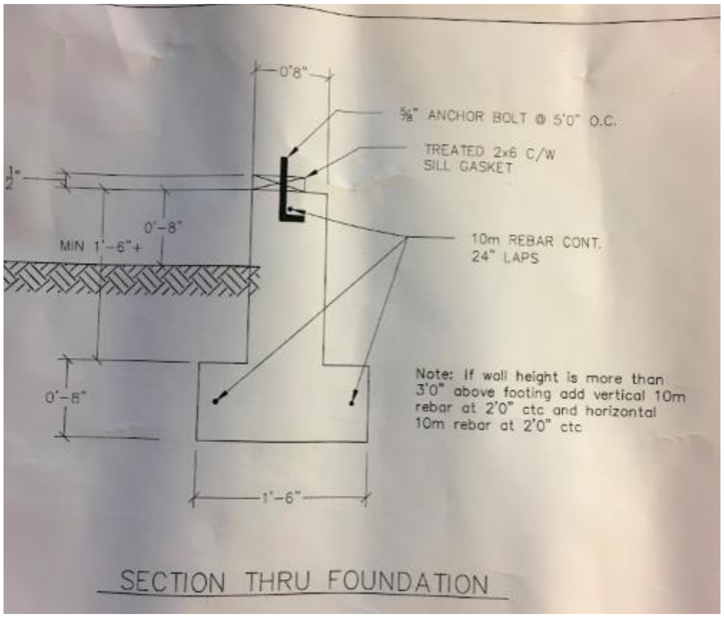
They have a way of letting you know that they are signing off.

If you intend to pull your water line or Electrical line below the footing, make sure you leave a block on the inner side of the footing so you can pull the lines flush with the foundation wall on the inside to avoid a kink going around the footing.

The vertical 2 feet drops maintain the same thickness of the footing at the drop.

If your footing thickness is greater than the width of the form, you can fill the gap at the bottom with soil or any other timber.

Once the form work is completed, you are ready to place the rebar in accordance with your Engineer's spec.



In the spec above, the Engineer is calling for two 10m continuous rebar (24" laps) in the footing and since all our walls are over 3', we will have dowels all around spaced at 2 feet.

In the 2 feet drops, the rebar is bent but continuous. Care is taken to ensure the rebar is not buried in grade. The cross pieces are not called for by the Engineer, but they do add rigidity to the rebar construction as they negotiate the drops.

Ensure the survey pins don't get buried during the pour by using a PVC pipe to protect them.

Inspection - Footing

Once the rebar is completed, you can call the Engineer and the municipality for inspection prior to the pour.

Once the Engineer signs-off, you can let the city know of your scheduled pour in case they wish to inspect the survey pins once again. Once both the city and the Engineer sign off, you can schedule the pouring of the footing.

Note that this method is referred to as the “double pour” since you have to call the concrete pump trucks twice - once for the footing and once for the foundation wall. If you build the form for the foundation wall at the same time, you can reduce cost by calling the pump truck just once and that is called the “single pour” method. But the form work is easier with the double pour method.

Note the use of a vibrator to even out the pour of the concrete. I must mention that the owner of the concrete pouring company was an inspiration for our project! He guided us well during the entire process and we will always be grateful to him!

Note the 3 pads along the 16’ foot mark. These are designed to support the posts that support a center beam. You can get engineered joists that can span the entire 30 feet, but we opted for off-the-shelf 2x10 for our floor joists and those have a span of just 16 feet max at 16” on-center spacing. So we need a beam that will support 14 feet joists on one side and 16’ joists on the other. Our structure is 30’ x 40’ and the joists are placed along the 30’ width.

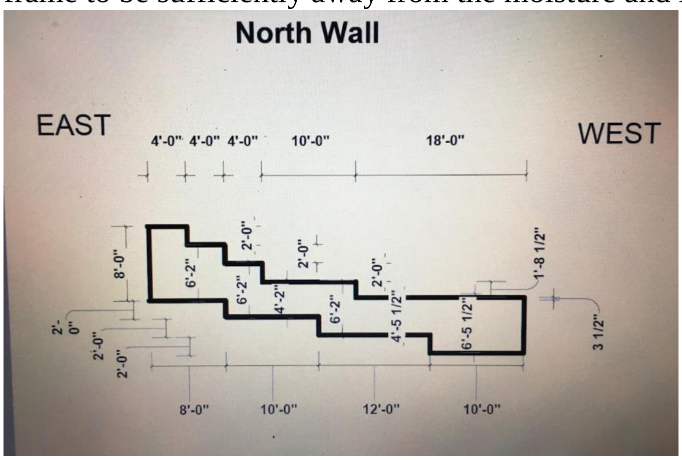
The additional two pads in the interior are designed to support our stairwell landing. These proved unnecessary since we were able to hang the stairs off our internal walls. The two exterior pads on the top right are designed to support a deck.

7.0 Foundation Wall

With the footing poured, you are ready to start the form work for the foundation wall. You have a choice of renting the forms, making your own forms with plywood that you can later use for your floors or you can go with Insulated-Concrete-Forms (ICF).

Because our pump truck friend had forms for rent, we opted to rent our forms from him. This option has the added advantage of coming with right angle corners.

We designed our foundation walls to follow the terrain as close as possible while ensuring we allowed at least 18” of concrete wall above grade. This will allow the wood frame to be sufficiently away from the moisture and insects in the soil.



Next, we start building the outside form around the entire perimeter.

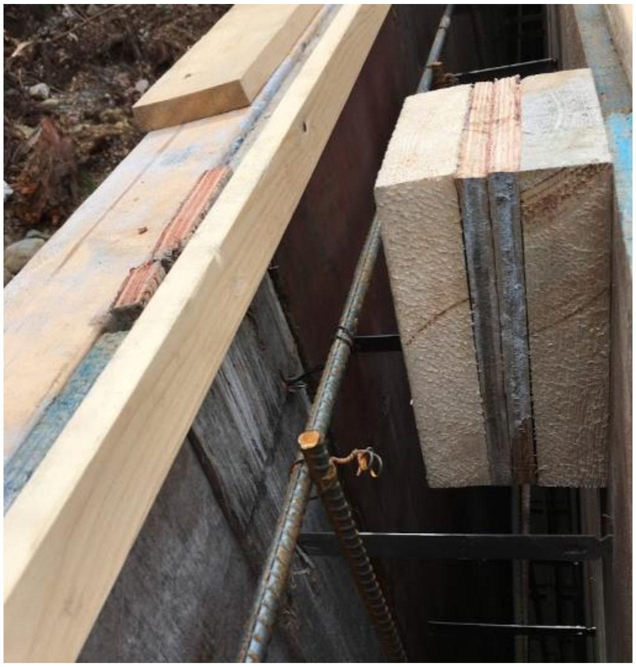
We support these forms with long 2x4s nailed to pegs in the lot. We can use a builder’s level to mark the height of each section of the wall to match our wall design. Along these marks we nail a 1x2 strip. This will serve 2 purposes – first it will tell the pour crew where the wall ends and second it will provide an edge cavity in the concrete wall for the ½” sheathing to nicely overlap the sill plate of the frame.

Next, we install the rebar as per our Engineer’s spec. We tie the vertical rebar to our Footing dowels. The rented forms come with slits for the wall spacers. Since our engineer called for an 8” wall, we got 8” spacers through these slits. Notice the diagonal rebar where the footings drop – this is to avoid cracks in the concrete at those drops.

Inspection - Foundation wall

The Engineer must be called for an inspection prior to placing the inner forms to verify the rebar and formwork. Once that is done, we are ready to cover with the inner forms. They are held in place with the 8” spacers.

We leave a block to create a slot for our center beam to rest.



It is time to call our pump truck again!

Don’t forget to sink the anchors into the foundation wall before the concrete sets. These anchors are what holds the wooden frame to the concrete foundation wall.

72 hours later, it is time to peel the forms out.

And waterproof the exterior of the foundation and get the solid foam insulation ready.

Always good to see the survey pins! You know your wall is at the right place!

