buildings

MDPI

Supplementary

Data-Driven Design as a Vehicle for BIM and Sustainability Education

Summary: This project is worth X% of your term and will be completed in pairs. It is intended to complement your studio project by integrating data-driven design elements and a multi-disciplinary (sustainability and cost) perspective to your massing study at a relatively simple level. This project is expected to take 15-20 hours; if you are spending longer than this, re-read this document to ensure you are not going into further detail than required and/or seek GA help on the software use.

This document provides all necessary information regarding project requirements and expectations. Refer to the BIM Curriculum Enhancement Toolkit for additional resources (i.e. video tutorials for the Revit method) to provide you with a "how to" for the project. To reflect current industry practice, either Revit (typically used for material take-offs) and/or Rhino (more generally used for massing) may be used; refer to the method table below. Should you have any questions, please reach out to your GAs.

Learning Outcomes: This project has been designed to provide an opportunity to engage with multiple drivers of design, namely construction cost, and energy efficiency and to develop an understanding of how they are affected by massing and material choices. Because of the tie to studio, a rational response to site is also expected, so please no monolithic uninhabitable blocks!

Project Expectations: In this project, you will analyse and refine your studio massing design to reduce capital cost and improve energy performance (decreased lifetime energy cost). This project will make use of two supporting tools: BIM (Revit or Grasshopper) and a BIM-based energy modeling tool (Green Building Studio (GBS) in Revit or Ladybug in Rhino)). GBS cannot be run on Cad Lab computers and will require an Autodesk login to run. Rhino requires Ladybug (a Grasshopper plug-in and requires students to have familiarity with Grasshopper), so it is not recommended for students without this background. To extract data from the Revit model, you need to first create schedules and then go the "R" button -> Export -> Reports -> Schedule and save as a delimited text file, which you can then import into Excel.

The project will progress as-follows:

1. Partner #1 creates a model of their preferred studio project massing (Massing 1) and analyse as-follows:
    a. Create a cost/area parameter and it to your wall and window families (only wall cladding variations are costed)
    b. Create window and wall schedules for your massing and calculate the total cost of your envelope.
    c. Estimate the life cycle cost of your building using the energy output (assume 50-year building life at 5% interest rate if using the Rhino/Ladybug approach) on a \$/m2 basis.
    d. Note the energy use intensity (EUI; ekWh/m^2/yr) for this base massing.
2. Create a variation (Massing 1B) with minor form and envelope changes to reduce lifetime energy and capital costs as well as EUI. You MUST maintain the same gross floor area.
3. Partner #2 also completes steps 1 & 2 with for their massing (Massings 2 and 2B) and summarizes their conclusions regarding the impact of massing (form, compactness,

orientation) and glazing (extent, orientation) on their results. Again, the same gross floor area must be used.

4. Compare the findings from the analysis of the first four massings to inform an "optimized" design that is suitable for your project. This is an iterative process and may require multiple steps to achieve the required EUI, per the attached rubric. You are encouraged to document lessons learned from intermediate iterations as the level of analysis is a key factor for evaluation in this project.

5. Present your massing progressions (including results and discussion of lessons learned from each step) and final massing on a 24x36 poster (portrait orientation, submitted as a PDF only).

Rubric: The project is marked out of 60 and worth X% of your term per the attached rubric. Note that a portion of the mark will be related to the energy use intensity achieved on the final design (minimum criteria of 150kWh/m2/year with additional marks for improved performance). Each partner must label their preliminary two massings and provide their own discussion of their findings (Steps 1 & 2 or 3, respectively) as these will be the basis for the individual portion of the mark.

Overall Project Expectations

- Critical thought and detailed discussion of your findings and the implications of each iteration are the single most important aspect of this project.
- Your refined design and its associate discussion should show clear evidence of your analysis and evaluation of your previous massings, as well as any intermediate process work presented. The highest level of achievement for this project requires that you **create** a new, highly-efficient design by ***analysing*** the performance of the initial massings, ***evaluating*** the performance of each, and ***synthesizing*** the knowledge gained from these steps to inform this refined design.
- Clear communication, spelling and grammar are expected as a given on all project elements.
- No plagiarism. Any project with missing sources or those using uncited information (costs, tables, procedures, standard WBS elements, etc.) will be given a zero and will be reported as suspicion of academic integrity. Failure to use Chicago citation format will result in a 10% penalty, in accordance with the course outline.

