Group FP-07

Complex Report

ENGINEER 3PX3

March 28, 2024

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Contribution List

Karol - Technical Analysis Overview & Detailed NVF, report formatting, Appendix creation, Risk Management, Stochastic Sensitivity Analysis, Final Recommendations

Liam - Problem Identification, Sensitivity Analysis, Final Design (Simple Report), Project Plan, Stochastic Sensitivity Analysis, Final Recommendations

Dexter – Change Log, Initial Solution Comparison, Optimization, NPV, Stochastic Sensitivity Analysis, Final Recommendations

Aaron - Detailed NVF and Conversion Factors

0. Change Log:

Change No.	Type	Description	Original	New	Section	Page
0	Addition	Original Submission	-	1	All	All
1	Revision	Revising initial solution comparison based on TA Feedback	1	2	3	4-6
2	Revision	Revising problem identification based on TA Feedback	2	3	1,5	9-11
3	Addition	Added the Change Log	3	4	0	2
4	Addition	Added Optimization section, placed new revenue term calculation in appendix	4	5	6	11-15, 26
5	Addition	Added Final Design section	5	6	7	15
6	Revision	Added References	-	-	All	All

7	Addition	Added NPV section	6	7	9	26-28
8	Addition	Added Project Plan	7	8	8	21-25
9	Revision	Added the plots to the optimization section based on feedback and Avenue announcement	8	9	6	13-19
10	Revision	Revised Final Design section	9	10	7	21
11	Addition	Added Risk Management	10	11	10	29-31
12	Revision	Explanation of lack of decommissioning tasks in project plan	11	12	8	25
13	Addition	Added Stochastic Sensitivity Analysis Section	12	13	11	32-36
13	Addition	Added Final Recommendations	13	14	12	37
14	Revision	Revised Project Plan	14	15	8	21-25
15	Revision	Revised Risk Management, updated format to be in-line with other sections	15	16	10	29-31

1. Problem Identification:

In Ontario, there is currently a shortage of housing and especially affordable housing. This deficit is expected to increase in the next 20 years [1]. This lack of housing impacts a majority the general population as it will either force people to live in places outside of their means or they will be left homeless, both preventing someone from living comfortably and not worrying about their next paycheck. To solve this problem, a mass production of homes and apartments needs to begin. Two potential ways to increase the rate of building houses are prefabrication, where housing modules are constructed in a factory and assembled on site, and 3D-printing concrete, where a machine prints out the walls of a house with concrete and the workers only must place the rebar. Both solutions allow for a reduced labor force by substituting workers with automation, reducing the cost of labor involved in building homes. The downside to this is that industrial machines are expensive and have high energy requirements for operation. There is also the potential that houses built using these methods might not be suitable for every environment. However, if this project is found to be feasible it will allow for an increase in the number of houses built, which should turn a great profit for the company through the number of new houses being sold. Additionally, the increased rate of houses being built should help to reduce the stress on the general population from the current housing market as well as bolster the retail industry in Ontario and especially around the GTA. We want to look at the viability of these solutions from a company’s perspective and evaluate whether an increased use of automation in the housing industry is an economically viable solution to the current housing deficit, as well as ensure that any home made with this solution is structurally sound and provides a safe and affordable place to live.

2. Detailed NVF and Conversion Factors:

NVF = HouseSalesRevenue – LabourCost – EnergyCost – MaterialsCost – R&D – UpfrontConstructionCost

Where the performance parameters and conversion factors are defined by the following:

- **Productivity and Housing construction rate**: This is defined by the rate of construction and the number of prefabricated units sold. The conversion factors are considered by the sold units, and such generate revenue. The assumption is a specific quota of units to be sold that meet the production capacity, as well as the price per unit sold are within market value.

- **Labour cost**: This is defined by the operational cost for a given number of workers to build the houses and automation. The conversion factors are derived from the average wage per hour, number of working hours per year, and number of workers on the project. The assumption here is that workers are paid according to their job and the number of hours they work. (i.e., no overtime, $35/hour, 45 hours/week)

- **Energy cost**: This is defined by the energy consumption for the construction and operation of the houses. The conversion factors are derived from the consumption per square foot, total operational area, and energy price. The assumption here is that the energy efficiency of workplace is within the standard and using market price for energy consumption per kWh.

- **Materials cost**: This is defined by the cost of materials for the construction of the houses. The conversion factors are derived from the average cost of material per square foot, the total area of the houses, and the number of houses built per year. The assumption, like as above, is that there is a certain quota of houses to be built, cost of raw materials required for construction meet standards and policies from rule makers.

- **R&D**: This is defined by the yearly budget for research and development to innovate and improve both the construction and the prefabricated units. The conversion factor is a lump sum of the budget allocated for R&D. The assumption for this is that the budget will be able to afford the best team and resources to innovate on current design.

- **Upfront construction cost**: This is defined by the initial investment to start the operation, including factory setup and equipment purchases, compliance with building codes, and other considerations. The conversion factor is an amortized, one-time cost of the initial investment. This will be reflected as the capital expenditure needed for the project.

Some of the following considerations are made for the NVF, as well as the performance parameters and conversion factors:

- **Environmental**: The focus on material uses should be vital, such that all materials are sustainable and non-toxic, to reduce emissions. Additionally, energy consumption would also be increased due to utilization of automation software and robotics. Therefore, The NVF should be reflected where both *EnergyCost* and *MaterialsCost* would be increased from initial assumptions and due diligence.

- **Regulatory**: Compliance with building codes and different considerations for prefabricated homes are recognized. Compliance can imply additional costs, and therefore, *UpfrontConstructionCost* could increase. This could also affect the operational feasibility of the projects if any of the regulatory requirements are not met.

- **Ethical and DEI**: Possible **DEI** concerns include the wage gap, the small number of workforce due to robots and automation, and the potential displacement of workers. Additionally, DEI is also considered to provide affordable housing to different socio-economics classes, such that it aligns with broader social objectives. However, this would then also increase `UpfrontConstructionCost`, like regulatory considerations.

3. Initial Solution Comparison

Automation is becoming more prevalent in industry every passing year. While already present in the manufacturing industry, it has not yet become a fully integrated process with respect to the consumer. This is a void in the industry we hope to address with the automated prefabrication of housing/components.

Our solution entails the construction of a manufacturing facility with many robotic arms and other equipment to quickly assemble the components needed to construct homes. The raw materials would enter through a conveyor system, then be formed into the necessary components by the arms/assemblers. This does not include the more intricate components, such as electric wiring or plumbing, but rather the larger structural components like sections of wall, beams, concrete slabs, etc. Manufacturing these bulky components offsite would reduce construction time, just needing to be put in place when delivered onsite. Long term, we envision a completely streamlined consumer experience from ordering a custom housing unit to the delivery of components on-site with minimal human intervention. A significant amount has been allocated to the initial R&D estimate, with further studies needed to examine the feasibility of this future.

The revenue would come from the sales of the houses/components, whereas the operating costs would include the labour costs of a minimal crew in the facility, maintenance and energy costs for the robotic equipment, cost of the raw materials themselves, R&D costs as well as the upfront costs of constructing the facility and purchasing the equipment. Keeping this in mind, we constructed our initial NVF from the perspective of the factory owner as follows:

NVF = House Sales Revenue – Labour Cost – Energy Cost – Materials Cost – R&D – Upfront Construction Cost

Assumptions: Amortize upfront cost over 15-year period, will earn $440,000 per house sold, 50 workers + 5 engineers + 12 robotic arms in facility, average power use is 95.1 kWh/sq ft/year [2], average material cost is $290/sq ft [3] for 1300 sq ft house, facility costs $250/sq ft [4] to construct for 7000 sq ft, robotic arms cost $200,000 [5], conveyor belt costs $1500/ft [6] for 100 ft belt, all other equipment will cost approx. 1.5 the amount of the previously listed upfront costs.

HouseSalesRevenue = ($440,000) * (310/year) = $136,400,000 / year

LabourCost = ($35/hour * 40 hours/week * 48 weeks/year * 50 Workers) + ($49.65/hour * 45h/week * 52weeks/year * 5 Engineers) + $5000*12 Robots* 12months/year = $4,660,905/year

EnergyCost = 95.1 kWh/sq ft / year * 7000 sq ft * $0.14 / kWh = $93,198 / year

MaterialsCost = AverageCostMaterials/sq ft * AvgHouseSize* BuiltHouses/year = $290/sq ft * 1300 sq ft / house * 310 houses / year = $116,870,000 / year

R&D = Amount/year = $2,500,000 / year

UpfrontConstructionCost = ConstructionCost + EquipmentCost = ($1,750,000 + $200,000 * 12 Robots + $1500 * 100) * 2.5 / 15yrs = $717,000 / year

NVF = $11,559,802/year

Our initial estimate for the NVF has a revenue of around $11.6 million. It is important to examine currently existing alternatives to our solution to determine the feasibility of our project. We first examined the baseline solution of traditional construction methods for homes. This approach was not pursued simply because it is the base case to compare our solution against, but nonetheless still crucial to examine. Strictly looking at the NVF, there would only be the sales revenue, cost of labour, and cost of materials:

NVF = HouseSalesRevenue – LabourCost – MaterialsCost

Assumptions: Perspective of contractor, average house price of $851,000 in Ontario [7], same cost of materials, each construction site has 10 people working 40hr/week at $35/hr for 7 months [8], assume same number of houses sold for direct comparison to our NVF

NVF = ($851,000 – 10 Workers * $35/hr * 40hr/week * 4weeks/month * 7 months - $290/sq ft * 1300 sq ft) * 310 houses/year = $25,420,000/year

The traditional construction method makes the contractor more money than our solution, whereas our solution offers consumers a cheaper housing price. However, it is important to note that a house takes multiple subcontractors, each with different specialties and pay, to construct a house from scratch. Therefore, this NV estimate is crude and would need to be further scrutinized should this project advance.

Another alternative to our solution is the 3D printing of homes [9], which uses 3D concrete printers to quickly fabricate a house onsite. This reduces the number of workers needed and increases affordability. To increase strength against weather and natural disasters, concrete columns can be used to reinforce the home, increasing the locations where it can be built. However, customization is reduced, and the aesthetic of the homes may not be pleasing to many consumers. We did not pursue this option for this reason, as it is already a well-established solution. For our purposes, we constructed the NVF like so:

NVF = HouseSalesRevenue – LabourCost – MaterialsCost

Assumptions: Perspective of 3D printing company, 1300 sq ft home costs $27,000 USD ($36,500 CAD) to purchase [9], takes one week to print, 5 workers with same wage as before

NVF = ($36,500 – 5 Workers * $35/hr * 40hr/week * 1 week) * 310 houses/year = $9,145,000

Therefore, the traditional approach for home construction may be the most profitable for the seller but results in a much higher price for the consumer. On the other hand, much more than 310 houses per year can be 3D printed due to the incredibly short print time, increasing revenue. However, the aesthetic and lack of customization may drive consumers away. Focusing on automation, we believe we can get the best of both options. Thus, our solution warrants further investigation.

4. Technical Analysis Overview & Detailed NVF

This section addresses the primary work completed in the tasks assigned for Week 4 of progress on this economic analysis project for the engineering economics class, ENGINEER 3PX3. The Technical Analysis section compiled the individual research and design efforts of each group member to specifically tailor the outlined and update the solution's NVF (net value function), by means of detailed decision variables being laid out.

Through the Technical Analysis Proposals of each team member, solution refinement was facilitated; and most notably included in the following findings.

I) The first technical analysis involved Karol Lukowski, who has brought experience in Civil engineering applications to this project. Assuming 4 general classes of prefabricated concrete product for the residential construction (based off the most common mix designs for residential construction in Ontario, as per the Ready-Mix Concrete Association of Ontario (RMCAO) [10]

Reference Appendix Section 1.1 for detailed explanations.

This would yield pricing for the given mix designs, and help in the calculation of:

Concrete Revenue
RESIDENTIAL HOUSING Price, based off a local concrete supplier in the GTA/Ontario Region
-Footings & Walls 15 MPa $215.00/m3 0.70w/c (OBC) Class R1 & R2
-Footings & Walls 20 MPa $223.00/m3 0.70w/c (OBC) Class R1 & R2
-Basement Floors 25 MPa 0.65w/c R3 (OBC) $230.00/m3
-32 MPa C-2, S-2 0.45w/c $253.00/m3 (standard concrete mix) [11]

Concrete Revenue = ($215.00/m3*R-1) + ($223.00/m3*R-2) + ($230.00/m3*R-3) + ($253.00/m3*C-2)

Total Concrete Volume Produced (m3) = R-1 + R-2 + R-3 + C-2

From group assumptions made on square footage of the house supplied for construction, and an estimated 310 houses constructed per year, it would yield the following:

1300 sq ft / house * 310 houses = 1300 sq ft/house * (0.0929m3/1 ft2) * 310 houses/year = approx. 37,438.7m^3 total volume concrete produced/ per year

With regards to the price of producing prefabricated concrete for the owner/factory, for materials and mix design, it involved assuming this pricing focuses solely on the material and mix design costs (labor force and machinery overhead is neglected here as it is considered with the other aspects of the NVF).

For a standard concrete mix, and the resulting calculations, reference Appendix Section 1.1 for an in-depth explanation. The result was found that for the Cost of Concrete Production (Material Costs) = around $60/m3 per year.

Environmental Aspect

Assuming from past data sets from 2020, of a standardized mix, which would be like our residential mixes, 73.1 kg C02 are emitted per ton of concrete produced. Hence, utilizing carbon capture technology for concrete production, it would eliminate these additional emissions produced, thus benefiting the environment immensely to prevent the carbon emissions from entering the atmosphere, as well as making use of/ and storing excess carbon into the concrete. [12]

Environmental Cost: assume density of concrete is around 2.5 metric Tonnes per cubic meter

Therefore, 73.1kg C02/per ton of concrete produced *(2.5 metric tons/per cub meter) = 182.5kg C02 emitted in production/ per cubic meter.

Economic Aspect

Carbon credits serve as a financial benefit with our proposed solution implementing carbon capture technology in the prefabricated concrete production process.

Carbon capture incentives = $50 per ton * 1 year/tons of concrete produced *metric tons/cubic meter of concrete

II) The second technical analysis involved Dexter Holst, mechatronics engineering, who considered the power equation to quantify the immense power demand needs with a heavily automated factory system, and large-scale industrial process of prefabricated modular construction concrete pieces.

Cost = E*14.1c/kwh + FlatCost = $2470/year/robot arm + $200,000/robot arm

Reference Appendix Section 1.2 for further details.

III) The third member of the team Liam Walker, involved in mechatronics engineering as well, looked at the electricity needed to cool factory (thermodynamic analysis, might have to assume how much heat generated by components) (Efficiency of Refrigeration Cycle, 2N03, Liam). Reference Appendix Section 1.3 to see the detailed solution and incorporation into NVF.

IV) The final group member Anh Pham, from software engineering looked at the automation process needs, such as an Embedded system design engineer salary per $49.65/hr [13] (as well as RPA (Robotic process automation) as a service: that can cost $5000-15000/month per robot. Reference Appendix Section 1.4.

Therefore, in summary, presented here is the following detailed Net Value Function with the corresponding relevant decision variables and parameters for the function to accurately work.

NVF = HouseSalesRevenue – LabourCost – EnergyCost – MaterialsCost – R&D – UpfrontConstructionCost

- HouseSalesRevenue = Price*NumSold/year = ($440,000) * (310/year) = $136,400,000 / year
- LabourCost = AverageWage/hr * hr/year * NumWorkers = $35/hour * 40 hours/week * 48 weeks/year * 110 workers + $49.65/hour * 45h/week * 52weeks/year * NumEng + $5000*NumRobot * 12months/year = $7,392,000 / year + $116,181/year * NumEng + $60,000/year * NumRobot
- EnergyCost = 95.1 kWh/sq ft / year * 7000 sq ft * $0.14 / kWh = $93,198 / year + $2470/year * NumRobot + CoolingCost
- MaterialsCost = AverageCostMaterials/sq ft * AvgHouseSize* BuiltHouses/year = $290/sq ft * 1300 sq ft / house * 310 houses / year = $116,870,000 / year
- R&D = Amount/year = $2,500,000 / year
- UpfrontConstructionCost = ConstructionCost + EquipmentCost = ($1,750,000 + $200,000 * NumRobot + $1500 * 100) * 2.5 = $4,750,000 + $500,000 * NumRobot

5. Sensitivity Analysis

Figures 1 and 2 are the results of a sensitivity analysis conducted on our decision variables. Figure 1 is a spider plot showing the change to the net value by incrementally changing each decision variable by ±50%. Figure 2 is a tornado plot which shows how much a ±50% change affects the net value and is a good indicator of what the NVF is most sensitive to. It can be seen from the charts that the Net Value function is the most sensitive to the volumes of each type of concrete used in the mixture for the housing modules. It is especially sensitive to the volume of C-2 concrete used with R-3, R-2, and R-1 being the variables that the NVF is the second, third, and fourth most sensitive to, respectively. On the manufacturing side, the number of Robot arms used for production is the fifth most impactful on the net value function with the number of factory workers being sixth and number of Engineers/Technicians being last and having such a minor impact compared to the other variables that we may potentially consider it negligible.