Now it is time to install the drain tiles and rain-water drains. The drain tiles are perforated pipes that guide the ground water away from the structure. You must ensure these pipes are below the concrete floor level to avoid basement flooding. The rain-water drains connect to the roof gutters. Septic or Sewer connections are also set up at this stage.

If your code calls for insulating foundation walls, this is the time to do it.

Inspection - Drain tiles

The drain tiles must be wrapped with filtering material and buried in coarse gravel to aid the flow of groundwater. You need to pass city and engineering inspections before covering it with gravel.

Now you can backfill. The fill inside the foundation wall must be compacted structural fill since it supports the weight of your basement floor in slab-on-grade construction.


Dow
Styrofoam

8.0 Framing

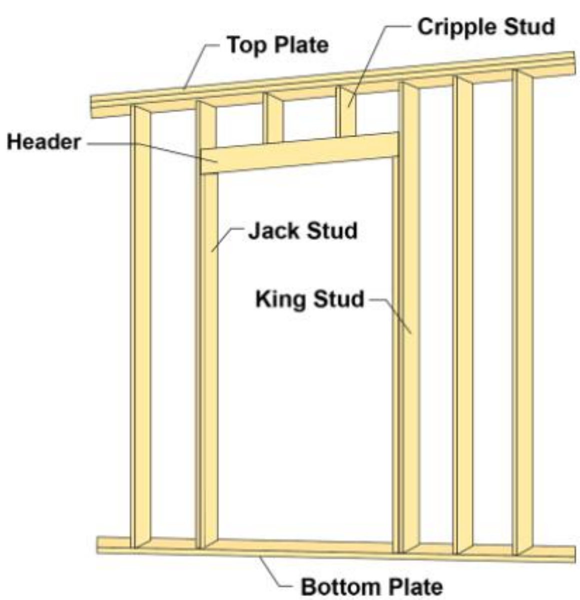
When people think of house construction, the image they conjure in their minds is that of framing because that is what is most visible externally. In our experience, framing represents only a six week phase in a two year project. Yet it is a very gratifying phase.

Framing starts with bolting the sill plate to the foundation wall. We put a layer of foam under the sill plate and used treated 2x6 for our sill plate. The plate is placed flush with the outer edge of the foundation wall and bolted on to the anchors.

Then we start constructing the walls.

It is best to get pre-cut studs delivered to site instead of getting 2x4x8 and cutting them to the right wall heights.

Depending on their purpose, Studs are referred to as a regular stud, King stud, Jack stud or a Cripple stud. Cripple studs can be upper (above door or window header) or lower (below Window) The bottom plate will rest on the sill (or floor) and the Top plate is usually doubled. If using a single top plate, your studs on each level will have to be exactly at the same location. This is difficult to do.



For lower Cripples, it is beneficial to cut the tops at a slight angle so the Window sills slope outward to aid precipitation drain.

Specs for Door and Window Headers along the number of Jack studs will be prescribed by your engineer. In our case, we used 3-ply 2x10s for most of our headers and double Jack studs. In situations where we didn't have adequate headroom for 2x10s, we used engineered headers (LVLs – Laminated Veneer Lumber) of lesser width.

½" plywood sheathing is what adds strength to your walls and it is a good practice to have the sheathing nailed to the wall sections before erecting them. We didn't follow this practice for the basement, but did do so for the other levels.

Since you are unlikely to have all the tools and help in a DIY, you will be lifting the walls in small sections. It is a good idea to have pencil marks at every 16" in the bottom and top plates of the entire perimeter before you erect the walls. That way you can be sure to space your studs correctly on the entire wall as opposed to individual sections.

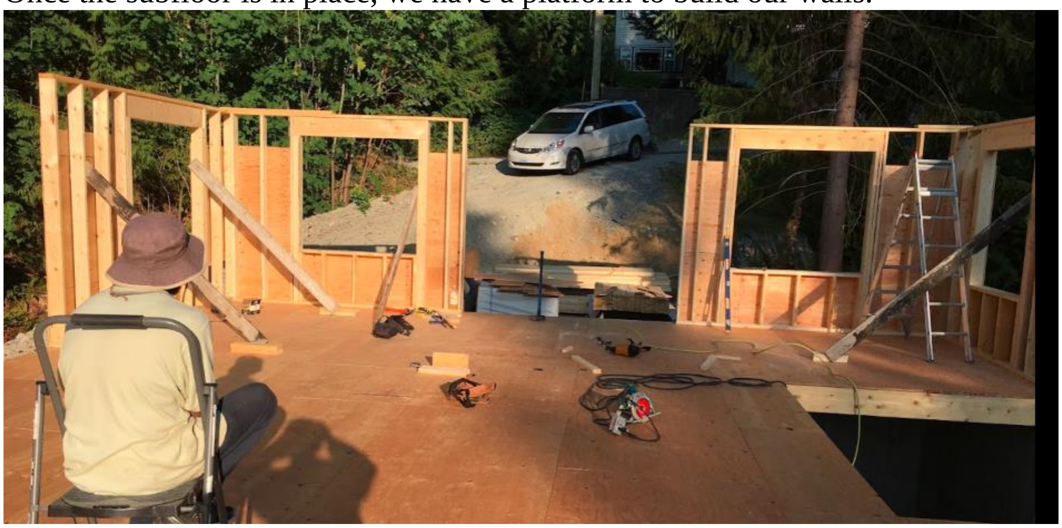
Once the Basement walls are erected, it is time to get the posts and center beam in place. You could choose to have engineered joist that span the entire width of your structure and that would save you from having to use a center beam. We opted for off-the-shelf 2x10 joists which have a maximum span of 16' and so we were forced to have a center beam.

Our beam was a 3-ply 2x10. It is important to have the ends of each ply resting at either end with at least 3" on the support. Ideally you can design your internal walls to line up with the beam to provide additional support. We used three 6x6 treated posts to support our beam as well as the walls on either end.

Once the walls and the center beam were erected, we were ready to place our floor joists. Like the wall studs, the joists are spaced 16" OC, with spacers between every 8'. To support the stairwell, we tripled up the joists on either end of the stairwell and hung a 3-ply beam between them to support the joists along the stairwell. We tie all the joist with a rim joist that is flush with the edge of the sill plate.

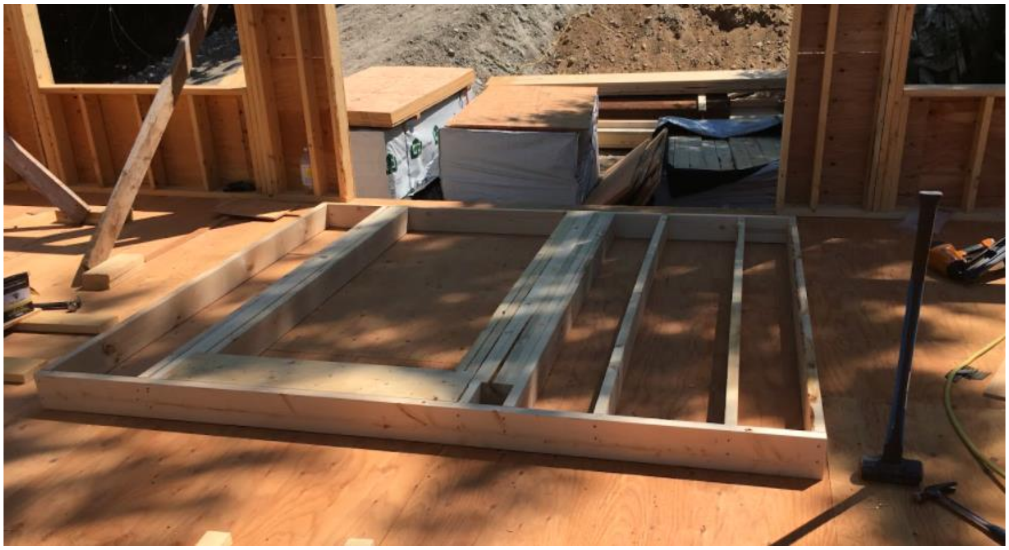
Now we can place our tongue & groove ¾" plywood subfloor. We used glue and flooring screws to fasten the subfloor to the joists.

Once the subfloor is in place, we have a platform to build our walls.