Rubric:

Your GAs wil use the rubric provided on the next page to mark this assignment.

Final Notes:

Do not leave this to the last minute. Attempt your preliminary massings as early as possible and make an appointment for guidance from your GA if you are struggling in any way with the software. Your professor is also happy to discuss results that seem unrealistic or do not align with your previous expectations of sustainable design; this could be due to either faulty modeling or a misunderstanding of our climate, and she will be able to clarify this for you.

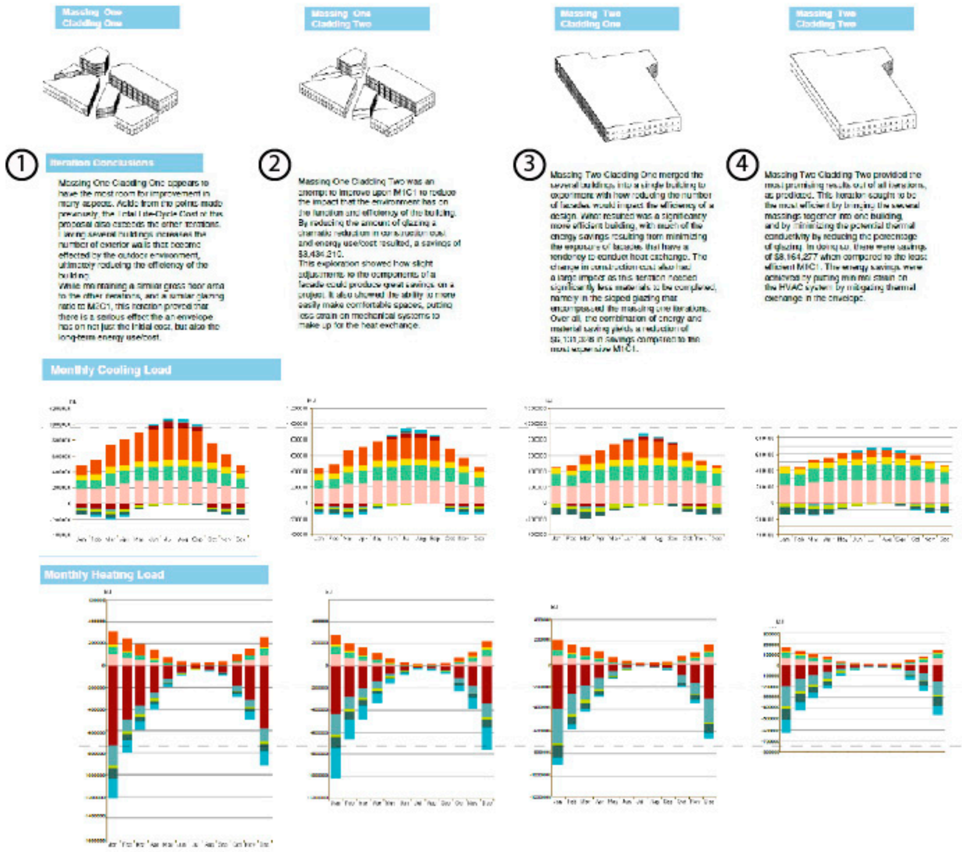

Figure 3. Example of a Factorial Investigation from Year 2 (image used with permission).

Due to the maximum figure size possible within ***Buildings***, the full text from each student work sample has been transcribed to show the extent of student reflection and synthesis present in each. Each figure has been provided and annotated with numbering that refers to the text following.

(1) "Massing Once Cladding One appears to have the most room for improvement in many aspects. Aside from the points made previously, the Total Life-Cycle Cost of this proposal also exceeds the other iterations. Having several buildings increases the number of exterior walls that become effected by the outdoor environment, ultimately reducing the efficiency of the building. While maintaining a similar gross floor area to the other iterations, and a similar glazing ratio to M2C1, this iteration proved that there is a serious effect that (that the) envelope has on not just the initial cost, but also the long-term energy use/cost."