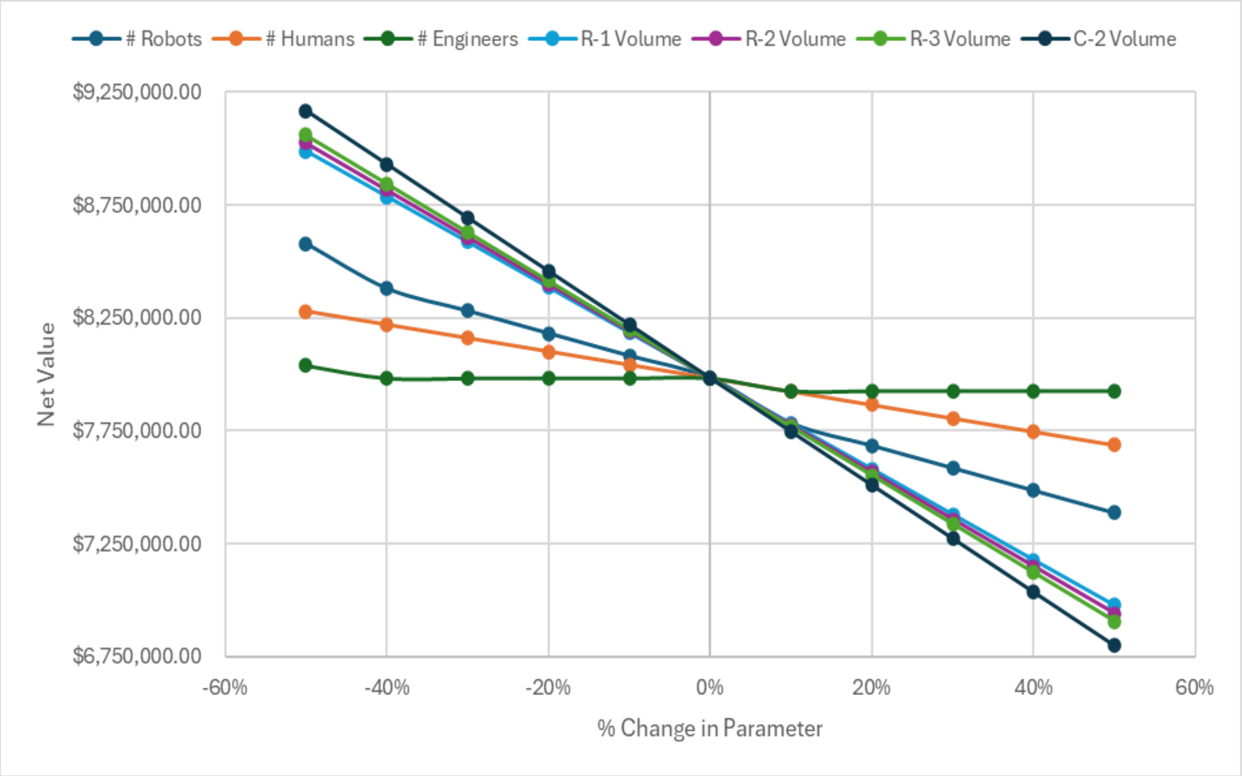


Figure 1: Spider plot of % change in decision variables

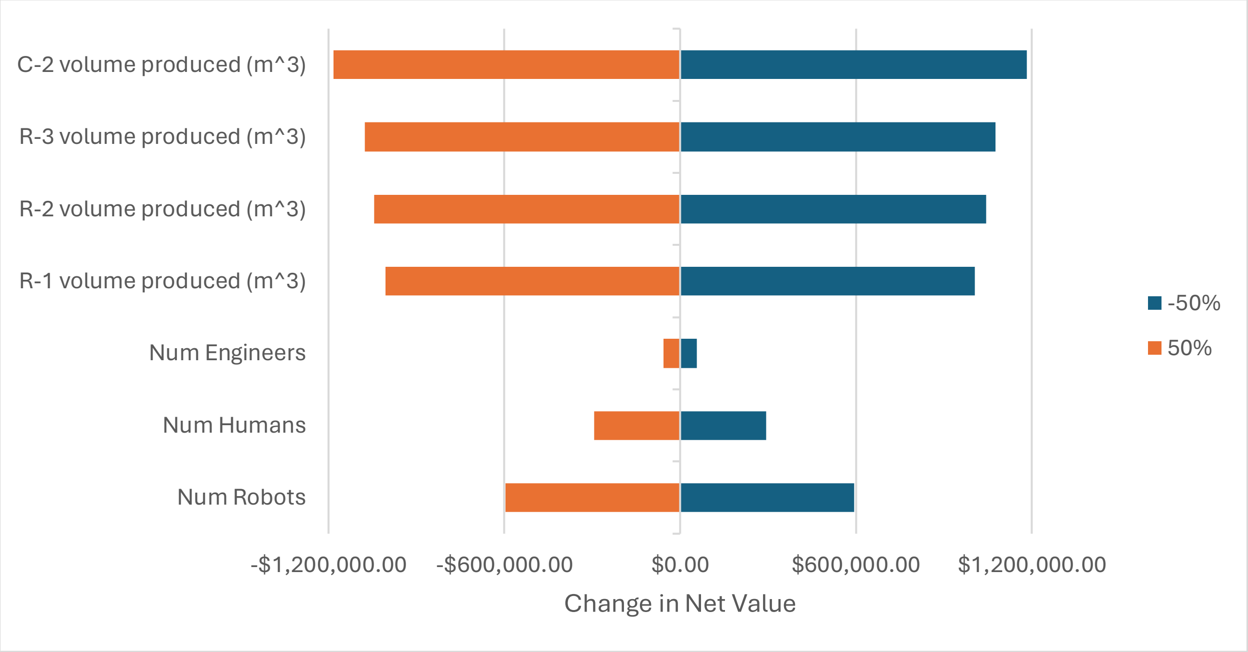


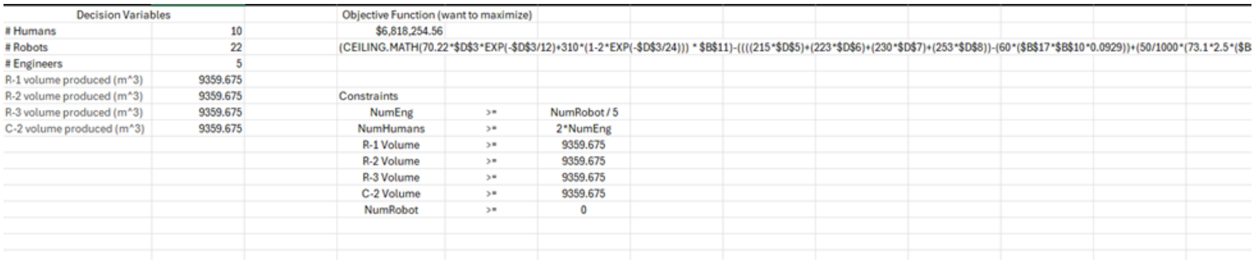
Figure 2: Tornado plot showing sensitivity of NVF to decision variables

Some parts of our net value function rely on values which are subject to change over time. One of these is the cost of electricity per kilowatt hour, which varies throughout the year and will have a net increase as time goes on. Similarly, the labor cost for employees is also subject to increase year upon year. We also still need to assess whether one production facility is enough to keep up with the demand for housing and whether our estimate for the size of the facility is accurate. The Research and Development cost included in our net value function is also an assumption and is potentially subject to change based on the time it takes to set up the facility and start production as well as further refining production methods to be more efficient. The final thing that is yet to be assessed is whether the price of the houses being sold will change based on the materials and production method which could significantly affect the net value of the solution. The last thing to note about the sensitivity analysis is that it does not consider how different decision variables interact and affect one another.

The sensitivity analysis shows that our greatest cost comes from the volumes of each type of concrete used when fabricating housing modules. Therefore, going forward, we must ensure that the cost of materials used in building a house is not too expensive for the factory as well as ensure that the houses being produced are still affordable. The other thing to keep in mind is that the number of industrial robots used also has a significant impact on our net value. Should we need a bigger facility or more factories in general to keep up with demand, we must be careful that the cost of the technology required does not outgrow the revenue generated from housing projects.

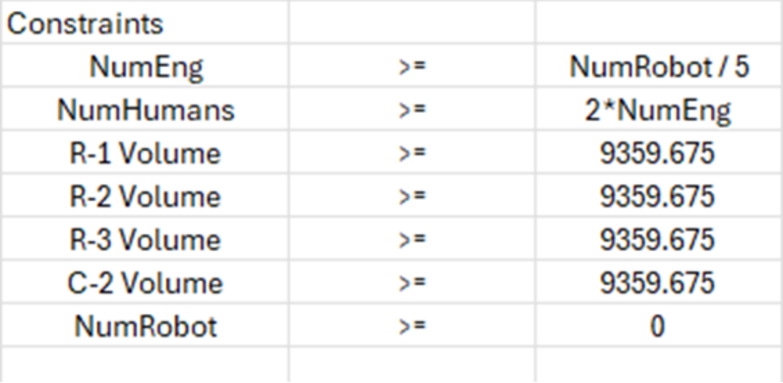
6. Optimization

To perform our sensitivity analysis, we had to re-examine our NVF and make a few modifications. It was a revenue term subtracted by multiple cost terms determined by our decision variables. Therefore, we did not need to run an optimization to find the best combination of variables since they would just be their lowest values. Though this may be a valid solution, we decided to rework the revenue term to include some of our decision variables to allow an optimal solution to emerge. The term used can be found in the appendix, where the number of houses constructed is a function of the number of robotic arms in two decaying exponentials. It was modeled this way to ensure 2 conditions: it rises from a negative or 0 value for no robotic arms, and then peaks and settles to a value that represents the maximum output of houses from our factory. All other conditions constant, increasing the number of robotic arms will have diminishing returns.



Decision Variables			Objective Function (want to maximize)		
# Humans	10		$6,818,254.56		
# Robots	22		(CEILING.MATH(70.22*$D$3*EXP(-$D$3/12)+310*(1-2*EXP(-$D$3/24))) * $B$11)-((((215*$D$5)+(223*$D$6)+(230*$D$7)+(253*$D$8))-(60*($B$17*$B$10*0.0929))+(50/1000*(73.1*2.5*($B		
# Engineers	5				
R-1 volume produced (m^3)	9359.675				
R-2 volume produced (m^3)	9359.675		Constraints		
R-3 volume produced (m^3)	9359.675		NumEng	>=	NumRobot / 5
C-2 volume produced (m^3)	9359.675		NumHumans	>=	2*NumEng
			R-1 Volume	>=	9359.675
			R-2 Volume	>=	9359.675
			R-3 Volume	>=	9359.675
			C-2 Volume	>=	9359.675
			NumRobot	>=	0

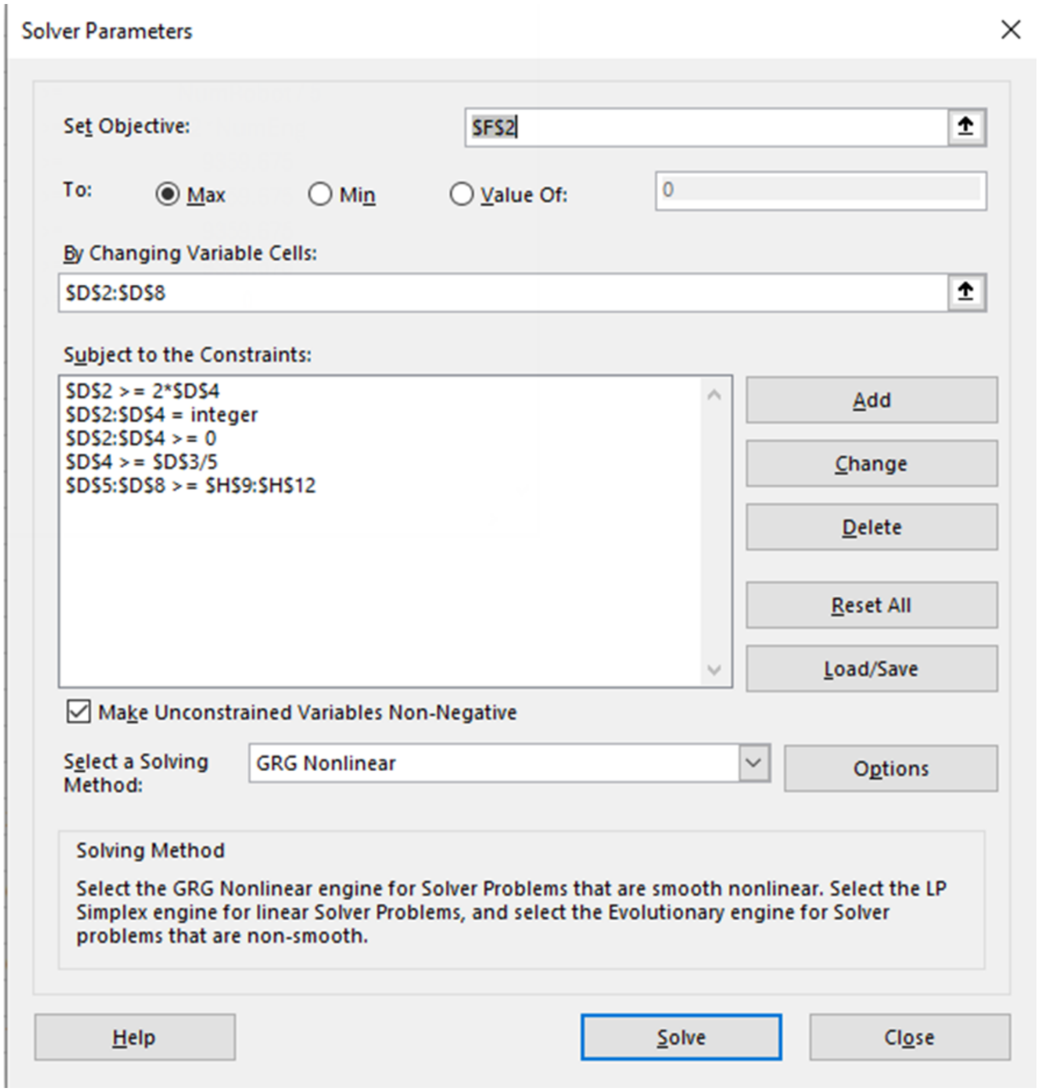
Figure 3: Overview of entire optimization calculation



Constraints		
NumEng	>=	NumRobot / 5
NumHumans	>=	2*NumEng
R-1 Volume	>=	9359.675
R-2 Volume	>=	9359.675
R-3 Volume	>=	9359.675
C-2 Volume	>=	9359.675
NumRobot	>=	0

Figure 4: Constraints included in the computation

Our objective function is our NVF, which we hope to maximize to guarantee the maximum profit to potential investors. Relevant constraints include one engineer per five robotic arms present to ensure adequate workloads, twice as many humans present than engineers to account for the heating cost and non-engineering work needed (helping with assembly, maintenance, etc.), the presence of robotic arms, and a minimum volume of concrete. For the concrete volumes, an assumption in the relevant technical analysis asserted that producing 310 1300 sq-ft homes needs about 37438 cubic metres of concrete, which was split 4 ways to find the appropriate amount. Not explicitly stated in the above figure is the requirement of number of people and robots being an integer value.



Set Objective: $F$2

To: ● Max ○ Min ○ Value Of: 0

By Changing Variable Cells:
$D$2:$D$8

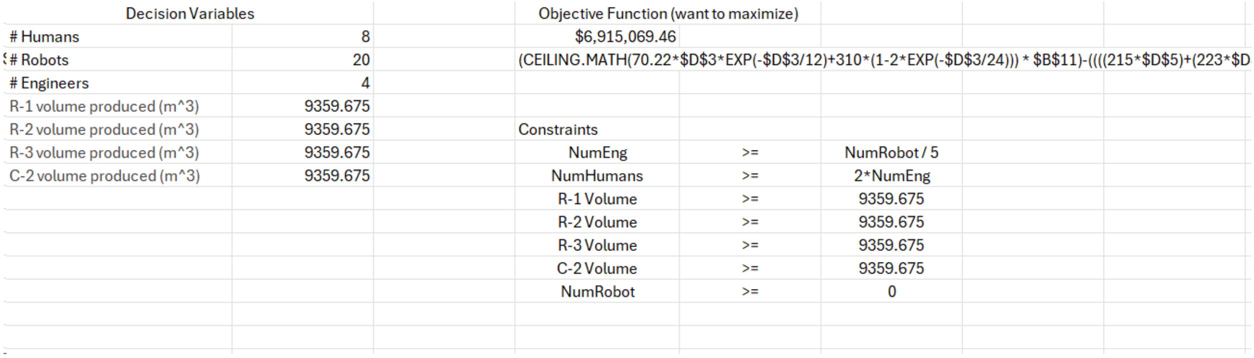
Subject to the Constraints:
$D$2 >= 2*$D$4
$D$2:$D$4 = integer
$D$2:$D$4 >= 0
$D$4 >= $D$3/5
$D$5:$D$8 >= $H$9:$H$12

☑ Make Unconstrained Variables Non-Negative

Select a Solving Method: GRG Nonlinear

Solving Method
Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Figure 5: Solver GUI (GRG Nonlinear), shows constraints



Decision Variables			Objective Function (want to maximize)		
# Humans	8		$6,915,069.46		
# Robots	20		(CEILING.MATH(70.22*$D$3*EXP(-$D$3/12)+310*(1-2*EXP(-$D$3/24))) * $B$11)-((((215*$D$5)+(223*$D		
# Engineers	4				
R-1 volume produced (m^3)	9359.675				
R-2 volume produced (m^3)	9359.675		Constraints		
R-3 volume produced (m^3)	9359.675		NumEng	>=	NumRobot / 5
C-2 volume produced (m^3)	9359.675		NumHumans	>=	2*NumEng
			R-1 Volume	>=	9359.675
			R-2 Volume	>=	9359.675
			R-3 Volume	>=	9359.675
			C-2 Volume	>=	9359.675
			NumRobot	>=	0

Figure 6: Results of optimization

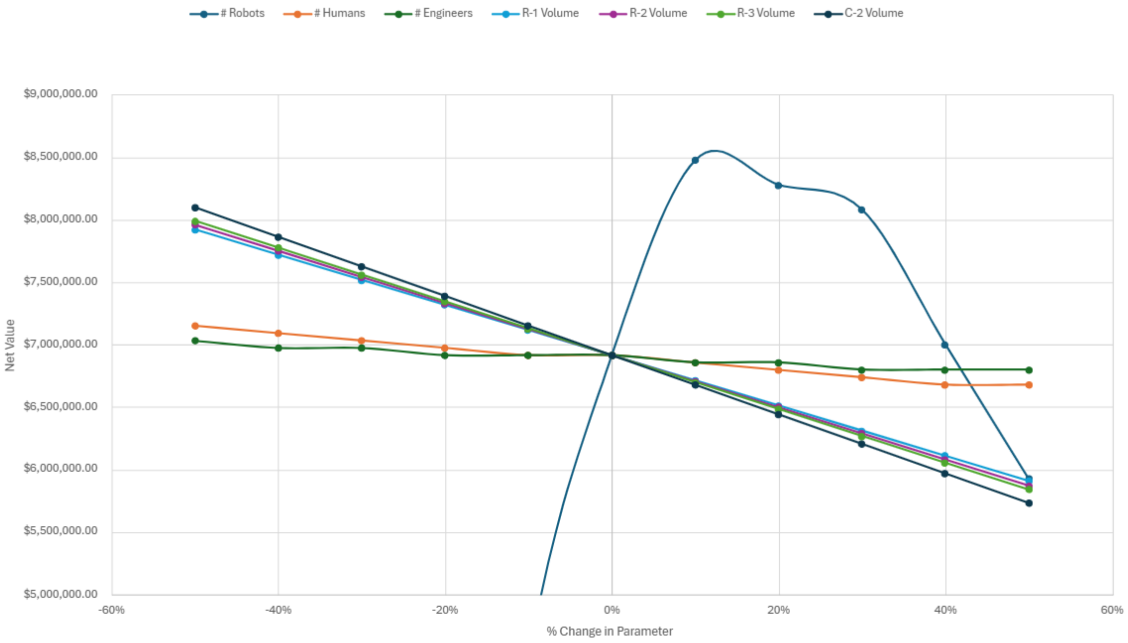


Figure 7: Spider Plot of Optimized Values

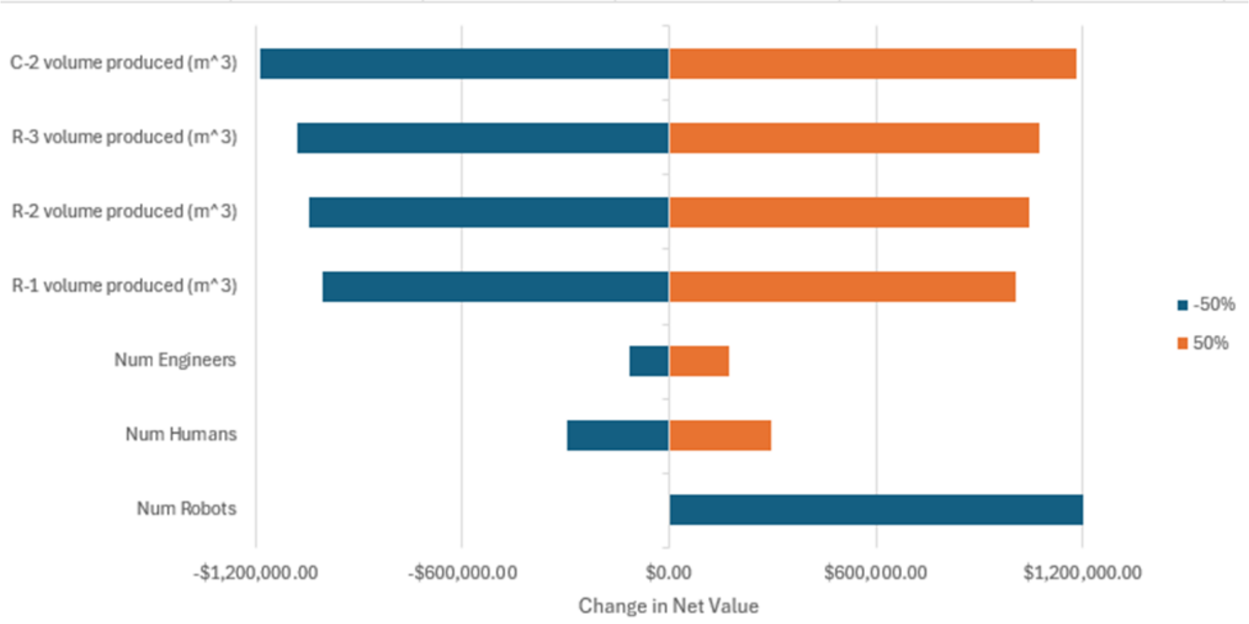


Figure 8: Tornado Plot of Optimized Values

Using the GRG Nonlinear solver tool in Excel to accommodate the decaying exponentials, we find that the optimal solution has 10 workers, 5 of which are engineers, and 22 robotic arms. Overall, these results make sense. The amount of concrete needing to be poured is the minimum since it is strictly a cost and has no impact on the revenue term. The number of human workers is non-zero because the number of engineers must be non-zero. The number of robotic arms needed is non-zero and is by the peak seen in Figure 7. This discrepancy is due to the integer constraint of the value. However, these are results of an imperfect simulation. It is not reflective of reality, but rather what we defined “reality” to be. The relations between the number of homes, selling price, materials, robotic arms, factory size, etc. are incredibly complex and would require a whole other course to fully breakdown.