It must be pointed out that professional framers generally frame the internal walls and stairs before moving to the next floor. We opted to erect the external walls (load bearing) and race to get the roof before the rains. We completed the framing in a 6 week window in summer when there was no rain. The first rain was a few minutes after we placed the last piece of roof sheathing. We rushed to put a tarp over the sheathing.

We built each section of the wall in-place and ensured squareness before sheathing and lifting. Squareness was achieved by making sure the diagonals were the same. Light taps with the sledge hammer helped correct diagonal inconsistencies.



The Irwin Quick Grip is pretty handy to straighten warps in the lumber before nailing.

To enhance shear strength, we ensured our sheathing spanned across floors. To achieve this we left 19” at the top and bottom of each wall so we could have a single 4x8 ½” plywood sheet spanning two floors and the intervening floor joist. This is only a requirement of shear walls, but we followed this practice for the entire structure.

Since our Door and Window Headers were 3-Ply 2x10s and our exterior walls were 2x6, we had 1” gap. We made sure the headers were flush with the exterior edge and used pegs to hold them in place while we nailed.

The 2nd of the double top plate was placed after all the walls were erected and ensured that individual sections were all tied together.

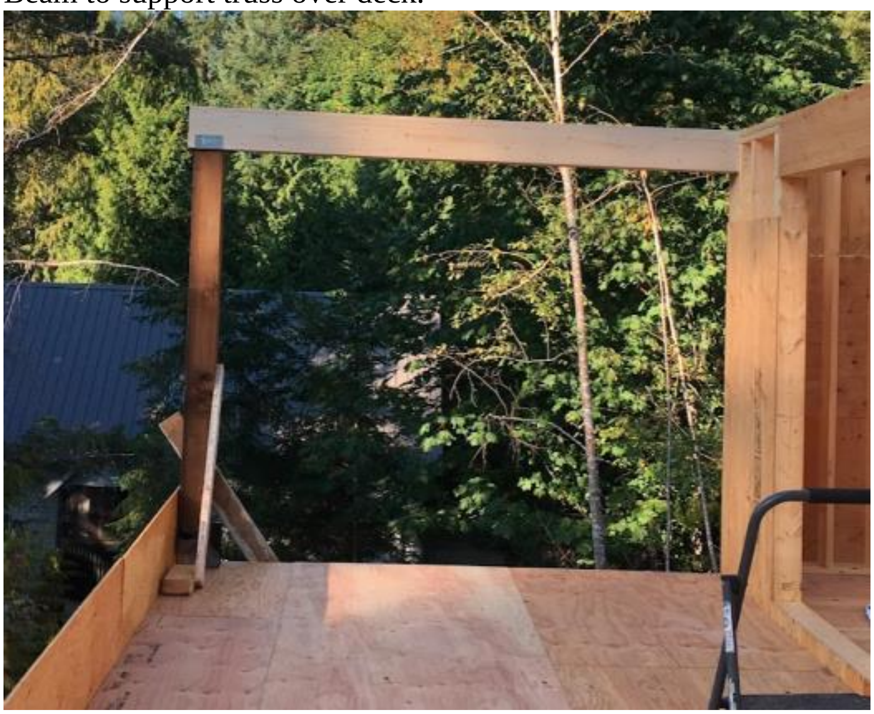
Once the walls were up, it was time for the posts and the beam. Since the loft had a Deck, we lowered the floor on the deck by 2” by changing the direction of the joist and using 2x8 instead of 2x10s in the portion supporting the deck.

Getting our subfloor plywood for the loft, required the building of a ramp.

Every work day ends with a sense of accomplishment!

To accommodate air flow over insulation batts, we raise the deck floor using 2x4s.

Beam to support truss over deck.

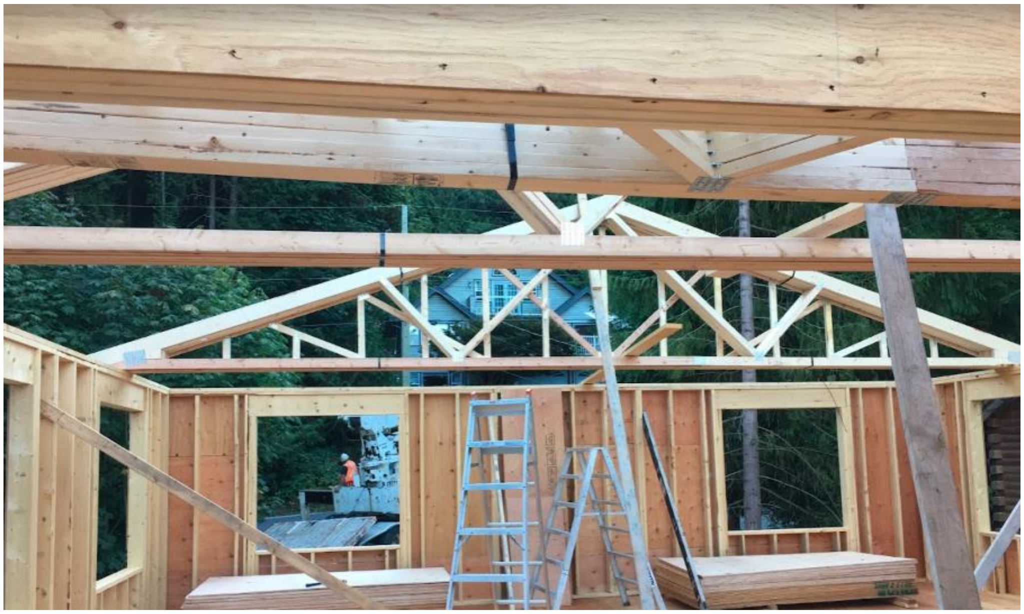


Raj lets the tuss company know that we are ready for the delivery!

9.0 Roofing

Trusses get placed over the wall.

It is best to lay them vertically and use a 2x4 to nail each truss. Then undo the nail on one truss at a time and move it to a previously marked position. Ideally you need 3 people, one at each end and one in the center.



Use 2x4s to hold the trusses in place after spacing them 24" O.C.

The trusses are fastened to the top plate of the wall with Hurricane ties.

The end trusses will be slightly smaller to accommodate look-outs for the overhang. Install the lookouts, and the 2x4 edge that ties all the trusses at either end and then sheath the edges. Make sure you use a safety harness when working on the roof.

Once you get this far, the rest of the sheathing is straight forward. We had placed the plywood on the floor of the loft ahead of time and we had one person pass each sheet up while another person placed and nailed the sheathing to the trusses. Leave a gap at the apex for air to flow from the soffit, through the attic and out this gap.

Inspection - Sheathing

You must call for a Sheathing inspection at this stage. This is generally done by the Structural Engineer and sometimes the Municipality will also require their inspector to view the sheathing. I have not seen inspectors climb on the roof to check the truss sheathing, but Engineers will pay close attention to size and type of nails used and the depth of the nail head into the plywood.

Finally cover the sheathing with "Secure Start". Make sure the air gap is open (not shown in pic).

We opted for metal roofing and placed one sheet at a time over the secure start.

10.0 Typar Wrap

Now that the roof is in place, the race is over! Our structure is safe from the elements. Next, we wrap the structure with breathable waterproof material Typar. There is another product called Tyvek used for the same purpose, but we opted for Typar.

Notice the “Blue Skin” on the windowsill. Substantial amount of care is taken to protect the openings from water penetration as required by code.

11.0 Windows and Doors

Once the structure is wrapped with Typar, you can take measurements of the rough openings and send your order for Doors and Windows. There are regulations on the type of Windows to be used in different weather zones in North America, but most suppliers will be aware of this and all you will have to do is give accurate measurements.

After placing a bead of silicon on the inside of top and slide flanges of the window, windows are nailed on left and right through the Typar into the Jack studs using the flanges on the side of the windows. On the top, you have to cut the Typar at a 45 degree angle and slip the window flange under the Typar and nail the flange into the header. Leave a ¼" gap at the bottom between the window and sill to allow precipitation to drain away. Sills should slope outward for this purpose. Code only calls for Blue-Skin on sill, but as added protection we used Blue-Skin over the nailed flanges on all three sides (bottom must be open).