(2) "Massing One Cladding Two was an attempt to improve upon M1C1 to reduce the impact that the environment has on the function and efficiency of the building. By reducing the amount of glazing a dramatic reduction in construction cost and energy use/cost resulted, a savings of $3,434,210. This exploration showed how slight adjustments to the components of a façade could produce great savings on a project. It also showed the ability to more easily make comfortable spaces, putting less strain on mechanical systems to make up for the heat exchange."

(3) "Massing Two Cladding One merged the several buildings into a single building to experiment with how reducing the number of facades would impact the efficiency of a design. What resulted was a significantly more efficient building, with much of the energy savings resulting from minimizing the exposure of facades that have a tendency to conduct heat exchange. The change in construction cost also had a large impact as this iteration needed significantly less materials to be completed, namely in the sloped glazing that encompassed the massing one iterations. Over all, the combination of energy and material saving yields a reduction of $6,131,328 in savings compared to the most expensive M1C1."

(4) "Massing Two Cladding Two provided the most promising results out of all iterations, as predicted. This iteration sought to be the most efficient by bringing the several massings together

into one building, and by minimizing the potential thermal conductivity by reducing the percentage of glazing. In doing so, there were savings of $8,164,277 when compared to the lease efficient M1C1. The energy savings were achieved by putting minimal strain on the HVAC system by mitigating thermal exchange in the envelope."

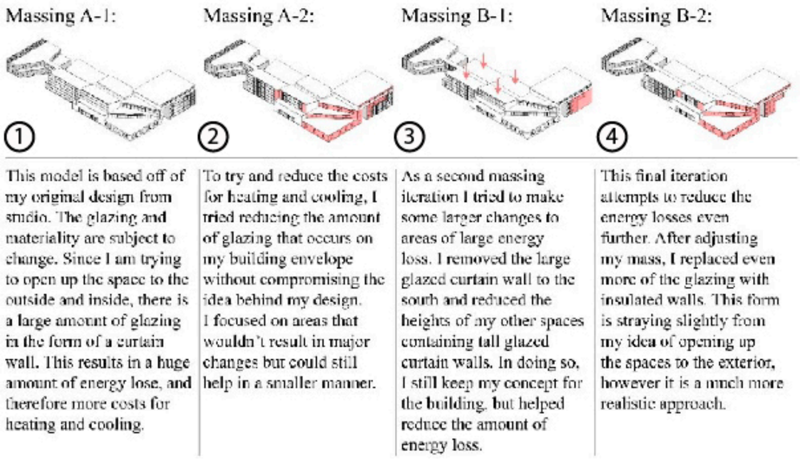

Figure 4. Factorial Investigation – Case Study #3 (Used with permission).

(1) "This model is based off of my original design from studio. The glazing and materiality are subject to change. Sine I am trying to open up the space to the outside and inside, there is a large amount of glazing in the form of a curtain wall. This results in a huge amount of energy lose, and therefore more costs for heating and cooling.:

(2) "To try and reduce the costs for heating and cooling, I tried reducing the amount of glazing that occurs on my building envelope without compromising the idea behind my design. I focused on areas that wouldn't result in major changes but could still help in a smaller manner."

(3) "As a second massing iteration I tried to make some larger changes to areas of large energy loss. I removed the large glazed curtain wall to the south and reduced the heights of my other spaces containing tall glazed curtain walls. In doing so, I still keep my concept for the building, but helped reduce the amount of energy loss."

(4) "This final iteration attempts to reduce the energy losses even further. After adjusting my mass, I replaced even more of the glazing with insulated walls. This form is straying slightly from my idea of opening up the spaces to the exterior, however it is a much more realistic approach."