Performing a similar analysis, we can see which parameters the NVF is most sensitive to. Gathering our 4 most relevant parameters (material cost, electricity cost, prices of houses, and hourly labour cost), changing by ±10%, the following behavior can be observed:

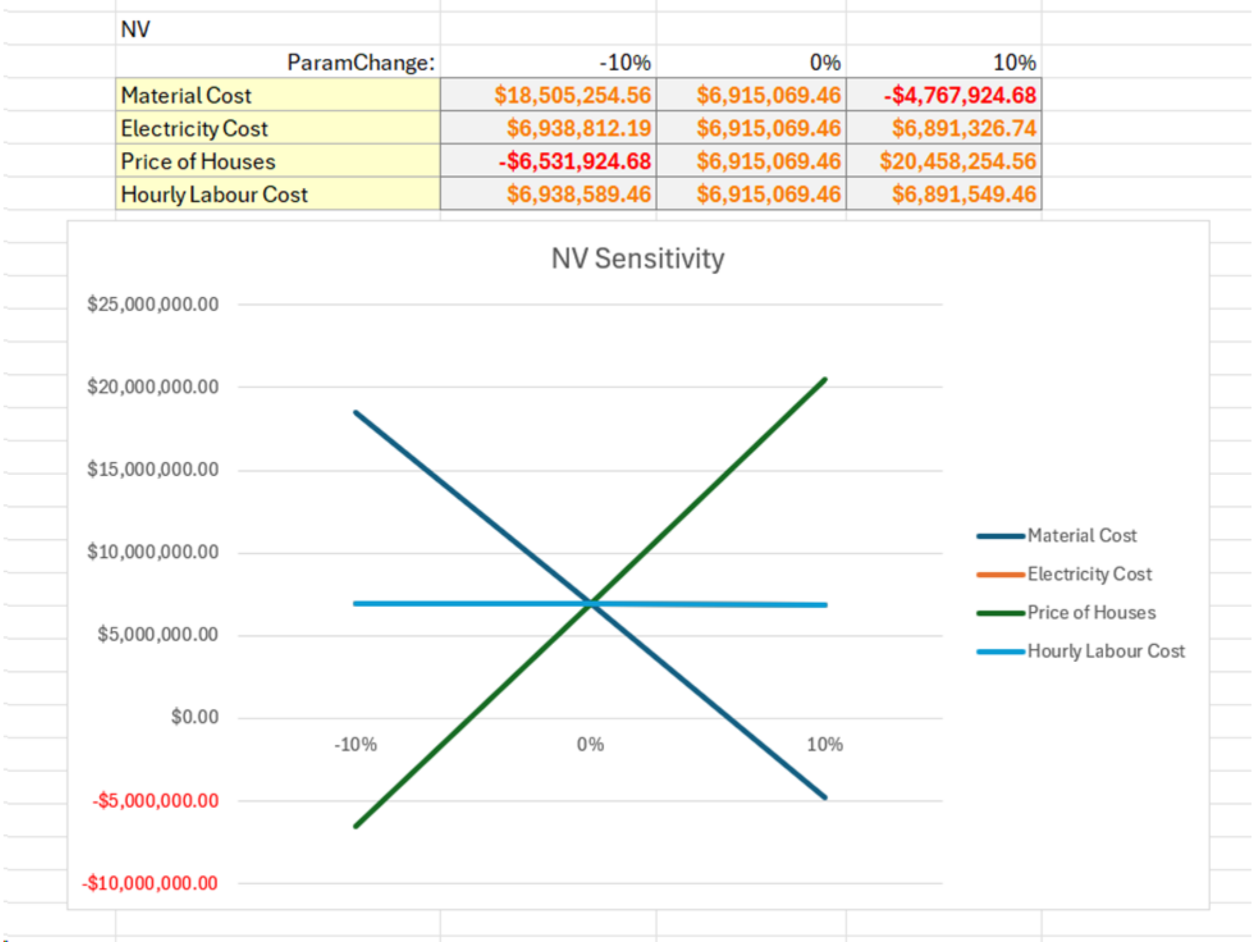
Record of Solutions:			
Material Cost	261	290	319
Electricity Cost	0.182	0.182	0.182
Price of Houses	440000	440000	440000
Hourly Labour Cost	30	30	30
NV	$18,505,254.56	$6,915,069.46	-$4,767,924.68
# Humans	10.000	8.000	8.000
# Robots	22.000	20.000	20.000
# Engineers	5.000	4.000	4.000
R-1 volume produced (m^3)	9359.675	9359.675	9359.675
R-2 volume produced (m^3)	9359.675	9359.675	9359.675
R-3 volume produced (m^3)	9359.675	9359.675	9359.675
C-2 volume produced (m^3)	9359.675	9359.675	9359.675

Record of Solutions:			
Material Cost	290	290	290
Electricity Cost	$0.16	0.182	$0.20
Price of Houses	440000	440000	440000
Hourly Labour Cost	30	30	30
NV	$6,938,812.19	$6,915,069.46	$6,891,326.74
# Humans	8.000	8.000	8.000
# Robots	20.000	20.000	20.000
# Engineers	4.000	4.000	4.000
R-1 volume produced (m^3)	9359.675	9359.675	9359.675
R-2 volume produced (m^3)	9359.675	9359.675	9359.675
R-3 volume produced (m^3)	9359.675	9359.675	9359.675
C-2 volume produced (m^3)	9359.675	9359.675	9359.675

Record of Solutions:			
Material Cost	290	290	290
Electricity Cost	0.182	0.182	0.182
Price of Houses	396000	440000	484000
Hourly Labour Cost	30	30	30
NV	-$6,531,924.68	$6,915,069.46	$20,458,254.56
# Humans	6.000	8.000	10.000
# Robots	15.000	20.000	22.000
# Engineers	3.000	4.000	5.000
R-1 volume produced (m^3)	9359.675	9359.675	9359.675
R-2 volume produced (m^3)	9359.675	9359.675	9359.675
R-3 volume produced (m^3)	9359.675	9359.675	9359.675
C-2 volume produced (m^3)	9359.675	9359.675	9359.675

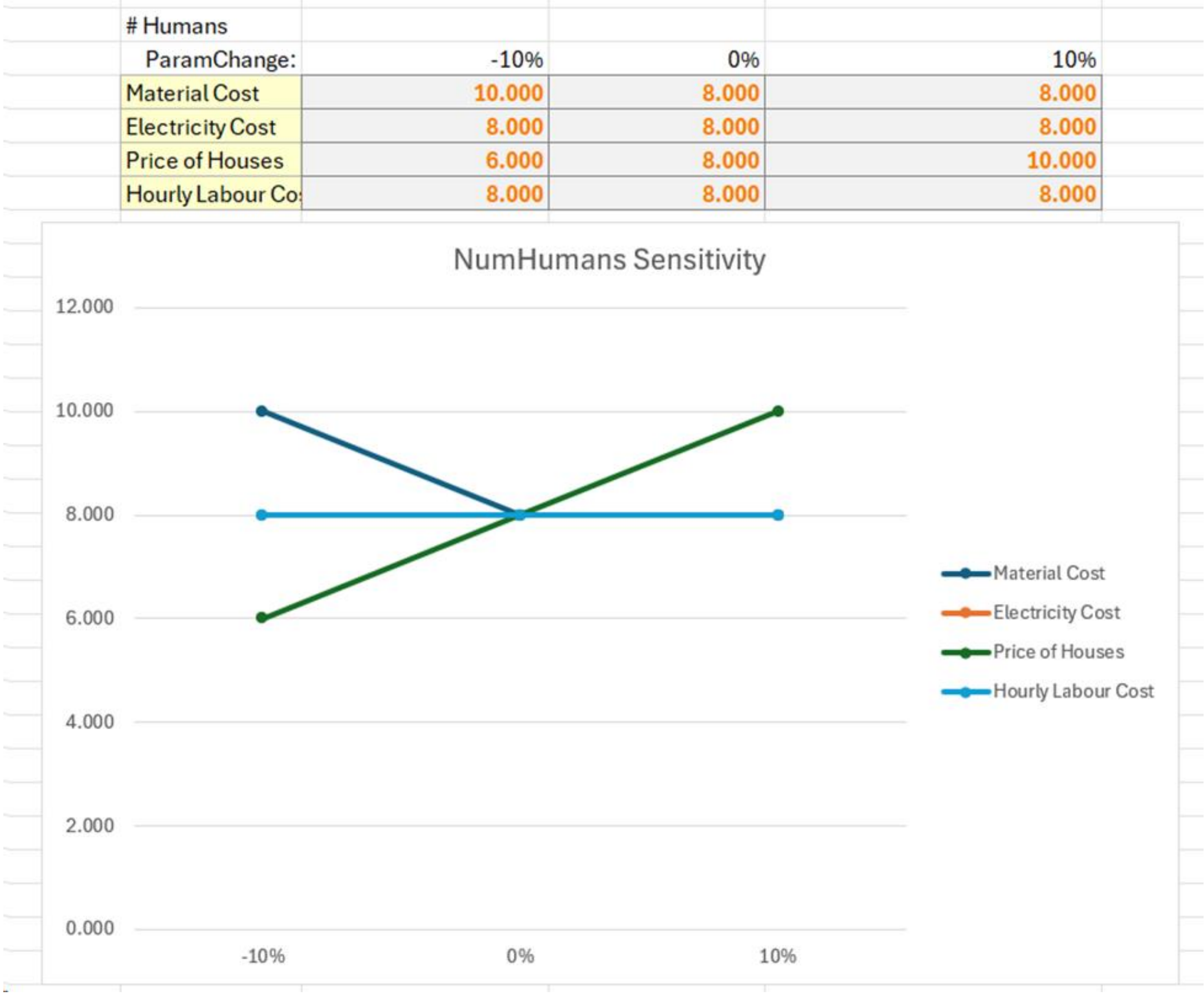
Record of Solutions:			
Material Cost	290	290	290
Electricity Cost	0.182	0.182	0.182
Price of Houses	440000	440000	440000
Hourly Labour Cost	27	30	33
NV	$6,938,589.46	$6,915,069.46	$6,891,549.46
# Humans	8.000	8.000	8.000
# Robots	20.000	20.000	20.000
# Engineers	4.000	4.000	4.000
R-1 volume produced (m^3)	9359.675	9359.675	9359.675
R-2 volume produced (m^3)	9359.675	9359.675	9359.675
R-3 volume produced (m^3)	9359.675	9359.675	9359.675
C-2 volume produced (m^3)	9359.675	9359.675	9359.675

Figure 9: Overview of parameter sensitivity analysis



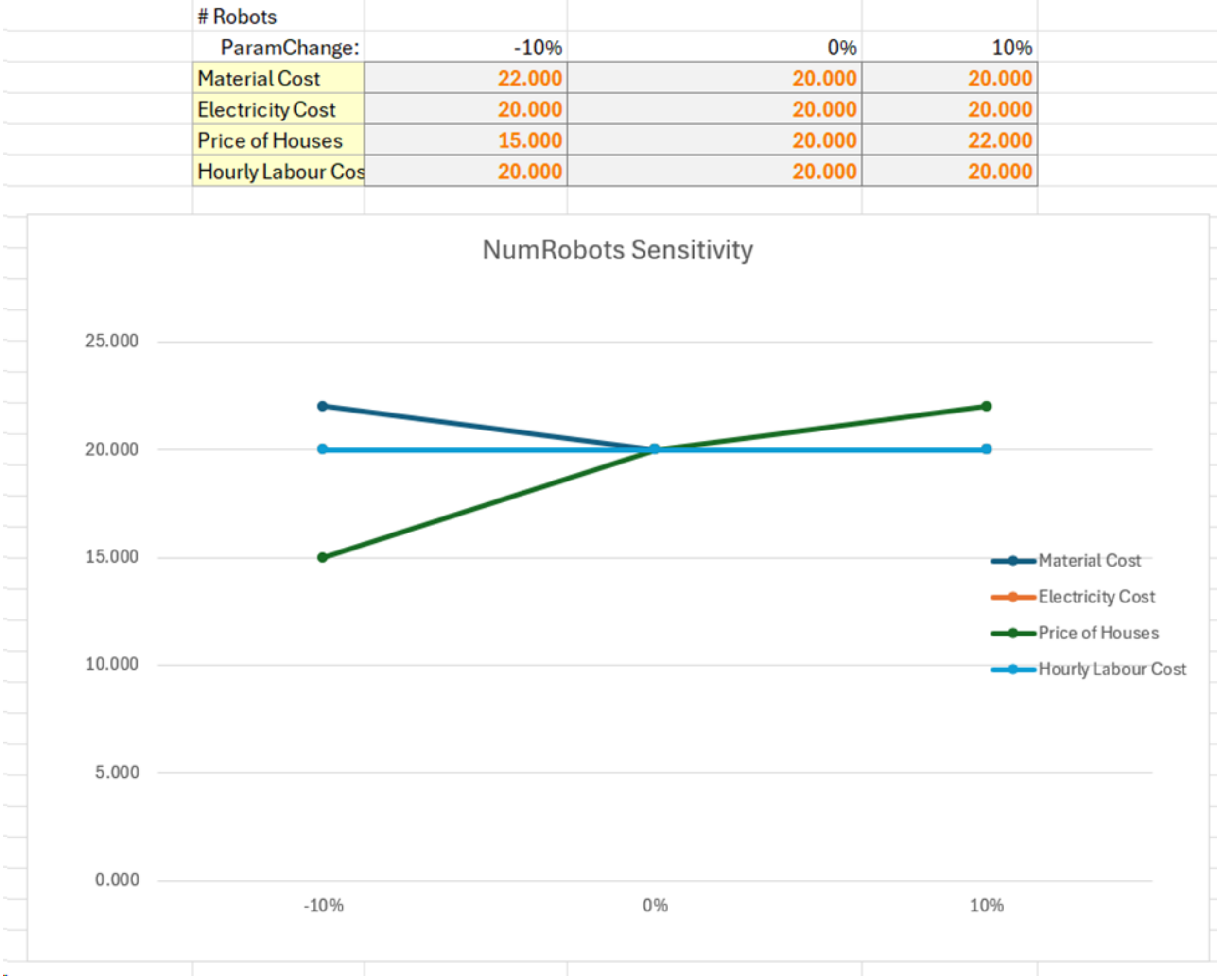
NV			
ParamChange:	-10%	0%	10%
Material Cost	$18,505,254.56	$6,915,069.46	-$4,767,924.68
Electricity Cost	$6,938,812.19	$6,915,069.46	$6,891,326.74
Price of Houses	-$6,531,924.68	$6,915,069.46	$20,458,254.56
Hourly Labour Cost	$6,938,589.46	$6,915,069.46	$6,891,549.46