Over the Blue-Skin on the top, you must place a metal drip flashing to direct water away from the Window opening. Once this is done, you put the previously cut Typar over this flashing and tape the cut.

Inspection - Windows & Doors

While not required by most municipalities, it is good practice to send pics of your windows and doors after you do the first few to get your Inspector's blessings. This is to avoid unwanted problems during the final inspection where the Inspector can require you to redo every window and door!

12.0 Siding

You can start the siding as soon as you have completed the Doors and Windows. You can do the siding as a side project in the evenings while you continue with other aspects of the house. The siding is not on the critical path since it is not a prerequisite for anything else and yet the earlier you do it, the faster the structure gets fully protected from the elements.

Furring Strips

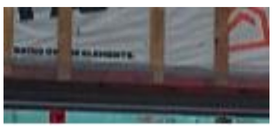
The first step in this project is to place your furring stips in line with your studs. This can be a challenge if you have not placed your studs 16" O.C. If you have placed your studs 16" O.C., the Typar wrap will have 16" O.C. markings that will help. It is important to check that the nails are going into the studs since the siding is fairly heavy and you want the load to be on the studs and not the sheathing. The furring strips are treated wood and so the nails you use must be galvanized. The furring strips are usually ⅜" or ½" and the reason for their use is to have an air gap between the siding and the Typar wrap.

Window & Door Trims

You can do your window trims as you hit the windows along the way. Generally you will make a ¾" indentation (with a table saw) on the inside of the window trips for your siding edges to be lapped. This is usually called for in the code to ensure water does not go through the siding-trim edge. If you don't have an indentation in the trim, you will have to seal the edges with silicon. The indentation is shown in the pic below. Notice the gecko tool used to ensure the overlap of siding panels are the same in every row.

Flashing & Wire Mesh

Start at the bottom by putting a wire mesh to reduce the possibility of insects getting into the air gaps provided by the furring strips (see pic above). Then place the first row of siding and work your way up. We used fiber cement (Hardie-plank) siding that was factory painted.



Hardie Planks

It is essential you invest in a cutting board to cut the Hardie-planks to size since the use of a saw can be very dusty. You will still end up using a circular saw when you need to make custom cuts, like around the top and bottom of window trims. Wear a mask when doing these cuts.

Floor demarcation facade

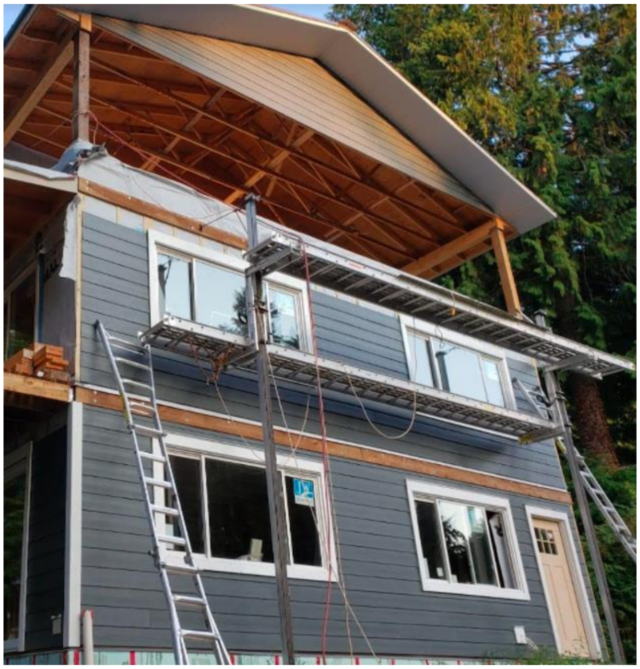
We opted to have a 2x8 treated facade around our rim joist. This gave us the option to do our siding one floor at a time. The facade has an ¾" indentation on the inside bottom for the siding to be lapped and metal flashing on the top for the water to roll off.

For the corners of the house, we used off-the-shelf indented corners.

While the siding project is time consuming, the actual technical aspects are fairly straightforward. Make sure you have studied the code with respect to "first layer of protection" to see if there is anything further required in your area.

Pump Jack

The height of our structure was the biggest challenge. We were fortunate enough to have access to a “pump jack” that made our task more doable. With the pump jack and a close friend who helped us a lot, we were able to complete the siding in a couple of weeks.



Soffits

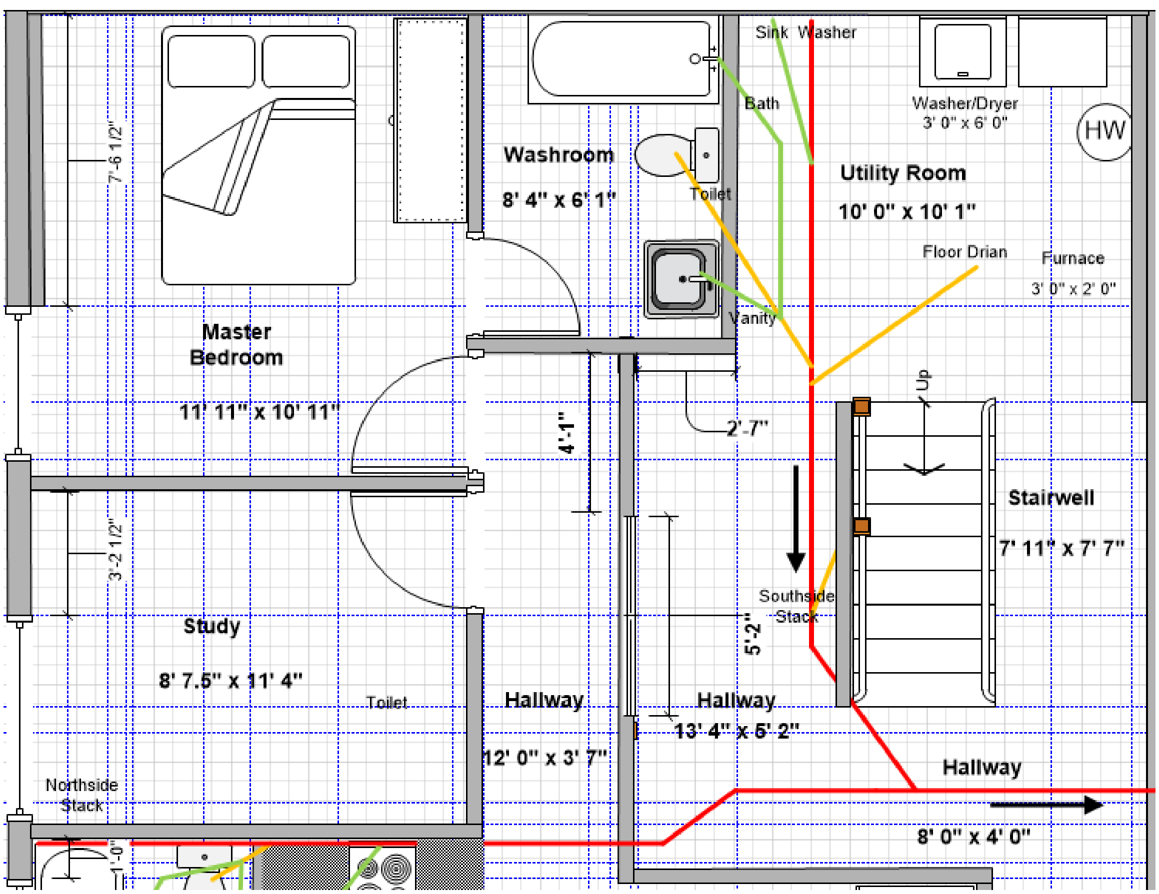
Soffits are an elegant addition that adds substantially to the exterior appointment of the house. Hiding the exposed portion of the trusses with a soffit can provide that added esthetic touch. Soffits come in Aluminum or PVC. Since the paint job on Aluminum stands out better, we opted for Aluminum. Some building codes will actually call for Aluminum soffits if the structure is too close to the next building as a fire retardant. Installing a soffit is relatively easy. You screw J-channels to the edges, cut the soffit to length and slide them between the J-Channels. If the span of the soffit is too long, you can screw them to the trusses along the way to make them sturdy.