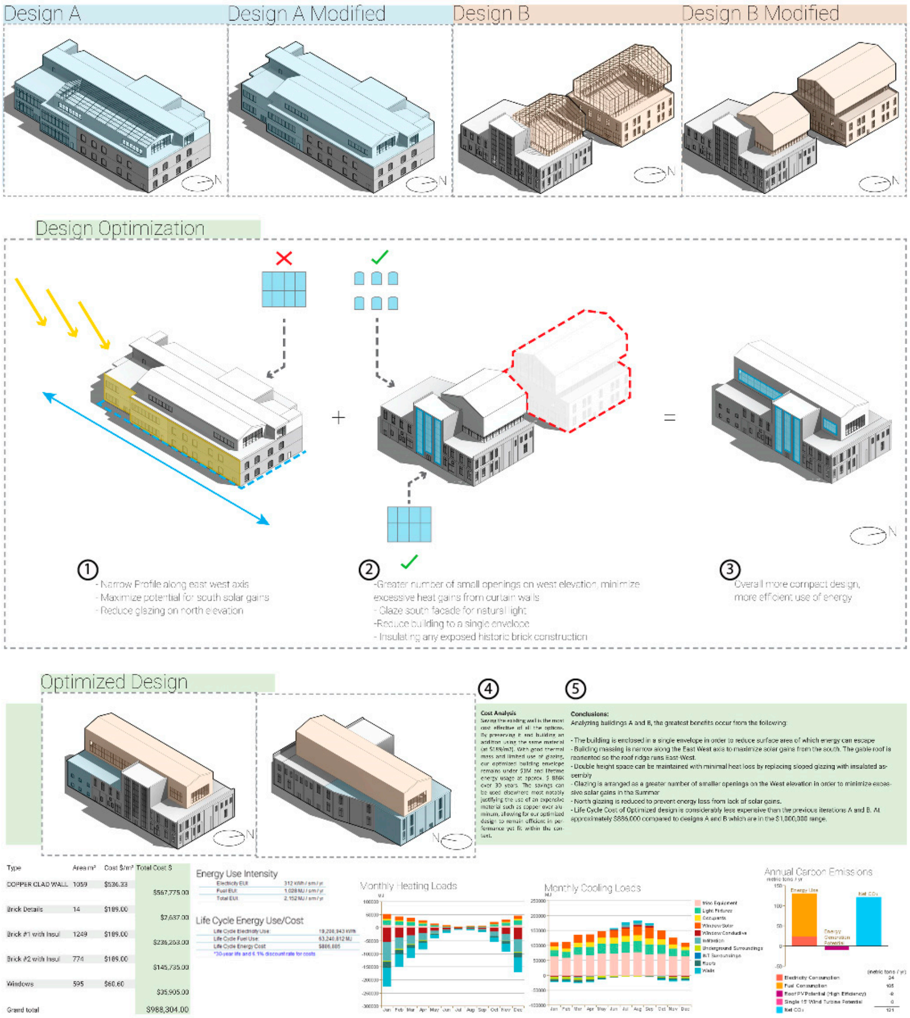

Figure 5. Year 3 Sample Showing Design Development Resulting in an Optimized (Life Cycle Cost + Energy) Design.

(1) "Narrow Profile along East West axis; Maximize potential for South solar gains; reduce glazing on North elevation"

(2) "Greater number of small openings on West elevation; minimize excessive heat gains from curtain walls; Glaze South façade for natural light; Reduce building to a single envelope; Insulating any exposed historic brick construction"

(3) "Overall more compact design, more efficient use of energy."

(4) "Cost Analysis: Saving the existing wall is the most cost effective of all the options. By preserving it and building an addition using the same material (at 189/m2). With good thermal mass and limited use of glazing, our optimized building envelope remains under $1,000,000 and lifetime energy use at approx. $886,000 over 30 years. The savings can be used elsewhere most notable justifying the use of an expensive material such as copper over aluminum, allowing for our optimized design to remain efficient in performance, yet fit within the context."

(5) "Conclusions: Analyzing buildings A and B, the greatest benefits occur from the following: The building is enclosed in a single envelope to reduce surface area of which energy can escape; Building massings is narrow along the East West axis to maximize solar gains from the South. The gable roof is reoriented so the roof ridge runs East-West; Double height space can be maintained with minimal heat loss by replacing sloped glazing with insulated assembly; Glazing is arranged as a greater number of smaller openings on the West elevation in order to minimize excessive solar gains in the Summer; North glazing is reduced to prevent energy loss from lack

of solar gains; Life Cycle Cost of Optimized design is considerably less expensive than the previous iterations A and B. At approximately $886,000 compared to designs A and B which are in the $1,000,000 range.