Figure 10: NV Sensitivity



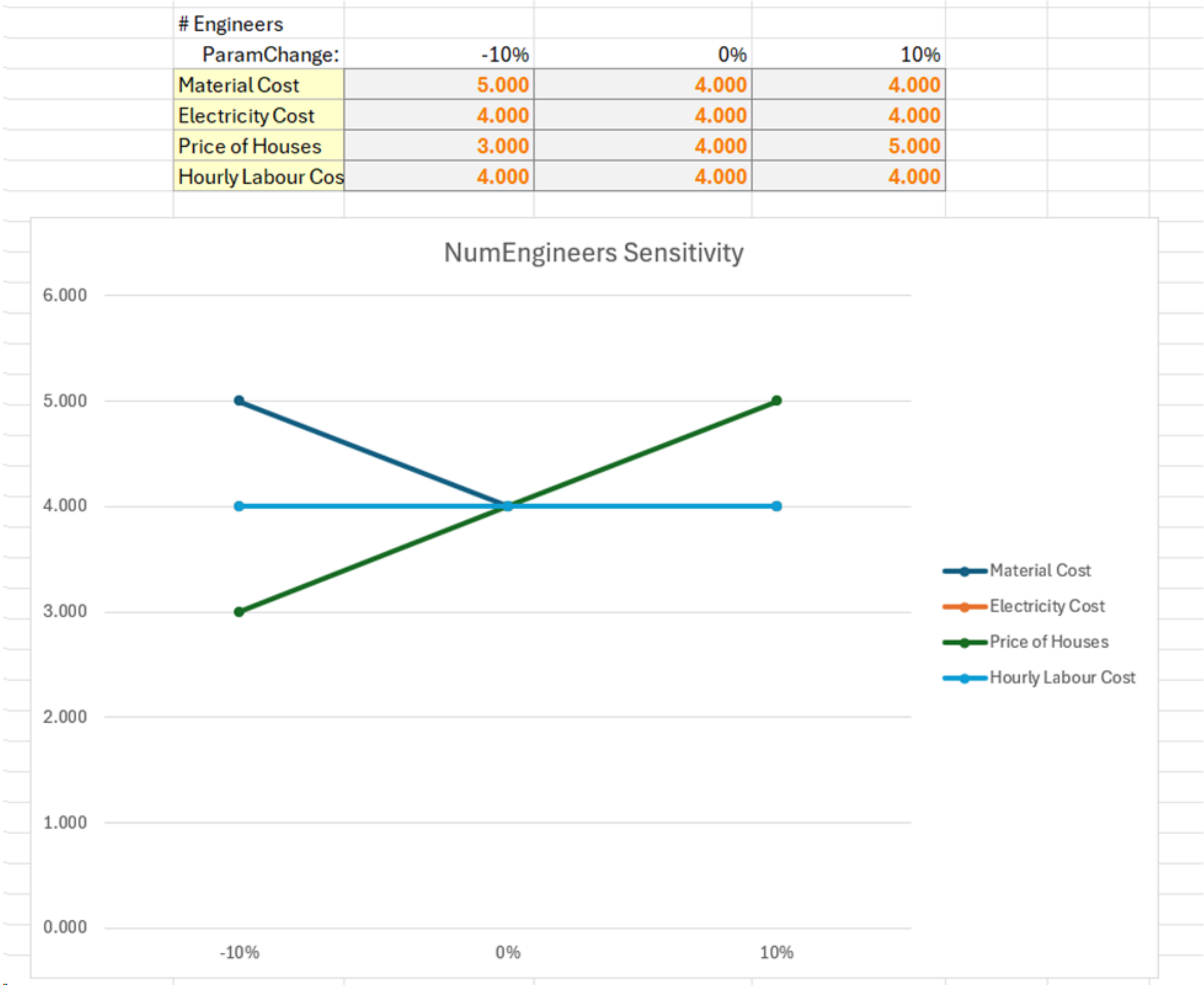
# Humans			
ParamChange:	-10%	0%	10%
Material Cost	10.000	8.000	8.000
Electricity Cost	8.000	8.000	8.000
Price of Houses	6.000	8.000	10.000
Hourly Labour Co	8.000	8.000	8.000

Figure 11: Num Humans Sensitivity



# Robots			
ParamChange:	-10%	0%	10%
Material Cost	22.000	20.000	20.000
Electricity Cost	20.000	20.000	20.000
Price of Houses	15.000	20.000	22.000
Hourly Labour Cos	20.000	20.000	20.000

Figure 12: NumRobots Sensitivity



Engineers

ParamChange:	-10%	0%	10%
Material Cost	5.000	4.000	4.000
Electricity Cost	4.000	4.000	4.000
Price of Houses	3.000	4.000	5.000
Hourly Labour Cos	4.000	4.000	4.000

Figure 13: Num Engineers Sensitivity

Our NVF is most sensitive to changes in the cost of materials as well as the selling price of homes. This was expected, as the revenue and cost terms are dominated by these two values. On the other hand, our NVF is least sensitive to the cost of electricity and hourly wages, whose values are comparatively small compared to other parameters. Thus, our NVF for the project will be maximized when all exclusive costs are minimized and the number of engineers is at the minimum amount specified by the number of robotic arms needed, with the largest instabilities caused by the cost of materials and sell point of the homes.

7. Final Design

Our Final Design involves creating a factory that uses industrial robots to automate the creation of concrete housing modules to increase the rate at which houses are built. By conducting a sensitivity analysis on our initial assumptions, adjusting our net value function and optimizing our decision variables, and conducting a second sensitivity analysis on our now optimized variables we have found that the ideal number of robots to have in the factory is 20 alongside a total of 8 employees of which 4 of them would be engineers or technicians. Through our first sensitivity analysis we determined that the net value function we were using did not relate revenue generated by the factory to any of our decision variables. If we were to optimize this NVF it would just set every decision variable to zero. Our NVF was then modified to have the revenue generated as a function of the number of industrial robots we had in the facility. The solution was then optimized in Excel using the GRG Nonlinear solver and another sensitivity analysis was performed on our modified NVF with the optimized values as the baseline.

From our optimization results we find that this project would have a net value of $6,915,069.46 and therefore can proceed with implementation as we have confirmed that this design is profitable. We cannot guarantee that the housing modules produced will be able to withstand all environmental conditions, while we do not see this as a problem for southern Ontario, other regions may have different requirements that we be unable to accommodate.

8. Project Plan

To pursue the implementation of this project, there are six main categories of tasks that must be completed. The facility must be constructed so that the production of the housing modules can begin. This included securing the property needed to build the facility as well as regulatory approval and permits for construction, creation of the floor plan for the facility, contracting companies to construct the facility, and creating a schedule to build the facility. The industrial robots to be used must be researched, procured, and installed and then a maintenance schedule must be created. The concrete mixes used in the housing modules must be designed and then suppliers must be contacted to purchase and store materials. Transportation must be organized with clients and contractors to get the housing modules to site including the pickup schedules and shipping manifests, and the modules must be loaded into their transport vehicles. Contractors and developers must be contacted to receive projects and be contracted onto jobs and therefore generate revenue. Finally, workers and engineers need to be hired and trained and shift schedules must be created for the facility to function. All tasks are detailed in the Work Breakdown Structure in Figure 9.

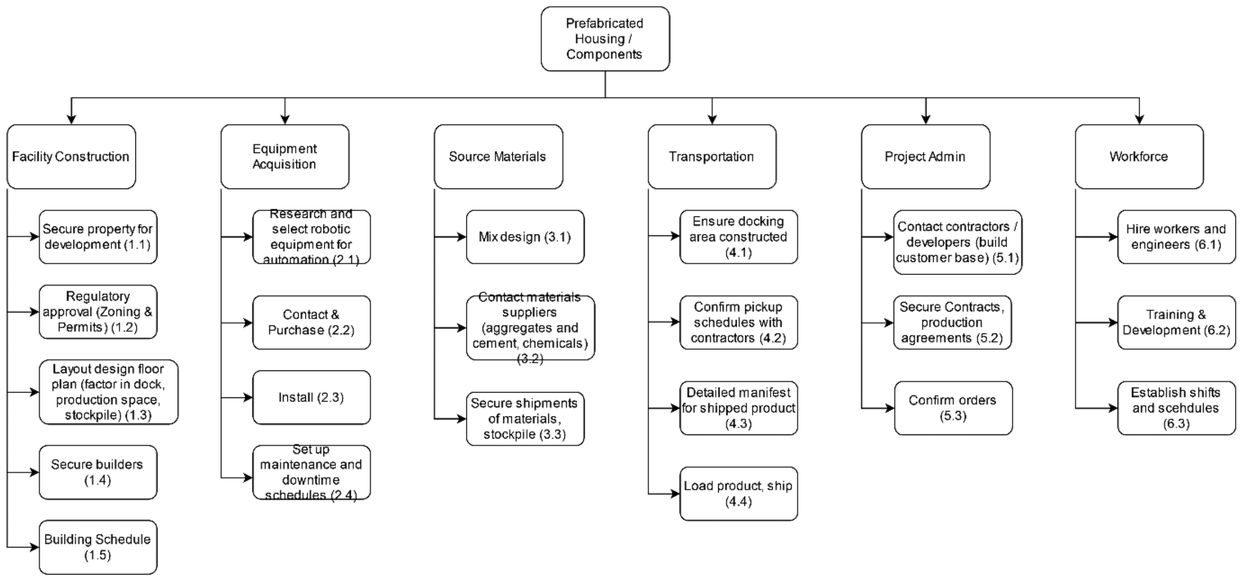


Figure 14: Work Breakdown Structure for the implementation of the project.

From analyzing the critical path method (CPM) diagram in Figure 10, several activities can occur concurrently at the start of the project, including:

- Designing the housing module mix
- Contacting contractors and developers
- Beginning to secure contracts
- Purchasing the property
- Researching the industrial robots needed

The critical first step is to start acquiring regulatory approval. Once the property to construct the factory is purchased, the floor plan design can begin. This allows construction to commence and hiring of construction companies to build out the factory. In parallel, the procurement of industrial robots can start, followed by the construction of the docking area. Also, procuring materials from suppliers can begin if they are aware of the project timeline. As the docking area is completed and robots are installed, the facility construction can finish. This enables the hiring of workers and confirmation of orders from clients that were initially contacted at the project's onset. Upon procured materials' arrival, order confirmation can proceed with establishing pickup schedules. This allows shipping manifests to be created. As workers are onboarded, training and development programs can be implemented, along with the creation of shift schedules. Once these critical steps are finished, the production and shipping of housing modules can start. The CPM in Figure 10 is dated by months since project start. Analysis reveals the critical path involves tasks in this sequence: 1.2, 1.1, 1.3, 1.4, 1.5, 5.3, 4.2, 4.3, 4.4

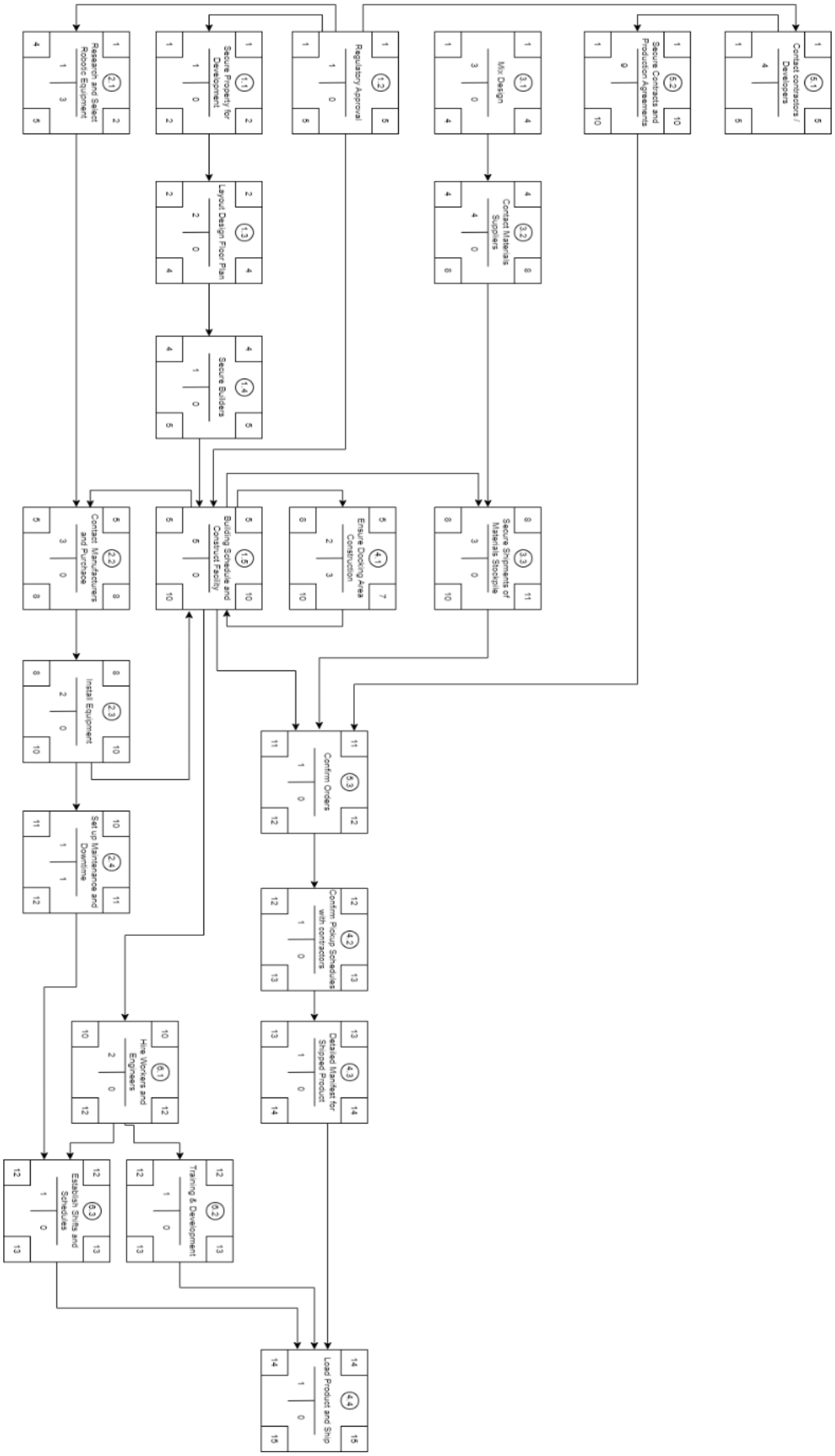


Figure 15: Critical Path Model of the tasks needed to implement the project

The following task list details all the tasks involved with implementation of the project including the start and end dates, the number of payments for each task, the cost per payment involved with each task, and whether the tasks are ongoing after implementation. Most tasks have already been accounted for in the initial Net Value Function including materials, labor, construction, and Research and Development costs, however tasks such as obtaining zoning permits and contacting contractors to build a customer base were not included in the initial NVF. Some tasks are listed to have a net value of $0, this is because they either n=have no inherent Net Value themselves, or the associated net value is included under another task such as the cost of constructing the docking bay is included in the overall cost of the facility's construction. It may be noted that tasks involved with decommissioning this project have not been included in the WBS and task list, this is due to the nature of the project as a new way to increase the rate of housing construction and therefore, should the project be pursued, the project should remain profitable unless either the construction of housing is no longer needed or more efficient ways of housing construction are developed by other companies.

Table 1: Task list of all tasks involved in implementation

Item #	Description	Start Date	End Date	Number of Payments	Realized NV each payment (nominal value)
1.1	Secure property for development	5/1/2024	6/1/2024	1	-$3,000,000.00
1.2	Regulatory approval (Zoning and Permits)	5/1/2024	10/1/2024	5	-$20,000.00
1.3	Layout design floor plan (factor in dock, production space, stockpile)	6/1/2024	8/1/2024	2	-$40,000.00
1.4	Secure builders	7/1/2024	8/1/2024	0	$0.00
1.5	Building schedule (build)	8/1/2024	1/1/2025	5	-$875,000.00
2.1	Research and select robotic equipment for automation	5/1/2024	6/1/2024	1	-$750,000.00
2.2	Contact & Purchase, shipped	12/1/2024	1/1/2025	1	-$9,000,000.00
2.3	Install	1/1/2025	2/1/2025	1	-$18,000.00
2.4	Set up, maintenance, and downtime schedules	2/1/2025	3/1/2025	1	-$90,000.00
3.1	Mix design	6/1/2024	8/1/2024	2	-$500,000.00
3.2	Contact materials suppliers (aggregates and cement, chemicals), ship	8/1/2024	12/1/2024	4	-$10,000.00
3.3	Secure shipments of materials, stockpile	12/1/2024	Ongoing	240	-$10,956,562.50

4.1	Ensure docking area constructed	12/1/2024	1/1/2025	0	$0.00
4.2	Confirm pickup schedules with contractors	1/1/2025	2/1/2025	0	$0.00
4.3	Detailed manifest for shipped product	2/1/2025	3/1/2025	0	$0.00
4.4	Load product, ship (starting production*)	3/1/2025	ongoing	240	$10,862,500.00
5.1	Contact contractors/developers (build customer base)	5/1/2024	ongoing	240	-$15,000.00
5.2	Secure Contracts, production agreements	5/1/2024	ongoing	240	-$15,000.00
5.3	Confirm orders	2/1/2025	ongoing	0	$0.00
6.1	Hire workers and engineers	1/1/2025	2/1/2025, then ongoing	240	-$54,176.00
6.2	Training & Development	1/1/2025	2/1/2025, then ongoing	240	-$2,000.00
6.3	Establish shifts and schedules	2/1/2025	ongoing	0	$0.00

9. NPV

We were able to compute the TVM conversion factors to determine the NPV of our project. Assigning monetary values to our tasks, we found that our project has a positive NPV and an IRR greater than the nominal MARR set by the client.

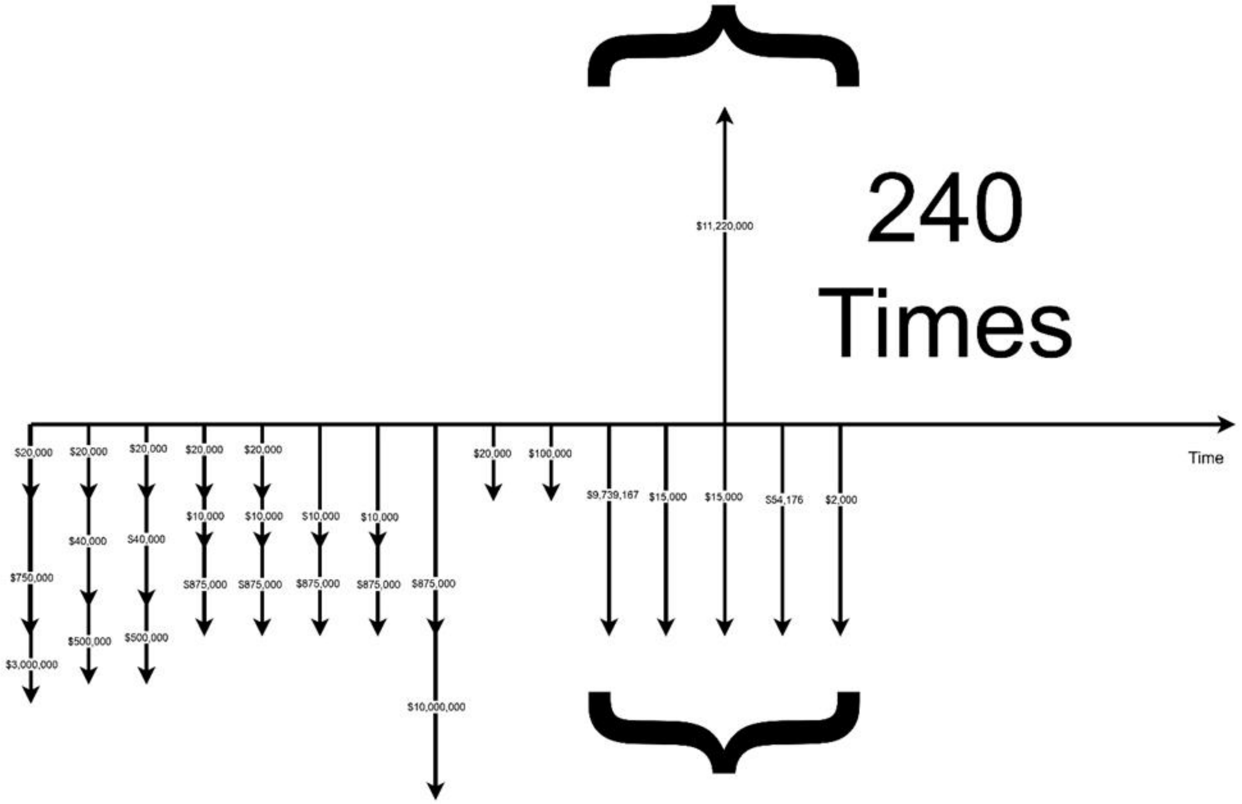


Figure 16: Value Flow Diagram

Our tasks can be divided into two categories: one-time costs that may extend for a few months and ongoing costs that span the life of the project. In the cash flow diagram above, the one-time costs are packed near the start of the project, representing the large start-up costs associated with purchasing land, equipment, etc. As the project progresses, the recurring revenue and costs appear, continuing up until the end of the project’s life. It is these continual costs that have the largest impact on our NPV, owing to both their repetition and large associated values.