13.0 Basement under-slab plumbing

Slab-on-grade construction is a common form of construction in North America where the floor of the lowest level (usually the basement) is a concrete slab that rests on compacted structural fill and the footing along the perimeter. In this type of construction, your drain pipes are placed under the concrete slab before the slab is poured. This is essential to support plumbing in the lowest level. The drain stacks for the upper levels are tied to this plumbing.

Our plumbing design called for 2 vertical stacks at either side of the building that are connected to the drains on each floor and continued all the way into the attic where they merged into a single 3” vent pipe that was routed out through the roof. These two 3” pipes connected to a main 4” pipe below the basement slab that went under the footing out of the house into the septic. All the basement plumbing was also tied into this 4” pipe.

Below is the design of the under-slab plumbing in the basement. The pipes in RED are 4”, Yellow are 3” and Green are 2” (all ABS). What is marked the “Southside Stack” and “Northside Stack” are the two vertical stacks that are both 3” ABS. The Drain exits under the footing and hooks into the Septic.



Inspection - Drain Waste Vent (DWV)

Once the pipe work is completed with adequate sloping provided, it is time to call for the first of two DWV (Drain-Waste-Vent) inspections. The second DMV inspection happens after the rest of the plumbing is completed. The way this inspection is conducted is to seal the outlet Drain (using an inflatable ball or any other method) and fill one of the vertical stacks with water until the water level reaches a visible height in the vertical stack. This will ensure that all the pipes are completely filled with water. The inspector will confirm that the water level does not change over a 10min period. This confirms all the seals are watertight and you are now ready to pour the concrete slab.

14.0 Septic / Sewer

We contracted out the Septic project in the interest of time. The process was however straight forward. The Septic Engineer decides on the size of the tank and number of runs for the septic field. He registers this information with the Ministry of Health. Then you buy a Septic tank that matches the size, hook it to the waste drain pipe coming out of the house. You then hook up the other section of the Septic to a distribution box and connect that to each of the runs. There is code on how deep and wide each run should be and type of perforated material to be used around the pipe. Note that this is based on the soil conditions on our lot which allowed for the simplest type of gravity fed septic system.

Inspection - Septic

Prior to filling the runs, the septic Engineer is required to inspect the work.

15.0 Basement concrete floor slab

Prior to calling for the pour of the Basement floor, you need to cover all the under-slab plumbing trenches, level the structural fill and place a 6mil poly over the entire area with airtight seals around all plumbing pipes sticking up as well as sealing the foundation wall perimeter with acoustic seal. This is to prevent radon gases from escaping into the house.

Inspection - Floor Slab

The municipality will require the 6mil poly installation be inspected prior to pouring the floor slab being poured. Once the inspection is done, you can pour the slab.

16.0 Internal walls

Professional framers will generally frame the internal walls on each floor before proceeding to the next floor. We chose to do just the load bearing walls and race to get to the roof to minimize the moisture on the structure. This was an effective strategy for us. The inconvenience was that we didn't have a staircase all this while (since the staircase hangs off the internal walls). But the compromise was worth it in our opinion.

Our design was optimized to minimise walls and have maximum open areas. So the framing of the internal walls is rather straightforward. One thing to note is that we lined up one of the internal walls with the support beam to provide additional support.

17.0 Staircase

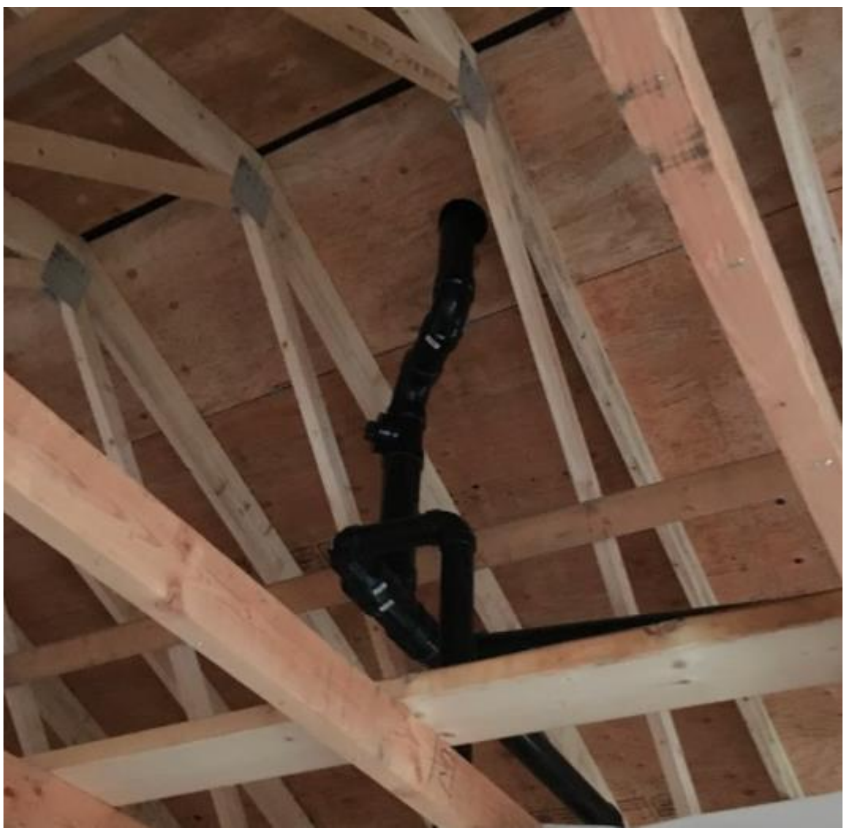
Once the internal walls were in place, we were able to make the stringers for our staircase and screw them into the internal walls.

We used 1” plywood for the steps on the stringers.

18.0 Plumbing

Our plumbing design aimed to reduce the amount of piping for both the inlet and the drain. We have a total of four washrooms in the main floor and the loft. These washrooms are at the same location on both floors. This allows a trunk inlet line to be easily split into the upper and lower washrooms. For the drain, we have lines from the vanity, toilet and bath in each washroom, going into a single 3” horizontal stack, which joins the 3” vertical stack that is closer to the washroom.

The two 3” vertical stacks combine into one in the attic and go through the roof as a single 3” pipe to provide venting for the entire plumbing drain system.



In the pic above, if you are wondering why we left a cleanout in the attic, it is to save us from going on the roof for our plumbing test. We could use a hose to fill the drain pipes from the attic.

Since the kitchen shares a wall with one of the washrooms, we were able to direct the Kitchen drain into one of the horizontal stacks associated with a washroom. Simple layout decisions like stacking the washrooms in the same location on each floor and sharing washroom walls with a kitchen can make the plumbing design particularly simple. For inlet cold and hot lines, we used Uponor piping. We were super impressed with Uponor technology! Copper soldering is a thing of the past! And so is PEX crimping (mostly)!

Once we got the rough plumbing installed, we quickly installed a sink and a toilet to enhance our camping setup!


Inspection - Plumbing rough-in

Once the plumbing rough-in is completed, it is time to hire a pressure testing pump and hook it to one of the laundry connectors.

You will have to bridge the hot and cold lines for this test. Pressurize the inlet pipes with water and then use the pump to raise the pressure to the maximum supported by your fitting. In our case, we went up to 180 psi. Inspectors will require you to keep that pressure for 10 min and confirm the pressure is maintained.

For the drain, you will have to seal the outlet with a test ball and fill the drain till the water level reaches the attic or the roof. Again inspectors will ask to see this level maintained for 10min. Note that pressure is determined by height of the water column (hpg) since the other two factors are constants. So release the test ball gently when you have completed the test. Also make sure all drain pipes are supported adequately with metal ties, since the weight of the water in a 3" pipe can be substantial.

19.0 Furnace & Ducting

Like most things associated with the government, the Building Code is highly influenced by lobby groups from various industries. In British Columbia there is a group called the Thermal Environmental Comfort Association (TECA) that has recently gotten the power to regulate the Design of Heating and Cooling systems. This group is made up of "Industry experts" who now have the power to give you a rather large quote to design and implement your Heating and Cooling system. Fortunately, you can get a TECA accreditation by taking an exam for $600 and design your own Heating/Cooling system. This is the approach we took.