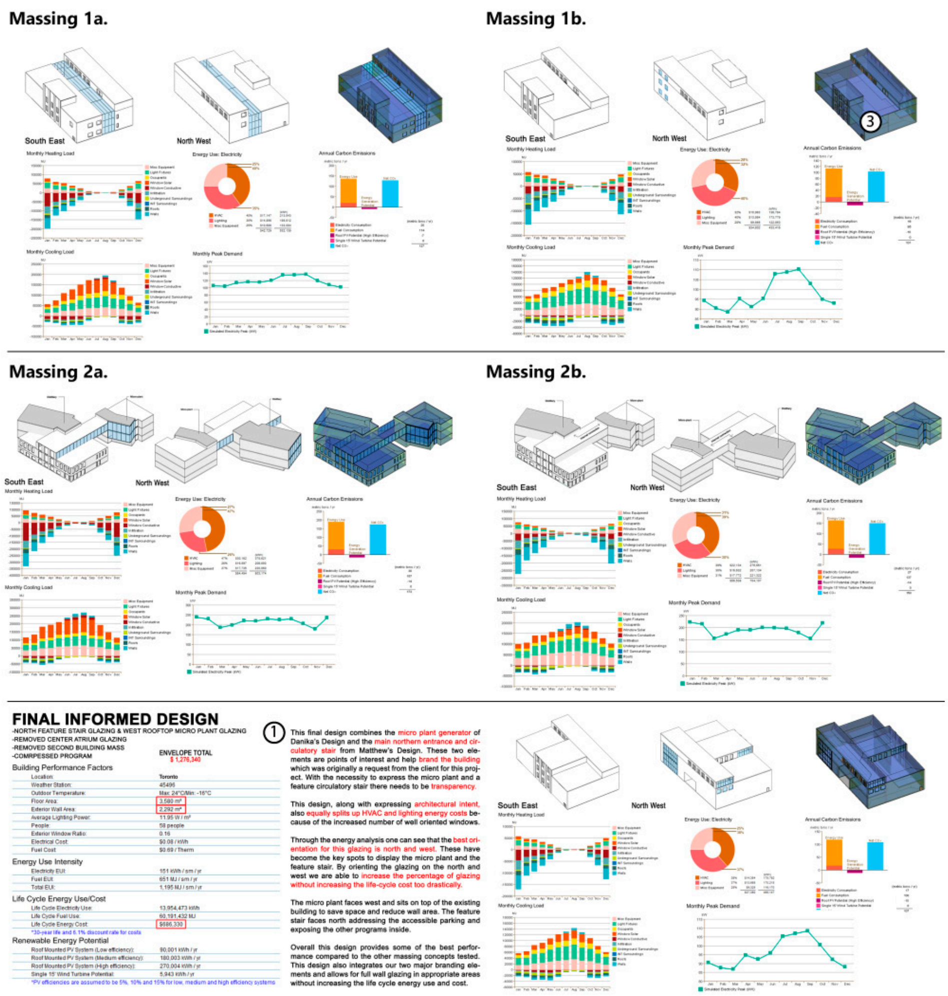

Figure 6. Year 3 Sample Showing Design Development Resulting in an Optimized (Life Cycle Cost + Energy) Design.

(1) "This final design combines the micro plant generator of (student 1)'s Design and the main northern entrance and circulatory stair from (student 2)'s design. These two elements are points of interest and help brand the building which was originally a request from the client for this project. With the necessity to express the micro plant and a feature circulatory stair there needs to be transparency. This design, along with expressing architectural intent, also equally splits up HVAC and lighting energy costs because of the increased number of well oriented windows. Through the energy analysis one can see that the best orientation for this glazing is north and west. These have become the key spots to display the micro plant and the feature stair. By orienting the glazing on the north and west we are able to increase the percentage of glazing without increasing the life-cycle cost too drastically. The micro plant faces west and sits on top of the existing building to save space and reduce wall area. The feature stair faces north addressing the accessible parking and exposing the other programs inside. Overall the design provides some of the best performance compared to the other massing concepts tested. This design also integrates our two major branding elements and allows the full wall glazing in appropriate areas without increasing the lifecycle energy use and cost."