Our solution is based in Southern Ontario. Therefore, our discount rate should reflect the current inflation rate in Canada. According to the Bank of Canada, interest rates are expected to stay around 3% for 2024 [23]. However, it was as high as 5% in 2023. To model the worst-case scenario, we will set our discount rate at 5%. The reference date, May of 2024, was chosen as the start date because we believe it is the soonest possible time to begin if this project was to be approved immediately. This made assumptions about interest rates and current estimates for the costs more accurate as those were made with nominal dollars.

To start the TVM conversion factors, we first converted the yearly discount rate to a monthly discount rate using:

$$r_{(d,monthly)} = \left(1 + r_{(d,yearly)}\right)^{(1/12)} - 1$$

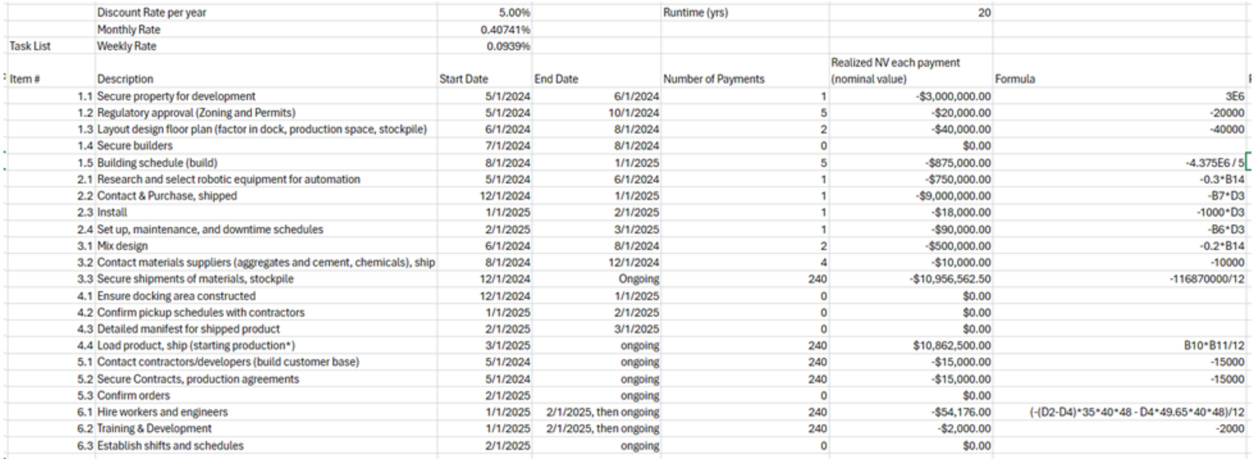
Even though they are not currently present, we did the same to find the rate for weekly costs. This is what will be used if we add weekly costs in the future. To find the present value of costs that start right at the start date, we used:

$$PV = \left(1 - 1/\left(1 + r_{(d,monthly)}\right)^{t}\right)/\left(r_{(d,monthly)}\right)$$

Where t is the period in months. For tasks that start at a much later date, we needed to include a correction factor to convert the amount back into nominal dollars:

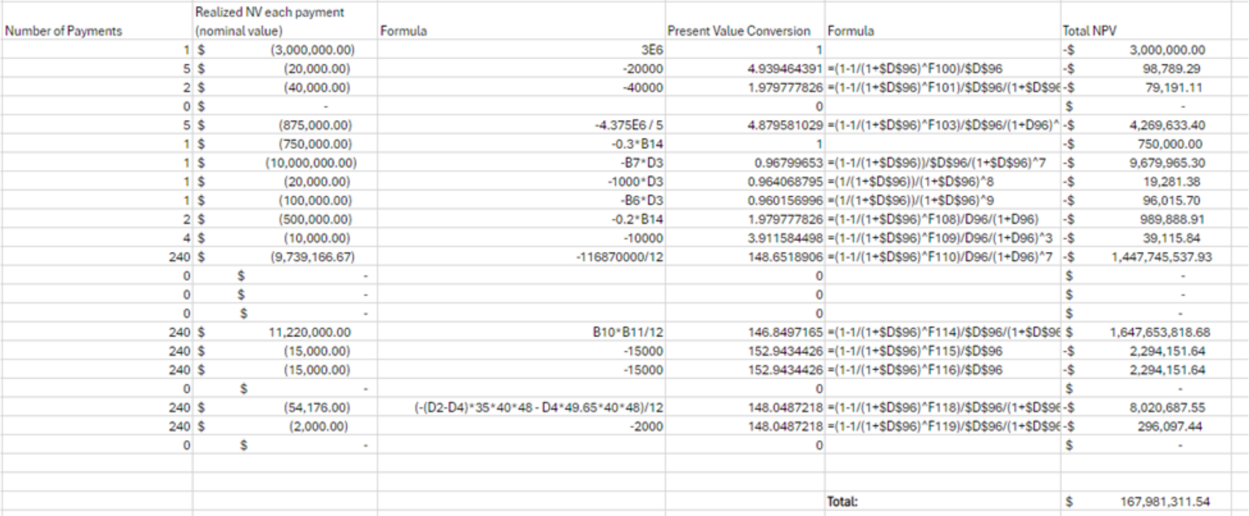
$$PV = \left(1 - 1/\left(1 + r_{(d,monthly)}\right)^{t}\right)/\left(r_{(d,monthly)}\right)/\left(1 + r_{(d,monthly)}\right)^{(t_s)}$$

Where t_s is the time since the start date the task begins.



	Discount Rate per year	5.00%		Runtime (yrs)	20	
	Monthly Rate	0.40741%				
Task List	Weekly Rate	0.0939%				
Item #	Description	Start Date	End Date	Number of Payments	Realized NV each payment (nominal value)	Formula
1.1	Secure property for development	5/1/2024	6/1/2024	1	-$3,000,000.00	3E6
1.2	Regulatory approval (Zoning and Permits)	5/1/2024	10/1/2024	5	-$20,000.00	-20000
1.3	Layout design floor plan (factor in dock, production space, stockpile)	6/1/2024	8/1/2024	2	-$40,000.00	-40000
1.4	Secure builders	7/1/2024	8/1/2024	0	$0.00	
1.5	Building schedule (build)	8/1/2024	1/1/2025	5	-$875,000.00	-4.375E6 / 5
2.1	Research and select robotic equipment for automation	5/1/2024	6/1/2024	1	-$750,000.00	-0.3*B14
2.2	Contact & Purchase, shipped	12/1/2024	1/1/2025	1	-$9,000,000.00	-B7*D3
2.3	Install	1/1/2025	2/1/2025	1	-$18,000.00	-1000*D3
2.4	Set up, maintenance, and downtime schedules	2/1/2025	3/1/2025	1	-$90,000.00	-B6*D3
3.1	Mix design	6/1/2024	8/1/2024	2	-$500,000.00	-0.2*B14
3.2	Contact materials suppliers (aggregates and cement, chemicals), ship	8/1/2024	12/1/2024	4	-$10,000.00	-10000
3.3	Secure shipments of materials, stockpile	12/1/2024	Ongoing	240	-$10,956,562.50	-116870000/12
4.1	Ensure docking area constructed	12/1/2024	1/1/2025	0	$0.00	
4.2	Confirm pickup schedules with contractors	1/1/2025	2/1/2025	0	$0.00	
4.3	Detailed manifest for shipped product	2/1/2025	3/1/2025	0	$0.00	
4.4	Load product, ship (starting production*)	3/1/2025	ongoing	240	$10,862,500.00	B10*B11/12
5.1	Contact contractors/developers (build customer base)	5/1/2024	ongoing	240	-$15,000.00	-15000
5.2	Secure Contracts, production agreements	5/1/2024	ongoing	240	-$15,000.00	-15000
5.3	Confirm orders	2/1/2025	ongoing	0	$0.00	
6.1	Hire workers and engineers	1/1/2025	2/1/2025, then ongoing	240	-$54,176.00	(-(D2-D4)*35*40*48 - D4*49.65*40*48)/12
6.2	Training & Development	1/1/2025	2/1/2025, then ongoing	240	-$2,000.00	-2000
6.3	Establish shifts and schedules	2/1/2025	ongoing	0	$0.00	

Figure 17: Overview of TVM calculations



Number of Payments	Realized NV each payment (nominal value)	Formula	Present Value Conversion	Formula	Total NPV
1	$ (3,000,000.00)	3E6	1		-$ 3,000,000.00
5	$ (20,000.00)	-20000	4.939464391	=(1-1/(1+$D$96)^F100)/$D$96	-$ 98,789.29
2	$ (40,000.00)	-40000	1.979777826	=(1-1/(1+$D$96)^F101)/$D$96/(1+$D$96	-$ 79,191.11
0	$ -		0		$ -
5	$ (875,000.00)	-4.375E6 / 5	4.879581029	=(1-1/(1+$D$96)^F103)/$D$96/(1+D96)^	-$ 4,269,633.40
1	$ (750,000.00)	-0.3*B14	1		-$ 750,000.00
1	$ (10,000,000.00)	-B7*D3	0.96799653	=(1-1/(1+$D$96))/$D$96/(1+$D$96)^7	-$ 9,679,965.30
1	$ (20,000.00)	-1000*D3	0.964068795	=(1/(1+$D$96))/(1+$D$96)^8	-$ 19,281.38
1	$ (100,000.00)	-B6*D3	0.960156996	=(1/(1+$D$96))/(1+$D$96)^9	-$ 96,015.70
2	$ (500,000.00)	-0.2*B14	1.979777826	=(1-1/(1+$D$96)^F108)/D96/(1+D96)	-$ 989,888.91
4	$ (10,000.00)	-10000	3.911584498	=(1-1/(1+$D$96)^F109)/D96/(1+D96)^3	-$ 39,115.84
240	$ (9,739,166.67)	-116870000/12	148.6518906	=(1-1/(1+$D$96)^F110)/D96/(1+D96)^7	-$ 1,447,745,537.93
0	$ -		0		$ -
0	$ -		0		$ -
0	$ -		0		$ -
240	$ 11,220,000.00	B10*B11/12	146.8497165	=(1-1/(1+$D$96)^F114)/$D$96/(1+$D$96	$ 1,647,653,818.68
240	$ (15,000.00)	-15000	152.9434426	=(1-1/(1+$D$96)^F115)/$D$96	-$ 2,294,151.64
240	$ (15,000.00)	-15000	152.9434426	=(1-1/(1+$D$96)^F116)/$D$96	-$ 2,294,151.64
0	$ -		0		$ -
240	$ (54,176.00)	(-(D2-D4)*35*40*48 - D4*49.65*40*48)/12	148.0487218	=(1-1/(1+$D$96)^F118)/$D$96/(1+$D$96	-$ 8,020,687.55
240	$ (2,000.00)	-2000	148.0487218	=(1-1/(1+$D$96)^F119)/$D$96/(1+$D$96	-$ 296,097.44
0	$ -		0		$ -
				Total:	$ 167,981,311.54

Figure 18: NPV Summation

Doing this for all listed tasks, we find that we still have a positive NPV of around $167 million. This is an extremely promising value but was found using many estimated values and assumptions of complex market behavior. As such, it does not definitively state that our solution is fantastic, but rather shows that it warrants further investigation.

Since the NPV is highly nonlinear and involves sums with terms of about 240, it is not feasible to solve for an exact solution of the IRR. As such, we manually adjusted the discount rate until an NPV as close to zero as possible emerged, which occurred at a rate of around 37.07%. The real MARR set by the client of 15% corresponds to a nominal MARR of around 21%. The IRR being larger than the nominal MARR shows that this project meets the client's constraints and can be profitable. No new decision variables were created because of this analysis. The values used are the optimized amounts found in our optimization analysis.

To summarize, we were able to find the positive NPV of our project using TVM conversion factors with a yearly discount rate mirroring Canada's inflation rate of 5%. The IRR of our project contains the MARR, showing there is merit to further developing the project.

10. Risk Management

Completing a risk management assessment involved brainstorming any events that had the possibly of occurring, and the risks of which could either provide benefits or costs to the net value (NV) of the project. For benefits, we determined that an influx of population or a government housing subsidy program was the most likely to occur, with a probability of 70% and 60% chance respectively of occurring over the lifetime of the project. These would directly increase our revenue, with a 30% increase in revenue for an influx in population and a $500,000 bonus every year for the subsidy program. However, to create effective mitigation strategies, we must also consider the costs of risks. We considered the following costs:

a. Housing market collapse. As a result, we would have to sell our components at a reduction of -25% worst case, assuming a 5% chance of occurrence.
b. Shortage of materials. This change in material pricing carries a 50% chance of occurrence. The difficulty to source materials due to a shortage in supply could significantly increase material costs by approximately 25%.
c. Labour Shortage (30% chance): Would increase cost of labour by 35%.
d. Shortage of silicon chips, harder to source robotic components. Would decrease number of robots by 40%, with a 20% chance of occurring.
e. Strikes (30% chance): Decreases revenue by 5%. Minimizing the reliance on labour by automating.

The next step to consider involved laying out these risks into a risk matrix for visual representation as well as organized analysis. The horizontal axis included the Relative Impact to the NV on a scale of low to high, along with the vertical axis representing the probabilistic occurrence of risk over the project's lifetime.

Table 2: Project Risk Matrix, most critical risks highlighted in green

		Impact (NV Impact each time it happens)		
		Low	Medium	High
Probability of happening (or expected frequency of happening) over lifetime of project	Low	g. Strikes		c. Housing market collapse
	Medium	b. Government creates housing subsidy program	e. Labour shortage	f. Shortage of silicon chips
	High			a. Influx in population, d. Shortage of materials

We were most interested in the top 3 risks that most negatively impacted our NPV. As seen from the matrix, the 3 most critical risks are:

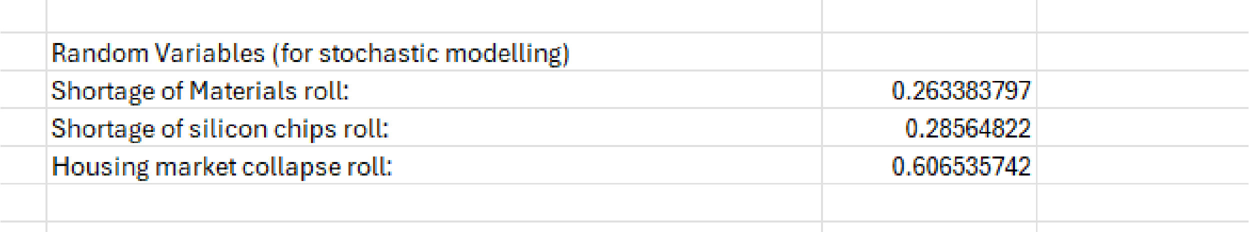
Shortage of materials: -$362 million * 0.5 = -$181 million over lifetime

Shortage of silicon chips: −$26,486,300.90 ∗ 35% =−$9,270,205.315−$26,486,300.90 ∗ 35% = −$9,270,205.315

Housing market collapse: -$410 million * 0.05 = -$20.5 million

Whereby the risks' magnitude and impact were determined by multiplying the NV impact if they do happen with the chance they happen, or the NV impact per occurrence with the expected rate of occurrence. To address these identified high impact risks, we created mitigation strategies that we believed offered a realistic approach in dealing with them. To address a housing market collapse, we considered selling our surplus materials to non-housing industries, resulting in a net monthly revenue of $75,000. For a silicon-chip shortage, we would allocate a large amount to an initial R&D cost to heavily explore the possibility of producing our own robotic equipment, resulting in an increase of 3 robotic arm. Lastly, we explored the possibility of importing our materials from non-local manufacturers to combat a possible materials shortage. This would reduce the impact of a materials shortage by 5%.

Once this analysis was completed, the risks were subbed into our task list with if-conditions and RAND functions to create our initial stochastic model. For our preliminary deterministic model, we instead subbed in the expected values of the affected variables into our task list.