While some tertiary background in fluid dynamics is helpful in the design of a ducting system, it is not necessary. The basic concepts are simple enough and where actual flow calculations are required, there are established tables for simple homes that can be exploited.

The scientific principle involved in the design of a ducting system is Bernoulli's principle. Bernoulli's principle states that an increase in velocity of a fluid occurs simultaneously with a decrease in its static pressure. This term "static pressure" refers to that which is not the dynamic pressure of the fluid (pressure associated with desired directional motion), but when added to the dynamic pressure gives the total pressure. Bernoulli's equation effectively states that the sum of the dynamic and static pressures (or the total pressure) is a constant if all other factors remain unchanged.

This nuanced definition of "static pressure" is a little hard to comprehend at first but is essential to understanding pressure changes in a duct system. To clarify this concept, let us study the flow of air from a circular duct of diameter 6" into a circular duct of diameter 5". As the air flows from the 6" duct to the 5" duct its velocity will increase, and consequently its dynamic pressure will increase. However as per Bernoulli's principle, what we gain in dynamic pressure will come at a cost in static pressure to ensure the total pressure remains unchanged. This example ignores frictional losses encountered by the constriction.

Let us consider another example where we have a 90-degree bend in our circular 6" duct. As the air negotiates the bend, its velocity will remain unchanged and so its dynamic pressure will remain unchanged, however its static pressure will take a hit, leading to loss in total pressure.

An anecdote that will help clarify the concept of static pressure is to think of yourself standing in a park. Assuming the air is still, you are still experiencing a constant pressure on your body associated with the mass of air around you. We refer to this as the atmospheric pressure and it is about 14.7 PSI on the surface of earth. This is equivalent to "static pressure". Now if a wind starts blowing in the park, you will experience an additional pressure associated with the wind and this is equivalent to "dynamic pressure". The total pressure on your body is the sum of the static and dynamic pressures.

The static pressure is an artifact of the directional pressure induced by the pump pushing a fluid. The fluid is not obliged to move in a particular direction. The fluid moves in all directions within the conduit. While the desire of the pump is to move the fluid in a particular direction, only a fraction of the pump's effort is utilized toward that end. The rest of the pump's effort is translated to a pressure by the fluid toward the surface of the conduit on the supply side and toward the center of the conduit on the return side. This pressure that is not moving the fluid in the desired direction is what we refer to as the static pressure. It is not aiding the flow of fluid in the desired direction. Instead, this static pressure is a force that restrains the flow of the fluid and hence adds to the load on the pump.

This is the reason why an air handler will specify what the maximum "**Total External Static Pressure**" is within the tolerance of the equipment. Generally, this is of the order of 0.5" W.C. (water column). Because the static pressure on the return and supply sides are in opposite directions, the return static pressure is referred to as negative, while the supply side static pressure is positive. For the sake of calculating the total external static pressure however, we simply add the absolute values of the static pressures on the return (just after the filter) and supply side (just before the heat exchanger). A nuanced point to be made here is that if bends are involved, the location where the static pressure is to be measured should be about 3 times the diameter of the conduit from the bend. This is because the area around the bend will be subject to high turbulence and will provide invalid results.

A specialized manometer probe is used to measure static pressure. This probe will have a 90-degree bend with a bullet head on it. This bullet head must point into the direction of airflow. To measure the total external static pressure, use two probes and get the static pressure before the filter and after the blower and add them up. If the value is greater than that allowed by your equipment, you will need to isolate the source of the extra static pressure and remedy the problem.

There are 2 common blower motor types – Constant Torque and Constant volume. In a constant volume motor, set volume such that External Static Pressure (ESP) is 70% of rated max ESP. In the case of the constant torque motor, look up the blower table and Manuals S & J.

The general idea of Heating/Cooling systems is that you are taking air from the home and forcing it through a heat exchanger and then blowing the air through a ducting system to every room in the house. It is common practice to suck air from the center of the home and push air into the perimeter of the home where the windows are located. The idea here is that air temperature will be closer to steady state at the center while heat loss will be greater at the perimeter. Depending on the heat exchanger, you are either cooling or warming the air.

Step 1 – Calculate the load to size equipment

The first step in designing your Heating system is to determine how much heat needs to be supplied. To do this you need to do a detailed calculation of how much heat is being lost from your home. The first step in this calculation is to determine the R-Value for the walls, Windows, Doors and Ceiling.

Different materials in your home will have different R-Values. Here are few R-Values for common building materials:

Siding: R-1 per inch
Sheathing: R-1 per inch
Insulation: R-20 (usually based on batt insulation)
Drywall: R-1 per inch
studs: R-1.25 per inch

Assuming wall areas are made up of 10% studs, here is rough R-Value for the walls:

The R value for area without studs:
Drywall = 0.5
Insulation = 20
Plywood = 0.5
Siding = 0.5
Total = 21.5

The R value for area with studs:
Drywall = 0.5
stud = 6.875 (5.5 x 1.25)
Plywood = 0.5
Siding = 0.5
Total = 8.375

Average R-Value of the exterior walls:
First Calculate the U-value
U-Value = (0.1/8.375) + (0.9/21.5) = 0.012 + 0.042 = 0.054
Then take the inverse to get the R-Value
R-Value = 1 / 0.054 = 18.51

Avoid the temptation to weight the R-Values with 10% studs and 90% walls. You will get incorrect results if you do that. You must do the weighting on the U values and add the U values before you take the inverse to get the R value.

The R Value for Double pane windows are **R-2.**

The R Value for the Ceiling is **R-40.**

The U Value is the inverse of the R-Value.

The formula for this calculation of Heat Loss is the following:

HL = SA x TD x UV

HL = Heat Loss (BTU/hour)
SA = Surface Area (ft^2)
TD = Temperature Differential (F)
UV = U-Value (BTU / ft^2 x F x hours)

Based on this formula you can tell that the Heat loss is directly proportional to the Temperature difference and exposed area and inversely proportional to the R-Value of the insulation used.

The heat loss modelling on a **concrete floor slab** is more complicated. However, an easy approximation in small houses is to multiply the perimeter length by the "F" factor and the temperature differential. You can determine the F factor from online tables. These tables will provide "F" values based on the amount of horizontal insulation under the slab or vertical insulation on the outside of the foundation wall.

Two other components of Heat Loss are **infiltration and ventilation**. These are harder to estimate. But we have used values of 25 CFM and with specific Heat Capacity for air at 0.018 BTU/cu ft.-F (1.08 for an hour), we get a value of 27 BTU/hr.F.

The following is a spreadsheet showing the Heat Loss calculation done on our home.

	Area	Perimeter	U-Value	F-Value	CFM	BTU/hr.F	Temp Delta	BTU/hr	KW
Windows	750		0.5			375	38	14250.00	4.176248
Doors	42		0.2			8.4	38	319.2	0.093548
Walls	2208		0.054			119.23	38	4530.82	1.327846
Ceiling	1200		0.02			24	38	912	0.26728
Floor		140		0.73		102.2	38	3883.6	1.138167
Infiltration					25	27	38	1026	0.30069
Ventilation					25	27	38	1026	0.30069
								25947.62	**7.60**

Since a 1-Ton unit is 12,000 BTU, our load (25,947 BTU) calls for a 3 Ton unit.

We opted for a Goodman ASPT37C14 3-Ton Air Handler along with a 3-Ton Goodman GSZ140361 Heat Pump. The Air Handler supports 5 speeds ranging from a CFM of 980 to 1565 at 0.1" (W.C) of static pressure. Part of the reason for going with Goodman is because they are one of the few companies that sell equipment online to anyone at a reasonable price.

Step 2 – Calculate the CFM required

The total CFM (cubic feet per min) required for the home can be calculated using the following formula…

MFR = HL / (SHC x TD)

MFR = Mass Flow Rate (CFM)
HL = Heat Loss (BTU/min)
SHC = Specific Heat Capacity of Air (BTU/cu ft. - F)
TD = Temperature Differential between Supply and Return Air

Based on the previously calculated 25947.62 BTU/hr, we get the following CFM…

(25947.62/60) / (0.018 x 38) = 632 CFM

Note I have gone with 38 for the temperature differential between Supply and Return. This can be higher for a Gas furnace.