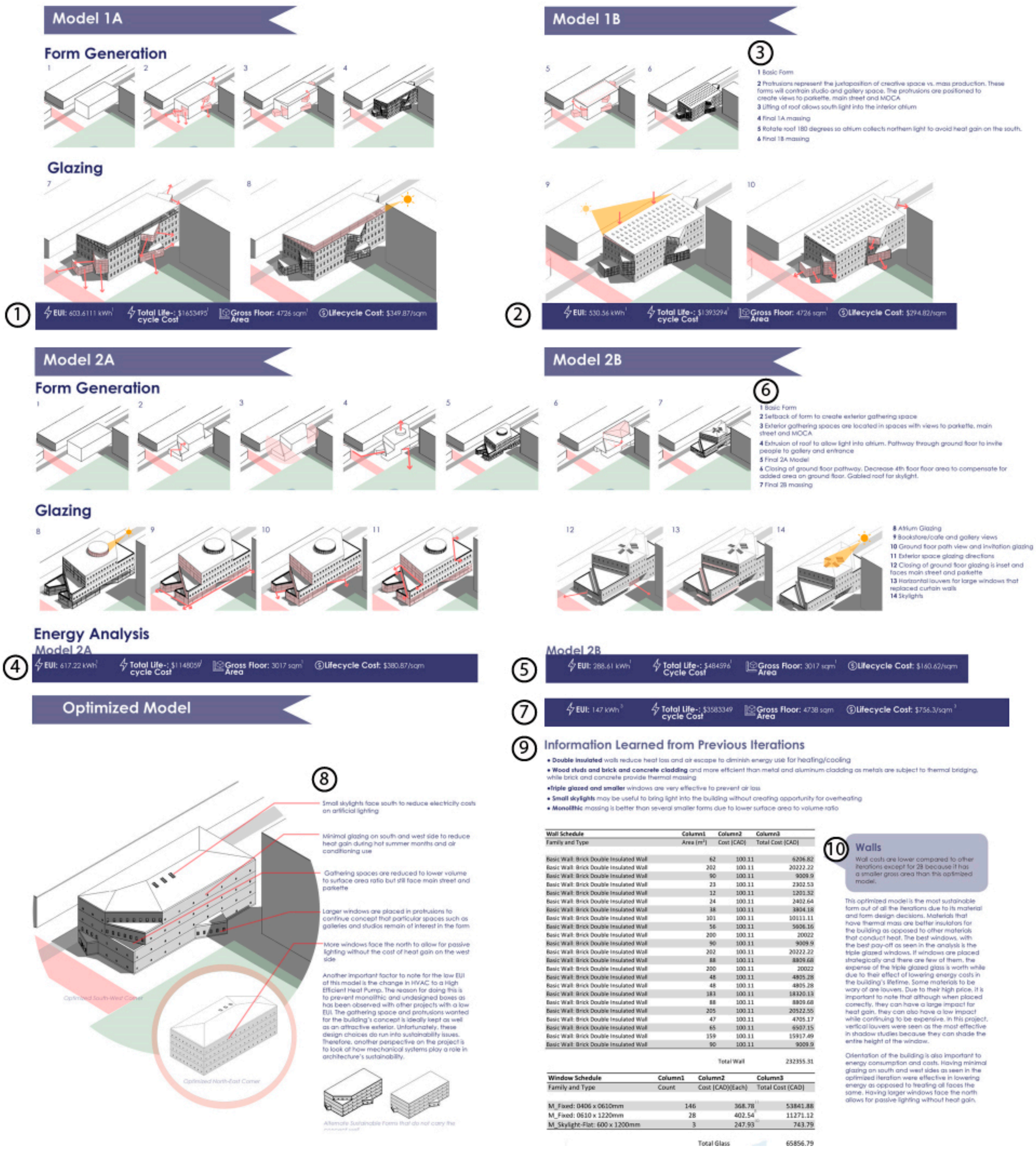

Figure 8. Year 4, Example 2 showing progression (Used with permission (name withheld)).