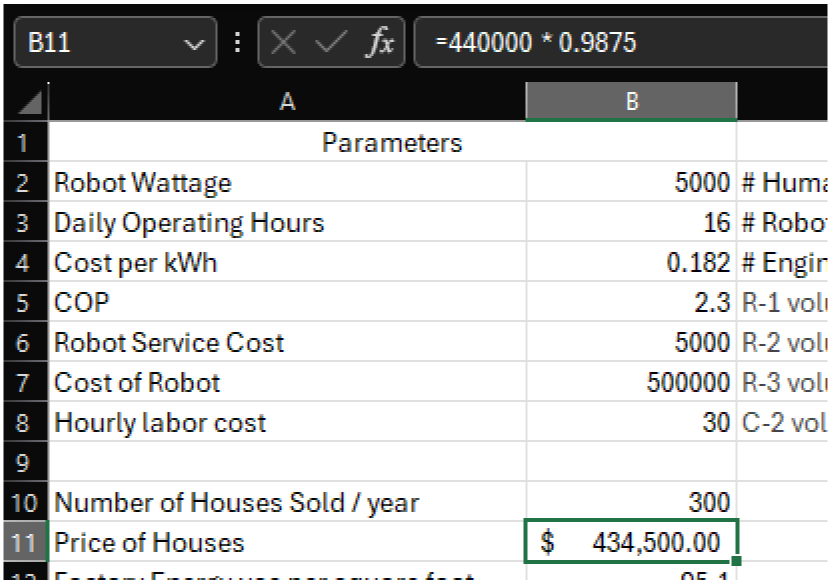


Random Variables (for stochastic modelling)	
Shortage of Materials roll:	0.263383797
Shortage of silicon chips roll:	0.28564822
Housing market collapse roll:	0.606535742

Figure 20: Excel with Critical Risks and set up for Stochastic Modelling and Deterministic Draft Modelling

Total:	$ 52,761,878.57

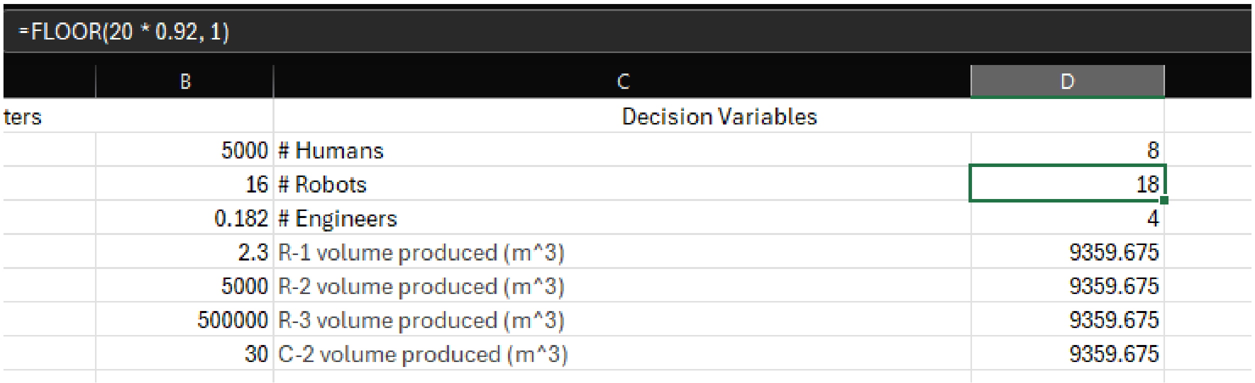
Figure 21: Update to NVF with the impact of Critical Risks Summed Up with mitigation strategies



=440000 * 0.9875

	A	B	
1	Parameters		
2	Robot Wattage	5000	# Huma
3	Daily Operating Hours	16	# Robo
4	Cost per kWh	0.182	# Engir
5	COP	2.3	R-1 vol
6	Robot Service Cost	5000	R-2 vol
7	Cost of Robot	500000	R-3 vol
8	Hourly labor cost	30	C-2 vol
9			
10	Number of Houses Sold / year	300	
11	Price of Houses	$ 434,500.00	

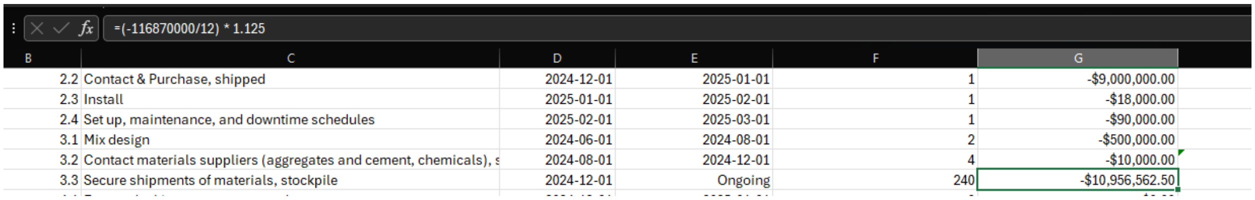
Figure 22: Expected value of Price of Houses sold



=FLOOR(20 * 0.92, 1)

	B	C	D
ters		Decision Variables	
	5000	# Humans	8
	16	# Robots	18
	0.182	# Engineers	4
	2.3	R-1 volume produced (m^3)	9359.675
	5000	R-2 volume produced (m^3)	9359.675
	500000	R-3 volume produced (m^3)	9359.675
	30	C-2 volume produced (m^3)	9359.675

Figure 23: Expected value of the number of robotic arms



=(-116870000/12) * 1.125

B	C	D	E	F	G
2.2	Contact & Purchase, shipped	2024-12-01	2025-01-01	1	-$9,000,000.00
2.3	Install	2025-01-01	2025-02-01	1	-$18,000.00
2.4	Set up, maintenance, and downtime schedules	2025-02-01	2025-03-01	1	-$90,000.00
3.1	Mix design	2024-06-01	2024-08-01	2	-$500,000.00
3.2	Contact materials suppliers (aggregates and cement, chemicals), s	2024-08-01	2024-12-01	4	-$10,000.00
3.3	Secure shipments of materials, stockpile	2024-12-01	Ongoing	240	-$10,956,562.50

Figure 24: Expected value of materials cost

Using preliminary deterministic modelling using expected values, we found an NPV of $53 million. This showed us that our mitigation strategies must be enabled to ensure a positive NPV and guarantee an attractive profit for potential investors.

11. Stochastic Sensitivity Analysis

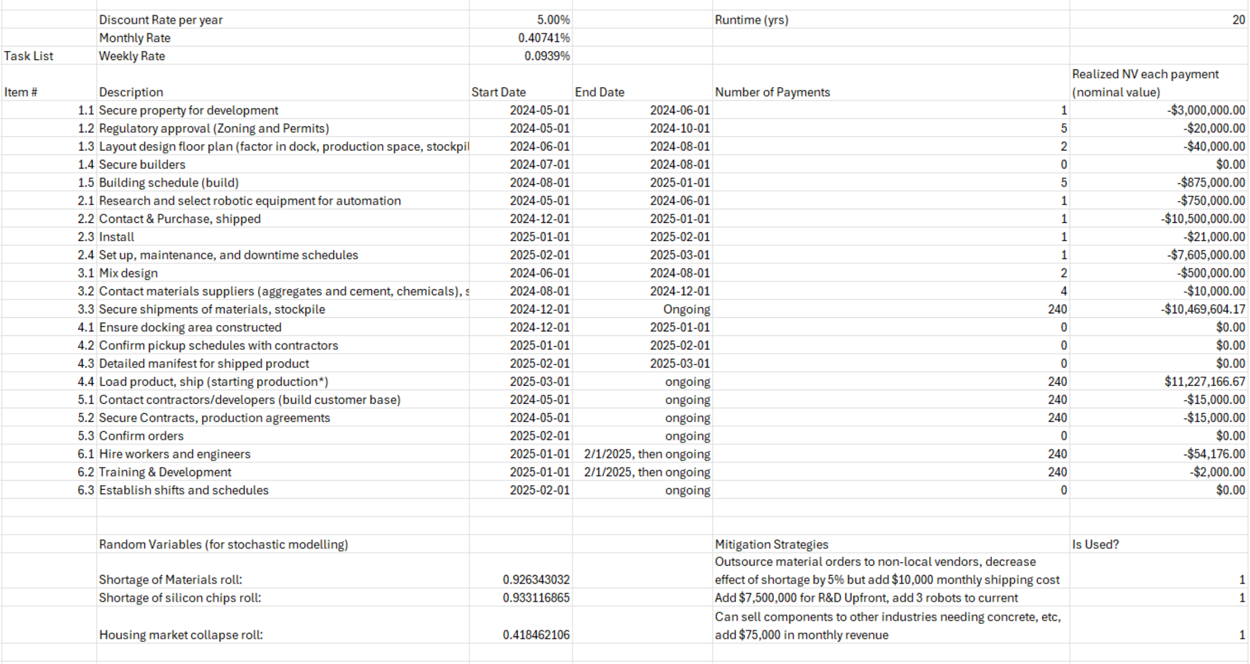
To perform our stochastic sensitivity analysis, we created and optimized a deterministic model based on the expected values of our variables impacted by the risks discussed above. Recall that,

$$CostOfMaterials_{new} = CostOfMaterials_{old} * (0.5 * 1 + 0.5 * 1.25)$$
$$= 1.125 * CostOfMaterials_{old}$$

$$NumRobots_{new} = NumRobots_{old} * (0.6 * 1 + 0.4 * 0.8)$$
$$= 0.92 * NumRobots_{old}$$

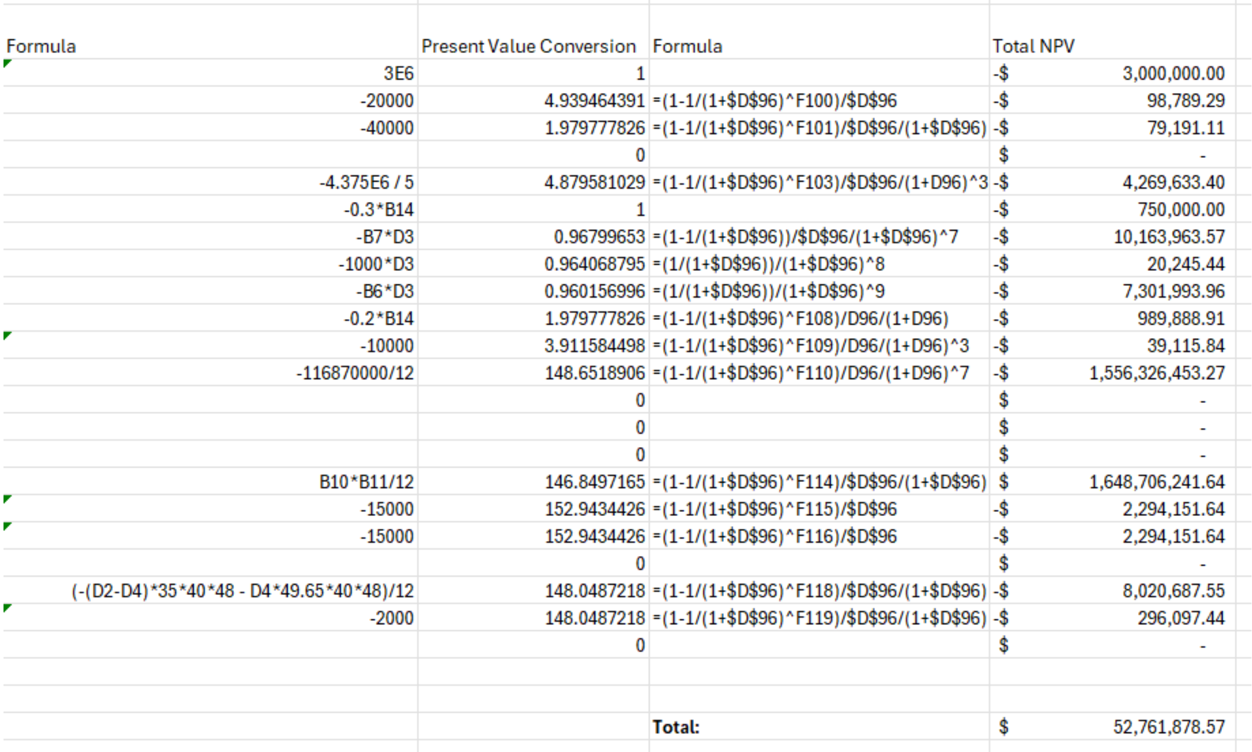
$$HousingPrice_{new} = HousingPrice_{old} * (0.95 * 1 + 0.05 * 0.75)$$
$$= 0.9875 * HousingPrice_{old}$$

The mitigation strategy associated with each risk was implemented in the spreadsheet as an if condition affecting their respective values if enabled. Replacing affected variables with their expected values in the task list from the NPV section and optimizing, we find the following optimized deterministic model:



	Discount Rate per year	5.00%		Runtime (yrs)	20
	Monthly Rate	0.40741%			
Task List	Weekly Rate	0.0939%			
Item #	Description	Start Date	End Date	Number of Payments	Realized NV each payment (nominal value)
1.1	Secure property for development	2024-05-01	2024-06-01	1	-$3,000,000.00
1.2	Regulatory approval (Zoning and Permits)	2024-05-01	2024-10-01	5	-$20,000.00
1.3	Layout design floor plan (factor in dock, production space, stockpil	2024-06-01	2024-08-01	2	-$40,000.00
1.4	Secure builders	2024-07-01	2024-08-01	0	$0.00
1.5	Building schedule (build)	2024-08-01	2025-01-01	5	-$875,000.00
2.1	Research and select robotic equipment for automation	2024-05-01	2024-06-01	1	-$750,000.00
2.2	Contact & Purchase, shipped	2024-12-01	2025-01-01	1	-$10,500,000.00
2.3	Install	2025-01-01	2025-02-01	1	-$21,000.00
2.4	Set up, maintenance, and downtime schedules	2025-02-01	2025-03-01	1	-$7,605,000.00
3.1	Mix design	2024-06-01	2024-08-01	2	-$500,000.00
3.2	Contact materials suppliers (aggregates and cement, chemicals), s	2024-08-01	2024-12-01	4	-$10,000.00
3.3	Secure shipments of materials, stockpile	2024-12-01	Ongoing	240	-$10,469,604.17
4.1	Ensure docking area constructed	2024-12-01	2025-01-01	0	$0.00
4.2	Confirm pickup schedules with contractors	2025-01-01	2025-02-01	0	$0.00
4.3	Detailed manifest for shipped product	2025-02-01	2025-03-01	0	$0.00
4.4	Load product, ship (starting production*)	2025-03-01	ongoing	240	$11,227,166.67
5.1	Contact contractors/developers (build customer base)	2024-05-01	ongoing	240	-$15,000.00
5.2	Secure Contracts, production agreements	2024-05-01	ongoing	240	-$15,000.00
5.3	Confirm orders	2025-02-01	ongoing	0	$0.00
6.1	Hire workers and engineers	2025-01-01	2/1/2025, then ongoing	240	-$54,176.00
6.2	Training & Development	2025-01-01	2/1/2025, then ongoing	240	-$2,000.00
6.3	Establish shifts and schedules	2025-02-01	ongoing	0	$0.00
	Random Variables (for stochastic modelling)			Mitigation Strategies	Is Used?
	Shortage of Materials roll:	0.926343032		Outsource material orders to non-local vendors, decrease effect of shortage by 5% but add $10,000 monthly shipping cost	1
	Shortage of silicon chips roll:	0.933116865		Add $7,500,000 for R&D Upfront, add 3 robots to current	1
	Housing market collapse roll:	0.418462106		Can sell components to other industries needing concrete, etc, add $75,000 in monthly revenue	1

Figure 25: Task List with Mitigation Strategies Enabled



Formula	Present Value Conversion	Formula	Total NPV
3E6	1		-$ 3,000,000.00
-20000	4.939464391	=(1-1/(1+$D$96)^F100)/$D$96	-$ 98,789.29
-40000	1.979777826	=(1-1/(1+$D$96)^F101)/$D$96/(1+$D$96)	-$ 79,191.11
	0		$ -
-4.375E6 / 5	4.879581029	=(1-1/(1+$D$96)^F103)/$D$96/(1+D96)^3	-$ 4,269,633.40
-0.3*B14	1		-$ 750,000.00
-B7*D3	0.96799653	=(1-1/(1+$D$96))/$D$96/(1+$D$96)^7	-$ 10,163,963.57
-1000*D3	0.964068795	=(1/(1+$D$96))/(1+$D$96)^8	-$ 20,245.44
-B6*D3	0.960156996	=(1/(1+$D$96))/(1+$D$96)^9	-$ 7,301,993.96
-0.2*B14	1.979777826	=(1-1/(1+$D$96)^F108)/D96/(1+D96)	-$ 989,888.91
-10000	3.911584498	=(1-1/(1+$D$96)^F109)/D96/(1+D96)^3	-$ 39,115.84
-116870000/12	148.6518906	=(1-1/(1+$D$96)^F110)/D96/(1+D96)^7	-$ 1,556,326,453.27
	0		$ -
	0		$ -
	0		$ -
B10*B11/12	146.8497165	=(1-1/(1+$D$96)^F114)/$D$96/(1+$D$96)	$ 1,648,706,241.64
-15000	152.9434426	=(1-1/(1+$D$96)^F115)/$D$96	-$ 2,294,151.64
-15000	152.9434426	=(1-1/(1+$D$96)^F116)/$D$96	-$ 2,294,151.64
	0		$ -
(-(D2-D4)*35*40*48 - D4*49.65*40*48)/12	148.0487218	=(1-1/(1+$D$96)^F118)/$D$96/(1+$D$96)	-$ 8,020,687.55
-2000	148.0487218	=(1-1/(1+$D$96)^F119)/$D$96/(1+$D$96)	-$ 296,097.44
	0		$ -
		Total:	$ 52,761,878.57

Figure 26: TVM Conversions with Optimized NPV

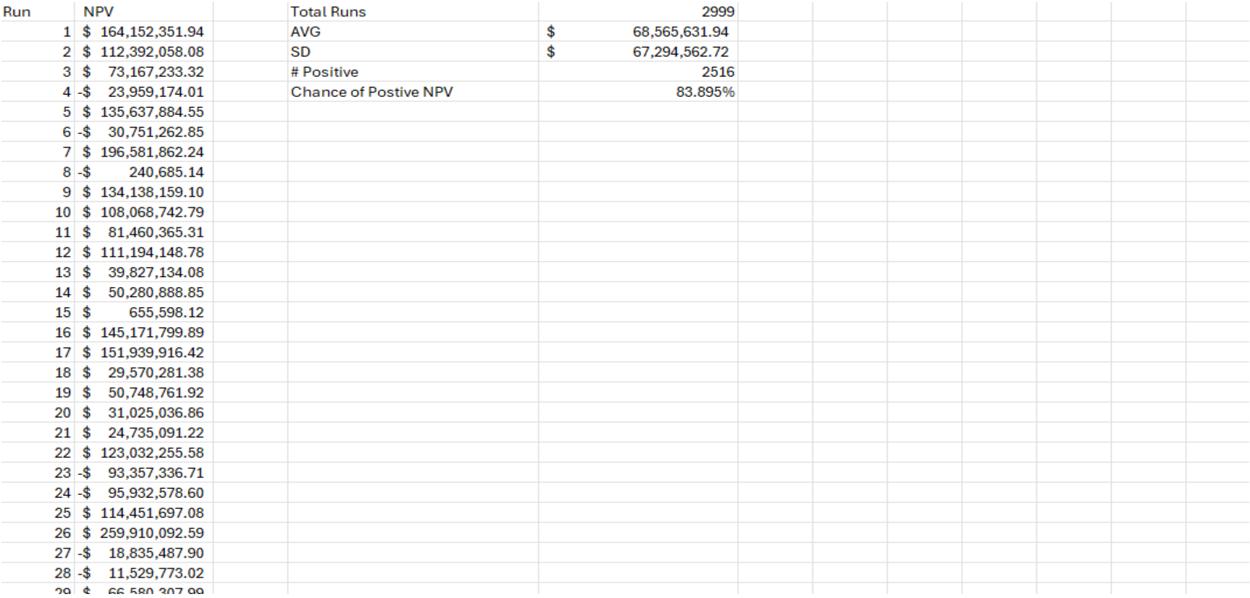
As can be seen, our optimized model has all mitigation strategies enabled with an NPV of around $53,000,000. These optimized variables must be placed back into our stochastic model to set up a series of Monte Carlo simulations. However, we discovered that, other than the mitigation strategies being enabled, our optimized variables had remained unchanged. This was because our optimum represented the maximum amount of profit possible, so the introduction of risks and their impacts only decreased the maximum amount possible. Therefore, no more iterations of optimization were necessary. The values obtained through the optimization were placed back into the stochastic model.

Enabling our mitigation strategies on the stochastic model, we were nearly ready to perform our Monte Carlo simulations. We first had to convert the chance of risks of occurring from an if-condition involving the RAND function into a normal random variable with expected values associated with their respective risks and a standard deviation of 3%. While the expected values are self-explanatory, the standard deviations are more subtle. This value was chosen partly based off the examples during lecture but was mostly decided based off the sensitivity of the NPV with respect to the impacts of these risks. If a large standard deviation were chosen, the NPV would vary greatly to both extremes, making an effective analysis of the results impossible.

Random Variables (for MC modelling)	
Shortage of Materials roll:	1.049686691
Shortage of silicon chips roll:	0.932413491
Housing market collapse roll:	0.989450753

Figure 27: Normal Random Variables used for Stochastic Modelling

With this, we were finally ready to perform Monte Carlo simulations. Referencing the stochastic NPV sum cell in a new sheet, we used the What-If data table analysis to run our stochastic analysis 2999 times. Using the built-in Excel functions, we found the average, standard deviation, and the number of positive NPV's in the results column.