Allowing for an additional 20% surplus we get a total CFM of **758 CFM.**

The specs for our chosen equipment is sufficient for that level of CFM.

You can work out CFM requirements for individual rooms using the formula above. In addition, you can consider the number of times you want the entire air in the room to be replaced by the supply. Picking the higher CFM of the two possible methods is desirable.

If your supply air is not particularly warm and if the return air is very cold, you can end up in a situation where CFM required is higher than allowed by the unit. This is why it is easier for a unit to keep a home warm when running continuously versus trying to heat a very cold home from scratch.

Step 3 - Sizing the Ducts

Ducting systems are categorized into 3 categories based on the static pressure in the system – Low (< 2" W.G), Medium (>2" < 6" W.G.) and High (>6" W.G.). A Low static pressure system consumes less power but requires larger ducts, while a high-pressure system requires higher power but less ducting. Most Single Family Dwellings will be Low static pressure systems.

There are three methods used to design Air Duct systems

1 Static regain method
2 Velocity method
3 Equal friction method

Of these, the equal friction method is the easiest method and the most common method used for Home Ducting systems. It relies on an assumption of an equal drop in static pressure per unit length of duct work. Friction loss is measured as the average pressure drop for 100' of duct work.

Every bend or any other constriction in the ducting system can be converted in an "equivalent length" to approximate its effect on static pressure. There are standard guides on what the equivalent lengths should be for every component in the ducting assembly. These can be found in Manual D.

The first step in duct sizing is to calculate the "**Total Equivalent Length" (TEL**). This involves adding the lengths of both the supply and return ducting as well as the equivalent length of every bend or constriction in the ducting (use Manual D).

Next calculate the "**Available Static Pressure" (ASP).** This is the balance of the **Maximum External Static Pressure** allowed by your Air Handler less the Static Pressures of the major components such as the Heat exchanger coil, filters, Registers etc.

The **Friction Rate (FR)** allowed per 100 ft of duct can then be calculate as

FR = (ASP x100)/TEL.

Once you work out the FR, you can use a Duct Meter to find the CFMs different size ducts will offer for that particular FR.

The table below provides the SP drops across common components in a ducting system.

Ducting Component	Common SP drops
Heat exchanger	0.01in W.C. to 0.5in W.C.
Filters	0.05in W.C. to 0.5in W.C.
Registers	0.02in W.C. to 0.25in W.C.
Boots	0.05in W.C. to 0.25in W.C.
Elbow	0.01in W.C. to 0.10in W.C.
100-ft duct	0.05in W.C to 0.20in W.C.

The table below shows the CFMs supported by our Air Handler (ASPT37C14) at various speeds up to a maximum of 0.9 Total external Static Pressure. This is a constant torque motor.

Model	Blower Speed	Static Pressure (in w.c.) Airflow (CFM)								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ASPT37C14AA	T1	980	935	895	860	825	800	755	710	665
	T2	1125	1075	1045	1000	965	930	880	845	820
	T3	1235	1190	1155	1120	1085	1045	1005	965	920
	T4	1485	1450	1425	1390	1355	1315	1275	1230	1190
	T5	1565	1535	1510	1480	1240	1390	1365	1320	1280

To calculate the CFM to allocated to each room, there are multiple methods. One common method is to calculate the volume of the room and decide how many times you want the air to be replaced in a given amount of time.

For a 10’x10’x8’ room, the volume of air is 800 cu ft. If you wanted to recycle the entire volume through the heat exchanger every 15 min, the CFM required would be 800/15 = **53CFM**.

By using a Ducting table, you can work out the size of the duct required to deliver a minimum of 53 CFM. Most tables will recommend a **5” circular duct** since it can deliver about 85 CFM when the maximum friction is less than 0.2 inches of W.C. per 100 ft. with an air velocity of about 1500 ft/min.

For a small house all you need to do is to source equipment of the right size and find the duct sizes for each room and try to minimize sharp bends in your ducting system. The new BC Building code (influenced by TECA) now requires intake air to be mixed with outside air and a continuously running exhaust fan. While mixing fresh air is not a bad thing, it is debatable if we really have to go to such extreme lengths when a slight increase in infiltration will achieve the same result without the added operational costs. But once things get into the code, you have lost your power to reason.

Below is a pic of us transporting our Air Handler.

Here Raj is installing a take-off into our Trunk line.

Inspection

Once the Ducting installation was completed, we used our TECA credentials to submit paperwork to the city.

20.0 Electrical

Of the three infrastructure items after framing (Plumbing, Ducting and Electrical), our recommendation is to do the Electrical after completing the other two. This is because electrical wires can negotiate the smallest opening whereas plumbing and ducting will benefit from some additional space.

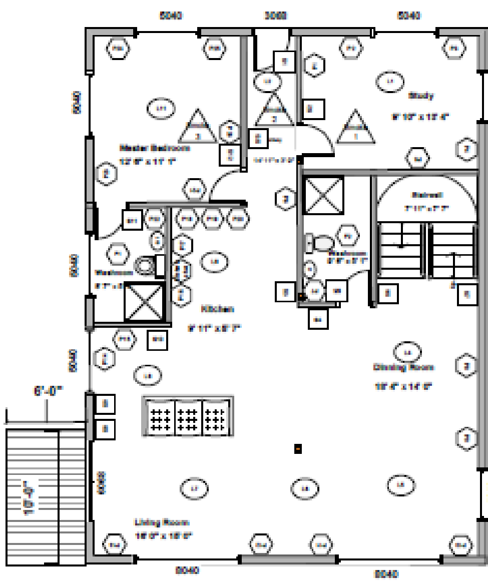
Electrical work usually requires a separate permit issued by an Electrical Safety body. To lessen the hassle of dealing with yet another permit, we decided to hire an electrician for one of the houses and got an owner builder electrical permit on the other. Our experience with electricians was pretty bad. We found them highly unreliable, their work was of poor quality and they held us hostage to a much higher price than we had negotiated. The inspectors never came to the site to inspect the work of the electricians, but were extremely picky when they came to inspect our work on the owner builder permit.

The technical aspects of the Electrical work are fairly straightforward:

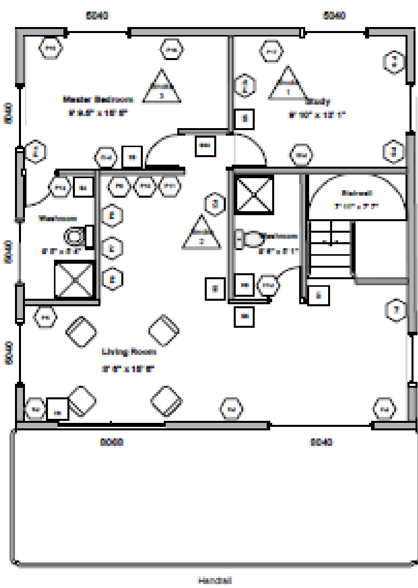
1. First you decide on the service amperage you want to go with and where you want your meter to be located. You must pick a spot with at least 10 feet of clear space for the Electrical company to pull the wires into your house.
2. Get a meter box and install it at the location you want the meter.
3. Pick the right gauge wire for your amperage, and run a length of wire from the meter box to where you intend to have your breaker box. Note that most electrical codes will not allow you to expose the high amperage wires for more than a few feet. So if your meter is located more than a few feet from your breaker box, you will have to bury the high amperage wire two feet under grade or in concrete.
4. Once you get to the breaker box, you can start running your "HomeRuns" to the different locations of the house for your lights, switches, sockets etc. The "HomeRuns" are the runs that go from the breaker box to the first location before it is split to other outlets that share the same breaker. Code will stipulate the max number of splits you can have only any HomeRun. Ideally you want to design the layout of all the outlets on each floor and the route your HomeRuns in a manner that optimises the length of wire. Below is the layout of the electrical fixtures in our house. We have used different symbols to distinguish Light fixtures, Switches, Sockets and Smoke Alarms.
5. It is best to buy 14/2, 14/3 and 12/2 gauge wires in bulk for your wiring. The majority of the outlets will use 14/2. The smoke alarm and the 3-way switches will use 14/3. The water heater and kitchen counter plugs (KCPs) will use 12/2. Similarly it is best to buy your light fixtures, switches and sockets in bulk.
6. All sockets needing 240V will require double-pole breakers. The Dryer (30A), Stove (40A), Water Heater (40A) and our Electric furnace (80A) needed 240V. Note that adjacent slots in a breaker box tap from alternate live lines that are 180 degree phase shifted. That is how we end up with 240V. The reason high wattage equipment is designed for 240V is to get away with lesser Amperage.

7. Carefully check that you are not exceeding the max allowed taps on each HomeRun, since the inspector will check that during the final electrical after the Drywall is on. At that time it will be way more difficult to remedy this problem.

MAIN FLOOR PLAN



LOFT FLOOR PLAN



Main floor

HR Lines
1. Fridge
2. All Switches except washroom
3. Dishwasher
4. Microhood
5. KCP – P18
6. KCP – P17
7. Washrooms
8. Sockets P13, P14, P15 and Data Box
9. Sockets P8, P9, P10, P11, P12
10. All Bedroom Sockets (12 Sockets)
11. Stove

Switch List
S1 : 3-way Hallway + Outside light
S2 : Bedroom Light
S3 : 3-way Hallway + Kitchen
S4 : 3-way Top of stairs + 4-way Living
S5 : Bathroom
S6 : 3-way Bottom stairwell + 3-way Top stairwell
S7 : 3-way Top stairwell + 3-way Living
S8 : Outside Deck
S9 : 3-way Living + 3-way Dinning
S10: 3-way Dinning
S11: Bathroom
S12: Bedroom
S13: 4-way Hallway

Loft

HR Lines
1. Fridge
2. All Bedroom Sockets P18, P19, P20, P21, P12 ->P16, P15, P14 -> P17, P17A
3. Washrooms
4. KCP - P7 and P8
5. Microhood
6. KCP – P9
7. Hotplate
8. Dinning Room Sockets P3, P4, DataBox, P5 (P5 to be tied in DataBox)
9. All Switches in Washroom
10. Living Area Plugs P1, P2, P3
11. Deck Socket

Switch List
S1 : 3-way Dinning + 3-way Stairs
S2 : 3-way Living + Deck
S3 : Bedroom Light
S4 :Attached Washroom
S5 : Bedroom 2
S6A : 3-way Hallway
S6 : 3-way Hallway + Kitchen
S7 : 3-way Dinning + 3 way Living
S8 : Washroom

Inspection - Electrical rough-in

Once you have completed all the wiring, you can call for an Electrical rough-in inspection. Once the inspection is completed, you can have the electrical company provide a meter connection and also plug-in a couple of breakers so you have some power for the remainder of the construction. Until this point, we were dependent on generators.

Inspection - Structural

Once the Electrical rough-in, plumbing and ducting are completed, you can call your Engineer and the city for a structural inspection since all the holes that need to be made are complete. Once you are done with this inspection, your interaction with your engineer is completed and the engineer will provide you with a "**Ready to Cover**" authorization.

21.0 Insulation and Vapor Barrier

Once you complete the structural inspection, you are on the final stretch! You can start placing your insulation batts between your 16” O.C. studs. The code in our region dictated a R-Value of 20 for wall insulation, 28 for the Deck floor (considered a flat roof) and 40 for the attic. Once the Batts are in place, you can cover them with a 6 mil poly as vapor barrier. Code asks for the edges of the vapor barrier to be sealed with an **acoustic seal** (tar like glue). This is the same seal used on the perimeter of 6 mil poly under the basement slab. This can be a straightforward process yet a very time consuming and messy process. Also all gaps in your windows would need to be sealed with silicon. To minimize moisture, it is good to heat the home before sealing your vapor barrier.

Below are some pics showing how this is done.

See vapor barrier around windows and electrical sockets.

Inspection - Insulation

Once you have sealed the vapor barrier, you can call the city for your insulation inspection.This will be your last inspection, before your final inspection (except for your Electrical final).

22.0 Drywall

Drywalling was one of the two difficult parts of the project (the other being Siding). As with Siding, we had a friend help us with this part of the project.

Drywall Placing

Some of the necessary tools for placing drywall are the following:

1. Drywall lifter

2. Drywall cutout tool

All the walls and ceiling were ½" Drywall. The Loft ceiling had ⅝" Drywall since it had to support R-40 insulation batts. We got the Drywall delivered in bulk and then distributed the sheets around the house, closer to where they were going to be used.

On the walls, the 8 foot side of the 4'x8' sheet was placed in the horizontal orientation, cut outs made for the electrical fixtures and Drywall screws used to fasten the Drywall to the studs.

The Drywall lifter was handy for placing the boards on the ceiling. The process for the cut outs for the ceiling electrical fixtures is similar to that on the wall.

Drywall Taping

Some of the necessary tools for taping drywall are the following:

1. Automatic Taper

We used paper tapes along with the taping mud. With the automatic taper tool, taping a room doesn’t take very long. For the inside and outside corners, we placed premade corners.

Drywall Mudding

Once the tape was on, we used the Drywall mudding compound to go over our joints with three coats. In some cases we put on a fourth coat.

23.0 Flooring and Painting

In terms of cost, there is a limit to how low you can go on the items so far. However, in the items that follow (which I like to refer to as “finishing”), there is a substantial variance in cost depending on your choice of materials and your ability to shop around.

Based on our previous experience with Pergo flooring, we decided to stick with Pergo along with a very high quality underlay to reduce sound transmission across floors. We were able to source Pergo from Home Depot on clearance sales and get our underlay from Costo online.

Laying the underlay and Pergo flooring is straightforward. You start at one end of a floor and work your way to the other end negotiating the internal walls along the way. If you decide to change direction, use thresholds to mask the transition location. As you lay each row, make sure the seams on any given row is offset from the seams on the adjacent rows.

Using Pergo for the staircase is very labor intensive. In one house we used Pergo for the staircase and on the other we went with carpet. Carpet on the staircase is a lot easier and faster.

We painted the house with a water based white paint. It is a good idea to paint the ceilings before you lay the floor.

24.0 Electrical final

Once all the painting is done, you can start placing all your electrical fixtures. This does not take very long. In our case it was just 2 days of labor to put in all the switches, light fixtures and sockets along with appropriate breakers for each HR line.

Inspection - Electrical final

Based on our experience with the Electrical Inspector, we opted to hire an electrician for our Electrical final on both houses. We were not particularly impressed with the electricians, although we did eventually find one that we enjoyed working with. As usual the inspectors seldom show up when an electrician is doing the work and two of the three electricians we worked with did a poor job.

25.0 Washroom fixtures

To expedite our journey to our final inspection, we opted for off-the-shelf shower sets instead of having to worry about tiling a bathtub. These are fairly easy to install. You can finish installing one in about 4 hours including the finished plumbing. The toilets take less than half an hour to install. We opted for linoleum flooring in the washrooms. We ordered custom vanities along with our Kitchen cabinets.

26.0 Kitchen Counter and Cabinets

Kitchen countertops and cabinets come at a variety of price points and you can shop around for the best quality and cost. We opted for a mid-range product and it was delivered and installed for us at a very reasonable price.

Inspection - Final Inspection

You are now ready to call for a final inspection!

Conclusion

Going into this project, we only had a very limited understanding of the entire process. We constantly focused on the next steps at each stage and avoided getting overwhelmed by the scope of the entire project. This proved to be a very effective strategy. While we encountered our fair share of charlatans and naysayers, we were also blessed to come across amazingly good humans who encouraged, guided and proved to be instrumental to our success. We have communicated our gratitude to these individuals and they know who they are.

One thing that is worth mentioning is that you will be hard pressed to find someone with knowledge of every stage in the process. The majority of contractors only focus on one area. It is only the General Contractors who have visibility to the entire process and they will seldom share their knowledge with you.

We have decided to document our entire experience in this set of notes in the hope that it will benefit future generations of owner builders. We know that access to a document like this would have helped us substantially.