Run	NPV
1	$ 164,152,351.94
2	$ 112,392,058.08
3	$ 73,167,233.32
4	-$ 23,959,174.01
5	$ 135,637,884.55
6	-$ 30,751,262.85
7	$ 196,581,862.24
8	-$ 240,685.14
9	$ 134,138,159.10
10	$ 108,068,742.79
11	$ 81,460,365.31
12	$ 111,194,148.78
13	$ 39,827,134.08
14	$ 50,280,888.85
15	$ 655,598.12
16	$ 145,171,799.89
17	$ 151,939,916.42
18	$ 29,570,281.38
19	$ 50,748,761.92
20	$ 31,025,036.86
21	$ 24,735,091.22
22	$ 123,032,255.58
23	-$ 93,357,336.71
24	-$ 95,932,578.60
25	$ 114,451,697.08
26	$ 259,910,092.59
27	-$ 18,835,487.90
28	-$ 11,529,773.02
29	$ 66,580,307.99

Total Runs		2999
AVG	$	68,565,631.94
SD	$	67,294,562.72
# Positive		2516
Chance of Postive NPV		83.895%

Figure 28: Monte Carlo Simulations

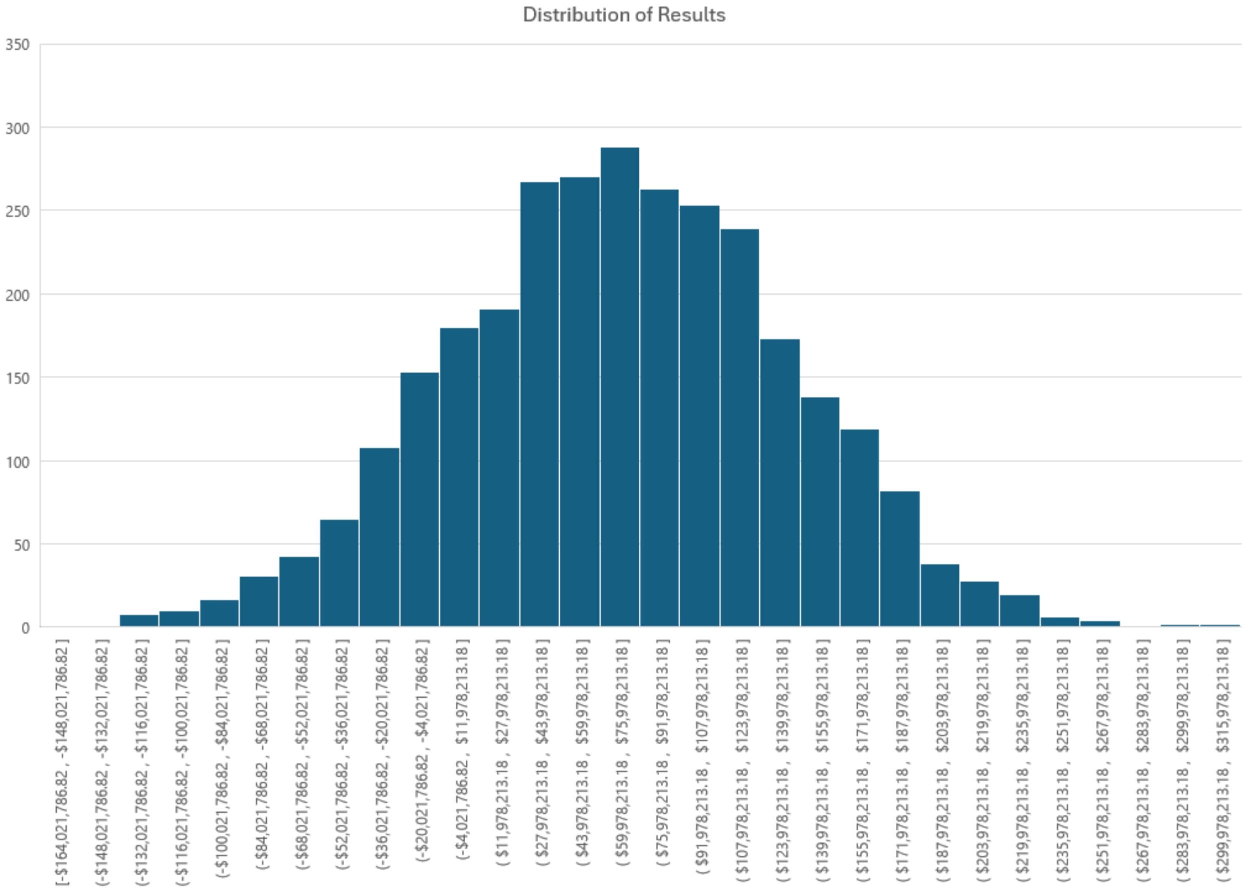


Figure 29: Histogram of NPV values

To summarize, we converted our initial stochastic model into a deterministic one using the expected values of the variables impacted by our risks. This model was optimized, and the resulting values returned to the stochastic model. The risks were converted into normal random variables to allow for variation in the output to model the uncertainty we had in these risks. With this new stochastic model, we ran 2999 simulations using the What-If tool, with the results displayed above. Our project has around an 85% chance of being profitable, with an average NPV and standard deviation of around $67 million. This seems like an incredibly promising result, but one must keep in mind that these results come from assumptions of assumptions of assumptions. This certainly does not reflect the reality of the project, only provides some groundwork for further analysis to be justified and pursued. Furthermore, a significant portion of the distribution has a negative NPV, which is something potential investors may notice first.

12. Final Recommendations

The final optimization process factored in the impacts of project planning, the time value of money for net present value, as well as the risk management of the project, regarding its final net value function. Over the weeks, we developed our NVF and performed a sensitivity analysis on our key decision variables, performed an optimization on this function after factoring in non-linear behavior of our decision variables, converted into a task list and included risks associated with the project, and ran Monter Carlo simulations on our final NPV to determine the likelihood of profitability.

Overall, after running the final optimization excel document with the Monte-Carlo simulations for Stochastic Sensitivity analysis over 2999 iterations, and factoring in all aspects of the project's exploration, the final conclusions were found. The project is producing an average Net Present Value of around $67.9 million over the project's lifetime, of running our prefabricated concrete component company for 20 years, targeting supply for the housing industry in Ontario for the foreseeable future. In conclusion, after counting the number of positive NPV's and comparing against the project's total, it is evident that our project has around an 85% chance of being profitable. Therefore, after completing the final optimization and through the project's in-depth economic analysis outline in this report, the economic viability of the project proves to be feasible.

As a result of the combined overwhelmingly positive NPV and large percentage chance of profitability, it can be stated with confidence that this project is indeed worth pursuing. Of final note, the knowledge that multiple assumptions were factored into the economic assessment, makes it imperative that before approving this project, a much more extensive analysis would need to be conducted to solidify our assumptions and provide the most accurate NPV, to best match realistic projections.

Appendix

Section 1 Technical Analysis

Section 1.1 - Karol Lukowski (Civil Engineering)

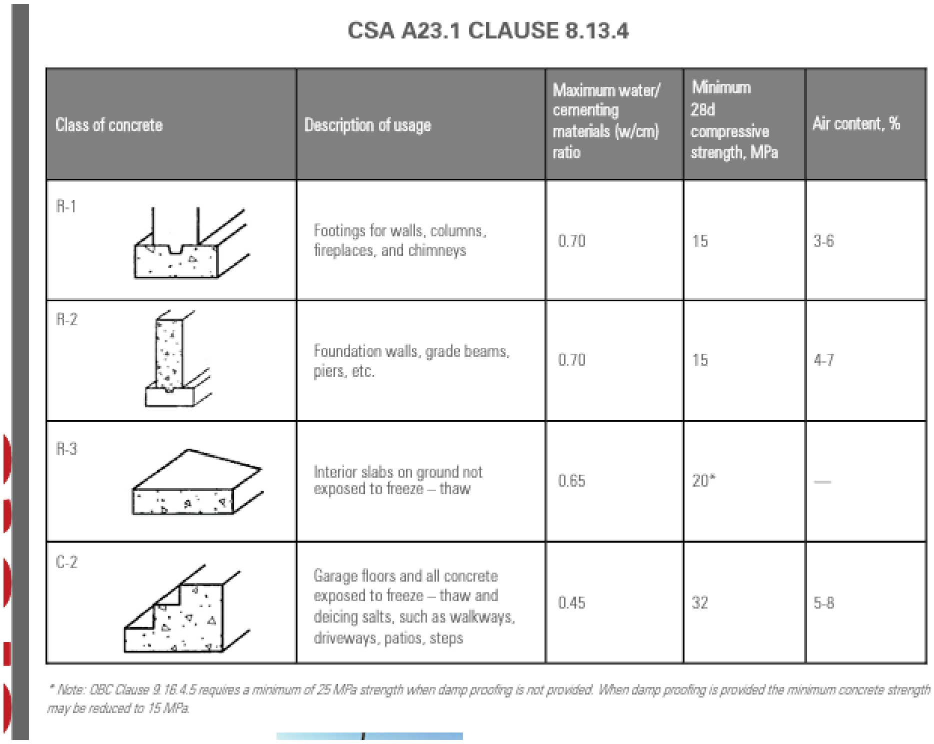
Concerning Safety Adaptation and Quality Control in Design for the Assembly of Prefabricated (Pre-Cast) Modular Concrete Components created in the factory.

Referencing course material from 3P04: Civil Engineering Materials and Design: As stated in the course calendar, concerning: “Characteristics, behavior and use of Civil Engineering materials: **concrete**, steel, wood, and composites; Physical, chemical and mechanical properties; Quality control and material tests; Concepts of structural design, limit states design, estimation of structural loads.”
-ref. course outline

Safety Features:

- code compliance and application

CSA A23.3 – Design of concrete structures CSA A23.4 – Precast concrete – Materials and construction [14]



CSA A23.1 CLAUSE 8.13.4

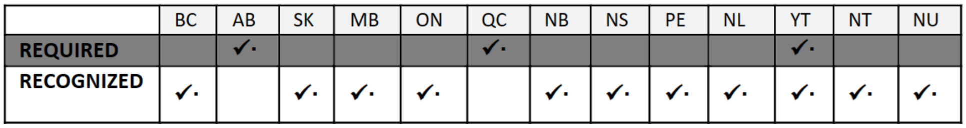
Class of concrete	Description of usage	Maximum water/ cementing materials (w/cm) ratio	Minimum 28d compressive strength, MPa	Air content, %
R-1	Footings for walls, columns, fireplaces, and chimneys	0.70	15	3-6
R-2	Foundation walls, grade beams, piers, etc.	0.70	15	4-7
R-3	Interior slabs on ground not exposed to freeze – thaw	0.65	20*	—
C-2	Garage floors and all concrete exposed to freeze – thaw and deicing salts, such as walkways, driveways, patios, steps	0.45	32	5-8

* Note: OBC Clause 9.16.4.5 requires a minimum of 25 MPa strength when damp proofing is not provided. When damp proofing is provided the minimum concrete strength may be reduced to 15 MPa.

[10]

- <u>Building code specifically for prefabricated construction, also in relation to providing service for the residential building sphere</u>

"This table shows where CSA A277 certification is REQUIRED by a province or territory—as in Alberta, Quebec and the Yukon—and where it is RECOGNIZED or ACCEPTED—either by provincial/territorial regulation or through municipal policy or regulation."



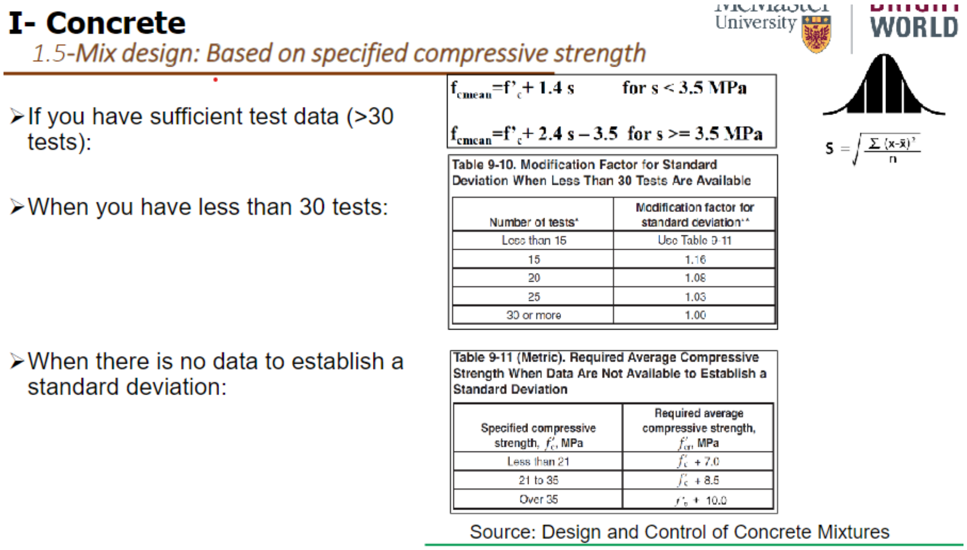
	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	YT	NT	NU
REQUIRED		✓				✓					✓		
RECOGNIZED	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓

[15]

<u>-safety buffers in design</u>

Regarding the concept of uncertainty in design, a crucial aspect taught from my design course. In practicality, this is applied in the form of determining functional strength through testing, thereby predicting giving a buffer with a set functional strength, and then establishing a design strength created from the mix design. Difficulties arise as costs increase with higher strength concrete, hence the need to evaluate if the functional strength may be modified depending on which component of the residential development is the prefabricated component being utilized for.

The functional strength



I- Concrete

1.5-Mix design: Based on specified compressive strength

➢If you have sufficient test data (>30 tests):

$f_{cmean} = f'_c + 1.4\ s$ for s < 3.5 MPa

$f_{cmean} = f'_c + 2.4\ s - 3.5$ for s >= 3.5 MPa

$s = \sqrt{\frac{\Sigma (x-\bar{x})^2}{n}}$

➢When you have less than 30 tests:

Table 9-10. Modification Factor for Standard Deviation When Less Than 30 Tests Are Available

Number of tests*	Modification factor for standard deviation**
Less than 15	Use Table 9-11
15	1.16
20	1.08
25	1.03
30 or more	1.00

➢When there is no data to establish a standard deviation:

Table 9-11 (Metric). Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Specified compressive strength, f'_c, MPa	Required average compressive strength, f'_{cr}, MPa
Less than 21	f'_c + 7.0
21 to 35	f'_c + 8.5
Over 35	f'_c + 10.0

Source: Design and Control of Concrete Mixtures

F prime c = specified compressive strength at 28 days
F prime c r = required average compressive strength from three tests cylinders
Assuming low range slump = 75 mm

Quality Control:

-mix design through materials used and different means of prefabricated concrete formation for pre-cast concrete. Meeting CSA specifications for following industry standards as a supplier/factory.

Depending on the applications of the selected client needs:
Various parameters are outlined for selecting the appropriate mix design and are characterized by a measure known as the mix design's exposure conditions, which is labeled as the Performance-Based Specifications for the Concrete.

CSA A23.1 – Concrete materials and methods of concrete construction (attached are Tables 1 and 2)

CSA A23.1 Table 1

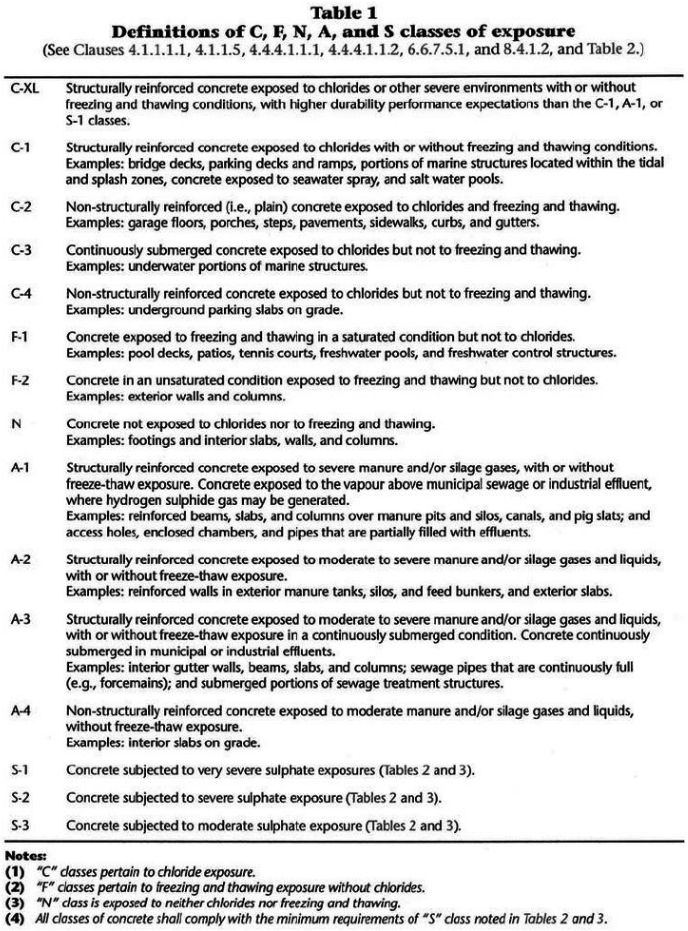


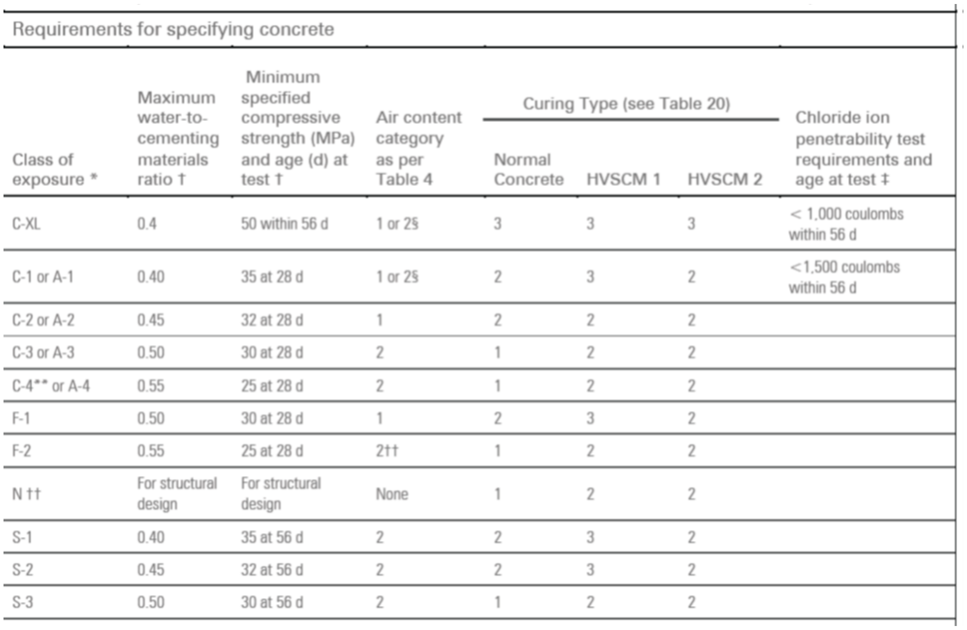
Table 1
Definitions of C, F, N, A, and S classes of exposure
(See Clauses 4.1.1.1.1, 4.1.1.5, 4.4.4.1.1.1, 4.4.4.1.1.2, 6.6.7.5.1, and 8.4.1.2, and Table 2.)

C-XL	Structurally reinforced concrete exposed to chlorides or other severe environments with or without freezing and thawing conditions, with higher durability performance expectations than the C-1, A-1, or S-1 classes.
C-1	Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions. Examples: bridge decks, parking decks and ramps, portions of marine structures located within the tidal and splash zones, concrete exposed to seawater spray, and salt water pools.
C-2	Non-structurally reinforced (i.e., plain) concrete exposed to chlorides and freezing and thawing. Examples: garage floors, porches, steps, pavements, sidewalks, curbs, and gutters.
C-3	Continuously submerged concrete exposed to chlorides but not to freezing and thawing. Examples: underwater portions of marine structures.
C-4	Non-structurally reinforced concrete exposed to chlorides but not to freezing and thawing. Examples: underground parking slabs on grade.
F-1	Concrete exposed to freezing and thawing in a saturated condition but not to chlorides. Examples: pool decks, patios, tennis courts, freshwater pools, and freshwater control structures.
F-2	Concrete in an unsaturated condition exposed to freezing and thawing but not to chlorides. Examples: exterior walls and columns.
N	Concrete not exposed to chlorides nor to freezing and thawing. Examples: footings and interior slabs, walls, and columns.
A-1	Structurally reinforced concrete exposed to severe manure and/or silage gases, with or without freeze-thaw exposure. Concrete exposed to the vapour above municipal sewage or industrial effluent, where hydrogen sulphide gas may be generated. Examples: reinforced beams, slabs, and columns over manure pits and silos, canals, and pig slats; and access holes, enclosed chambers, and pipes that are partially filled with effluents.
A-2	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure. Examples: reinforced walls in exterior manure tanks, silos, and feed bunkers, and exterior slabs.
A-3	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure in a continuously submerged condition. Concrete continuously submerged in municipal or industrial effluents. Examples: interior gutter walls, beams, slabs, and columns; sewage pipes that are continuously full (e.g., forcemains); and submerged portions of sewage treatment structures.
A-4	Non-structurally reinforced concrete exposed to moderate manure and/or silage gases and liquids, without freeze-thaw exposure. Examples: interior slabs on grade.
S-1	Concrete subjected to very severe sulphate exposures (Tables 2 and 3).
S-2	Concrete subjected to severe sulphate exposure (Tables 2 and 3).
S-3	Concrete subjected to moderate sulphate exposure (Tables 2 and 3).

Notes:
(1) *"C" classes pertain to chloride exposure.*
(2) *"F" classes pertain to freezing and thawing exposure without chlorides.*
(3) *"N" class is exposed to neither chlorides nor freezing and thawing.*
(4) *All classes of concrete shall comply with the minimum requirements of "S" class noted in Tables 2 and 3.*

[16]

CSA A23.1 Table 2



Requirements for specifying concrete

Class of exposure *	Maximum water-to-cementing materials ratio †	Minimum specified compressive strength (MPa) and age (d) at test †	Air content category as per Table 4	Curing Type (see Table 20)			Chloride ion penetrability test requirements and age at test ‡
				Normal Concrete	HVSCM 1	HVSCM 2	
C-XL	0.4	50 within 56 d	1 or 2§	3	3	3	< 1,000 coulombs within 56 d
C-1 or A-1	0.40	35 at 28 d	1 or 2§	2	3	2	<1,500 coulombs within 56 d
C-2 or A-2	0.45	32 at 28 d	1	2	2	2	
C-3 or A-3	0.50	30 at 28 d	2	1	2	2	
C-4** or A-4	0.55	25 at 28 d	2	1	2	2	
F-1	0.50	30 at 28 d	1	2	3	2	
F-2	0.55	25 at 28 d	2††	1	2	2	
N ††	For structural design	For structural design	None	1	2	2	
S-1	0.40	35 at 56 d	2	2	3	2	
S-2	0.45	32 at 56 d	2	2	3	2	
S-3	0.50	30 at 56 d	2	1	2	2	

Selection of a relevant exposure condition will modify the mix design process for that specific mix, hence change the pricing of assembly and production due to factors such as changing material costs, with variations in aggregates and admixtures (chemicals applied to the concrete) for example, as well as time to batch each separate concrete mix.

- testing methods

Non-invasive and efficient methods such as the impact/Schmidt hammer test are examples of tests used to monitor quality and would concern costs such as QA (quality assurance) and further testing of product after assembly, to ensure top product.

CSA A23.2 – Test methods and standard practices for concrete

- environmental impact considerations, while maintaining structural and technical integrity of the concrete

With the focus on trying to be as environmentally friendly with a reusability factor of producing precast concrete, LCA of the concrete and materials, and reducing carbon footprint of the product such as using carbon sink concrete technology, reference a new Quebec company, “Carbi-Crete” that is doing so, explored these applications in class for CIVENG 3P04.

“By incorporating biochar into concrete, they are exploring the potential of CO2-neutral or even CO2-negative concrete. For optimal applicability, they process the biochar into pellets and use them to replace conventional aggregates.” [17]

“CarbiCrete announced today that Enviro-access, a Canadian leader in the quantification of environmental impacts, has completed an environmental benefits report validating that CarbiCrete’s concrete block manufacturing process can eliminate more than 100% of the global warming potential (GWP) of concrete blocks, compared to those made using a conventional, cement-based process.” [18]

Resulting Changes to NVF:

- code compliance and functional strength with differing compressive strengths, research how much it costs for different strengths (done)
- changing costs based off design parameters for differing mix designs with varying exposure classes, research how much it costs for differing applications (done)
- NVF benefit added with the positive environmental aspect of using the concrete as a carbon sink (done)
- NVF benefit with the incentives gained from carbon capture and using the concrete as a carbon sink (done)

Pre-Cast Concrete Products for Residential Construction

Assuming 4 general applications (4 classes) of prefabricated concrete product for the residential construction (based off the most common mix designs for residential construction in Ontario, as per the Ready-Mix Concrete Association of Ontario (RMCAO) [10]

- R-1: footings for walls, columns, fireplaces, and chimneys. 0.70 w/c ratio, 15 MPa
- R-2: foundation walls, grade beams, piers. 0.70 w/c ratio, 15 MPa
- R-3: interior slabs on ground not exposed to freeze-thaw. 0.65 w/c ratio, 20 MPa
- C-2: garage floors and all concrete exposed to freeze-thaw and deicing salts, such as walkways, driveways, patios, steps. 0.45 w/c ratio, 32 MPa

Concrete Revenue

RESIDENTIAL HOUSING Price, based off a local concrete supplier in the GTA/Ontario Region
- Footings & Walls 15 MPa $215.00/m3 0.70w/c (OBC) Class R1 & R2
- Footings & Walls 20 MPa $223.00/m3 0.70w/c (OBC) Class R1 & R2
- Basement Floors 25 MPa 0.65w/c R3 (OBC) $230.00/m3
- 32 MPa C-2, S-2 0.45w/c $253.00/m3 [11]

Concrete Revenue = ($215.00/m3*R-1) + ($223.00/m3*R-2) + ($230.00/m3*R-3) + ($253.00/m3*C-2)
Total Concrete Volume Produced (m3) = R-1 + R-2 + R-3 + C-2

1300 sq ft / house * 310 houses = 1300 sq ft/house * (0.0929m3/1 ft2) * 310 houses/year = approx. 37,438.7m^3 total volume concrete produced/ per year

Concrete Price (price of materials and mix design)
Assuming this pricing focuses solely on the material and mix design costs (labor force and machinery overhead is neglected here as it is considered with the other aspects of the NVF)

For a standard concrete mix

"To calculate the 1 cubic meter concrete rate, Let us consider the concrete mix of M 20 (1:1.5:3), where, 1 is the part of cement, 1.5 is the part of fine aggregates and 3 is the part of coarse aggregates having a size of 20mm. The water-cement ratio adopted for mixing concrete is 0.45.

Assumptions

Bulk Density:

1. **Cement = 1500 kg/m^3**
2. **Sand = 1700 kg/m^3**
3. **Coarse aggregates = 1650 kg/m^3**

Materials Calculation For 1 m3 Concrete

Dry volume = Wet Volume X 1.52

Volume of Cement = (Dry volume X Cement ratio)/ Sum of ratio

Volume of Cement = (1 X 1.52)/(1+1.5+3)
= 1. 52/5.5

= 0.28m^3

Weight of the cement = 0.28 X 1500

= 420 kg.

Volume of Sand = (1.5 X 1.54)/(1+1.5+3)
= 2.31/5.5
= 0.42m^3
Weight of the Sand = 0.42 X 1700
= 714 kg.

Volume of Course Aggregate= (3 X 1.54)/(1+1.5+3)
= 4.62/5.5
= 0.84m^3

Mass of the Coarse Aggregate = 0.84 X 1650
= 1386 kg.

3. Cost Calculation

Cost of cement for 1 m^3 =
No of Bags = 420/50
=8.4 Bags

As per the present market rate, the cost of 1 bag of cement is taken as Rs: 330
= 8.4 X 430
= 3612 Rs

Cost of sand for 1 m^3 =
As per the present market rate, the cost of 1 m^3 of sand is taken as Rs: 1200
= 0.42 X 1200
= 504 Rs

Cost of course aggregate for 1 m^3 =
As per the present market rate, the cost of 1m^3 of course aggregate is taken as Rs.1500
= 0.84 X 1500
= 1260 Rs

Therefore, the total cost for 1m3 of M – 20 concrete is
=Cost of cement + sand + coarse aggregate
= 2772 + 504 + 1260 = 4536 Rs.
Say Rs 4500 Rs. or 60 Dollars

Therefore, the Cost of Concrete Work per sq. ft. is 4500 for 1 m3 of concrete volume.

Hence, 1m3 concrete is around 4500 Rs. or 60 Dollars

We can also calculate 1 cft concrete price from 1 m3 concrete price,

We know that 1 m3 is equal to 35.3147 cft.

So, 4500/35.3147 = 127.42 Says 128 Rs. per Cft

Therefore, 1 cft concrete price is 128 Rs. per Cft or 1.70 Dollars Per Cft, and 1 cubic meter concrete cost is 4500 Rs. or 60 Dollars"

Cost of Concrete Production (Material Costs): around $60/m3

Carbon Capture

In fact, of interest is the technology with "concrete - carbon capture and utilization (CCU). In CCU, emissions from the concrete and cement industries, as well as other large emitters, are injected into precast concrete where it is permanently mineralized, and can therefore, replace some of concrete's energy-intensive cement...Several studies have also shown that CO2 cured concrete has greater compressive strength, 10% to 30% more depending on the technology, compared to traditionally cured concrete. Moreover, curing concrete with CO2 could replace the steam that is normally used and thus, reduce energy consumption for concrete products even further." [19]

Environmental Aspect

Assuming from past data sets from 2020, of a standardized mix, which would be like our residential mixes, 73.1 kg C02 are emitted per ton of concrete produced. Hence, utilizing carbon capture technology for concrete production, it would eliminate these additional emissions produced, thus benefiting the environment immensely to prevent the carbon emissions from entering the atmosphere, as well as making use of/ and storing excess carbon into the concrete. [20]

"The weight of 1 cubic meter of concrete in metric tonnes depends on its density, which typically ranges from 2.2 to 2.5 metric tonnes per cubic meter." [21]

Environmental Cost: assume density of concrete is around 2.5 metric Tonnes per cubic meter

Therefore, 73.1kg C02/per ton of concrete produced *(2.5 metric tonnes/per cub meter) = 182.5kg C02 emitted in production/ per cubic meter.

Economic Aspect

Carbon credits serve as a financial benefit with our proposed solution implementing carbon capture technology in the prefabricated concrete production process.

Receiving financial incentives from the government for the major carbon emissions innovation would benefit the business and operation of the company as a private entity.

Carbon offsets in Canada vary in price, depending on many factors. For example, the location of the project and the current market demand can affect the price. However, emission credits typically cost between $40-$50 per ton. [22]

Carbon capture incentives = $50 per ton * 1 year/tonnes of concrete produced *metric tonnes/cubic meter of concrete

Section 1.2 - Dexter Holst (Mechatronics Engineering)

-Power of robotics (power equation, 2E04, Dexter)

https://www.intel.com/content/www/us/en/robotics/robotic-arm.html
https://www.universal-robots.com/in/blog/types-of-robotic-arms/
-According to universal-robots, articulated robot arm used for industrial automation

https://www.motoman.com/getmedia/36690f87-7e83-4b05-8381-060709a1deaa/180704-1CD.pdf.aspx
-From sources, 20-hour working day for one arm operating at 240V and drawing 20A (AC) will require E = P*t = I_rms*V_rms*t = (240V/sqrt(2))*(20A/sqrt(2))*(20h)*(365d) = 17 520 kwh/year
-Assuming operation in Ontario, where electricity costs on average 14.1c/kwh (https://www.energyhub.org/electricity-prices/)
-Each arm has flat cost of about $200,000
https://www.evsint.com/industrial-robotic-arm-cost/

Cost = E*14.1c/kwh + FlatCost = $2470/year/robot arm + $200,000/robot arm

Section 1.3 - Liam Walker (Mechatronics Engineering)

-Electricity needed to cool factory (thermodynamic analysis, might have to assume how much heat generated by components) (Efficiency of Refrigeration Cycle, 2N03, Liam)

COP of HAVC System: 2.3 - 3.5 (https://en.wikipedia.org/wiki/Coefficient_of_performance#:~:text=The%20COP%20is%20used%20in,COP%20of%202.3%20to%203.5.)

Average Ontario Electricity Price: $0.182/kWh (https://www.oeb.ca/consumer-information-and-protection/electricity-rates/historical-electricity-rates)

Human hourly heat production (Labor): 200 W (https://www.researchgate.net/publication/271444362_Predicting_Energy_Requirement_for_Cooling_the_Building_Using_Artificial_Neural_Network)

Computer Dissipated heat: 150 W

Wattage of industrial robot: 5000 W (https://www.ti.com/lit/ab/sboa555b/sboa555b.pdf?ts=1706988178445&ref_url=https%253A%252F%252Fwww.google.com%252F#:~:text=The%20industrial%20robots%20typically%20operate,is%20moving%20around%20the%20facility.)

Efficiency of a motor: 80% (https://www.sciencedirect.com/topics/engineering/motor-efficiency#:~:text=Motor%20efficiency%20varies%20between%2070,heat%2C%20which%20is%20mostly%20unusable.)

Unit cost: $12303.85 (https://hvactrust.ca/product/bosch-bovb20-4-5-ton/?gad_source=1&gclid=Cj0KCQiA5fetBhC9ARIsAP1UMgHTvNDVJVpodWQpxMXA0KBaohbC-Fe854jvMrP-QJSgKWqtb7YQTqAaAolcEALw_wcB)

Unit Lifetime: 15 years (https://www.unitedmech.com/blog/commercial-hvac-life-expectancy#:~:text=Commercial%20HVAC%20Equipment%27s%20Expected%20Lifespan,is%2015%20to%2020%20years.)

HVAC cooling capacity: 15826 W (https://hvactrust.ca/product/bosch-bovb20-4-5-ton/?gad_source=1&gclid=Cj0KCQiA5fetBhC9ARIsAP1UMgFajLZLdkdUmPAv4HRxb1maPvg4Btou9KtBlnoZLiZOIv1U9YiCTjsaAhD6EALw_wcB)

If an industrial robot has a similar efficiency to that of an electric motor and most of the lost energy is through heat:

$$P_{lost} = 5000W * (1 - 0.8) = 1000W$$

$$Q_L = 200W * H + 1000W * R$$

$$W_{in} = \frac{Q_L}{COP_R} = \frac{200 * H + 1000 * R}{2.3}$$

$$W_{in(kWh)} = \frac{W_{in}}{1000} = \frac{200 * H + 1000 * R}{2300}$$

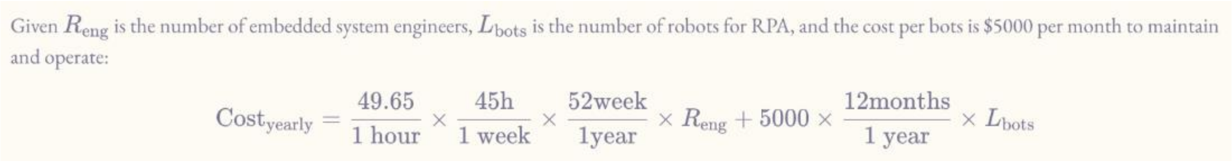
$$C_{initial} = \frac{\$12303.85}{15yr} * \left[\frac{200 * H + 1000 * R}{2.3} W * \frac{1}{15826} W_{Unit\ Cooling\ Capacity}\right] = \$820.26 * \left[\frac{200 * H + 1000 * R}{2.3 * 15826}\right] /year$$

$$C_{yearly} = \$820.26 * \left[\frac{200 * H + 1000 * R}{2.3 * 15826}\right] + \$0.182 * \left(\frac{200 * H + 1000 * R}{2300}\right) kWh * 5840\ hrs$$

Section 1.4 - Aaron Pham (Software Engineering)

-Thread-safe software for controlling embedded system (Concurrency System Design, 3BB4)
Embedded system design engineer salary per $49.65/h
(https://www.ziprecruiter.com/Salaries/Embedded-Software-Engineer-Salary--in-Ontario)

Work-hours: 45h/w
RPA (Robotic process automation) as a service: can cost $5000-15000/month per robot. (https://itrexgroup.com/blog/robotic-process-automation-cost/#:~:text=Given%20that%20robotic%20process%20automation,to%20achieve%20company%2Dwide%20automation.)



Given R_{eng} is the number of embedded system engineers, L_{bots} is the number of robots for RPA, and the cost per bots is $5000 per month to maintain and operate:

$$\text{Cost}_{\text{yearly}} = \frac{49.65}{1\ \text{hour}} \times \frac{45\text{h}}{1\ \text{week}} \times \frac{52\text{week}}{1\text{year}} \times R_{\text{eng}} + 5000 \times \frac{12\text{months}}{1\ \text{year}} \times L_{\text{bots}}$$

Section 1.5 - Update to NVF in optimization analysis

For the optimization analysis, the number of houses sold was reworked to the following function:

NumHousesSold = ceiling (70.22*NumRobots*exp(-NumRobots/12) +
310*(1-2*exp(-NumRobot /24)))

The first term in the ceiling function creates a rapidly rising then falling exponential term that peaks around our specified max production of houses (~310) and begins rapidly falling to zero. To arrest the descent, the second term adds the constant 310 after a certain rising time specified by the exponent in the second exponential. The goal of this term was to simulate a rise from zero production of houses with no robotic arms to a constant production of houses, since productivity will cap no matter how many robots you have.

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