(1) "EUI: 603.6111 kWh; Total Life Cycle Cost: $1,653,495; Gross Floor Area: 4726sqm; Lifecycle Cost: $349.87/sqm"

(2) "EUI: 530.56 kWh; Total Life Cycle Cost: $1,393,294; Gross Floor Area: 4726sqm; Lifecycle Cost: $294.82/sqm"

(3) "1: Basic Form; 2: Protrusions represent the juxtaposition of creative space vs. mass production. These forms will contain studio and gallery space. The protrusions are positioned to create to create views to parkette, main street and MOCA; Lifting of roof allows south light into the interior atrium; Final 1A massing; Rotate roof 180 degrees so atrium collects northern light to avoid heat gain on the South; Final 1B Massing"

(4) "EUI: 617.22 kWh; Total Life Cycle Cost: $1,148,059; Gross Floor Area: 3017sqm; Lifecycle Cost: $380.87sqm"

(5) "EUI: 288.61 kWh; Total Life Cycle Cost: $484,596; Gross Floor Area: 3017sqm; Lifecycle Cost: $160.67/sqm"

(6) "Basic Form; Setback of form to create exterior gathering space; Exterior gathering spaces are located in spaces with views to parkette, main street and MOCA; Extrusion of roof to allow light into atrium. Pathway through ground floor to invite people to gallery and entrance; Final 2A Model; Closing of ground floor pathway. Decrease 4th floor area to compensate for added area on ground floor. Gabled roof for skylight; Final 2B Massing; Atrium Glazing; Bookstore/café and gallery views; Ground floor path view and invitation glazing; Exterior space glazing directions; Closing of ground floor glazing is inset and faces main street and parkette; Horizontal louvers for large windows that replaced curtain walls; Skylights."

(7) "EUI: 147 kWh; Total Life Cycle Cost: $3,583,349; Gross Floor Area: 4738sqm; Lifecycle Cost: $756.3/sqm"

(8) "Small skylights face south to reduce electricity costs on artificial lighting; Minimal glazing on south and west side to reduce heat gain during hot summer months and air conditioning use; Gathering spaces are reduced to lower volume to surface area ratio but still face main street and parkette; Larger windows are placed in protrusions to continue concept that particular spaces such as galleries and studios remain of interest in the form; More windows face the north to allow for passive lighting without the cost of heat gain on the west side; Another important factor to note for the low EUI of this model is the change in HVAC to a High Efficient Heat Pump. The reason for doing this is to prevent monolithic and un-designed boxes as has been observed with other projects with a low EUI. The gathering space and protrusions wanted for the building's concept is ideally kept as well as an attractive exterior. Unfortunately, these design choices do run into sustainability issues. Therefore, another perspective on the project is to look at how mechanical systems play a role in architecture's sustainability."

(9) "Information Learned from Previous Iterations: Double insulated walls reduce heat loss and air escape to diminish energy use for heating/cooling; Wood studs and brick and concrete cladding and more efficient than metal and aluminum cladding as metals are subject to thermal bridging, while brick and concrete provide thermal massing; Triple glazed and smaller windows are very effective to prevent air loss; Small skylights may be useful to bring light into the building without creating opportunity for overheating; Monolithic massing is better than several smaller forms due to lower surface area to volume ratio."

(10) "Walls: Wall costs are lower compared to other iterations except for 2B because it has a smaller gross area than this optimized model; This optimized model is the most sustainable form out of all the iterations due to its material and form design decisions. Materials that have thermal mass are better insulators for the building as opposed to other materials that conduct heat. The best windows, with the best pay-off as seen in the analysis is the triple glazed windows. If windows are placed strategically and there are few of them, the expense of the triple glazed glass is worth while due to their effect of lowering energy costs in the building's lifetime. Some materials to be wary of are louvers. Due to their high price, it is important to note that although when placed correctly, they can have a large impact for heat gain, they can also have a low impact while continuing to be expensive. In this project, vertical louvers were seen as the most effective in shadow studies because they can shade the entire height of the window. Alternate Sustainable Forms that do not carry the concept well; Orientation of the building is also important to energy consumption and costs. Having minimal glazing on south and west sides as seen in the optimized iteration were effective in lowering energy as opposed to treating all faces the same. Having larger windows face the north allows for passive lighting without heat gain."

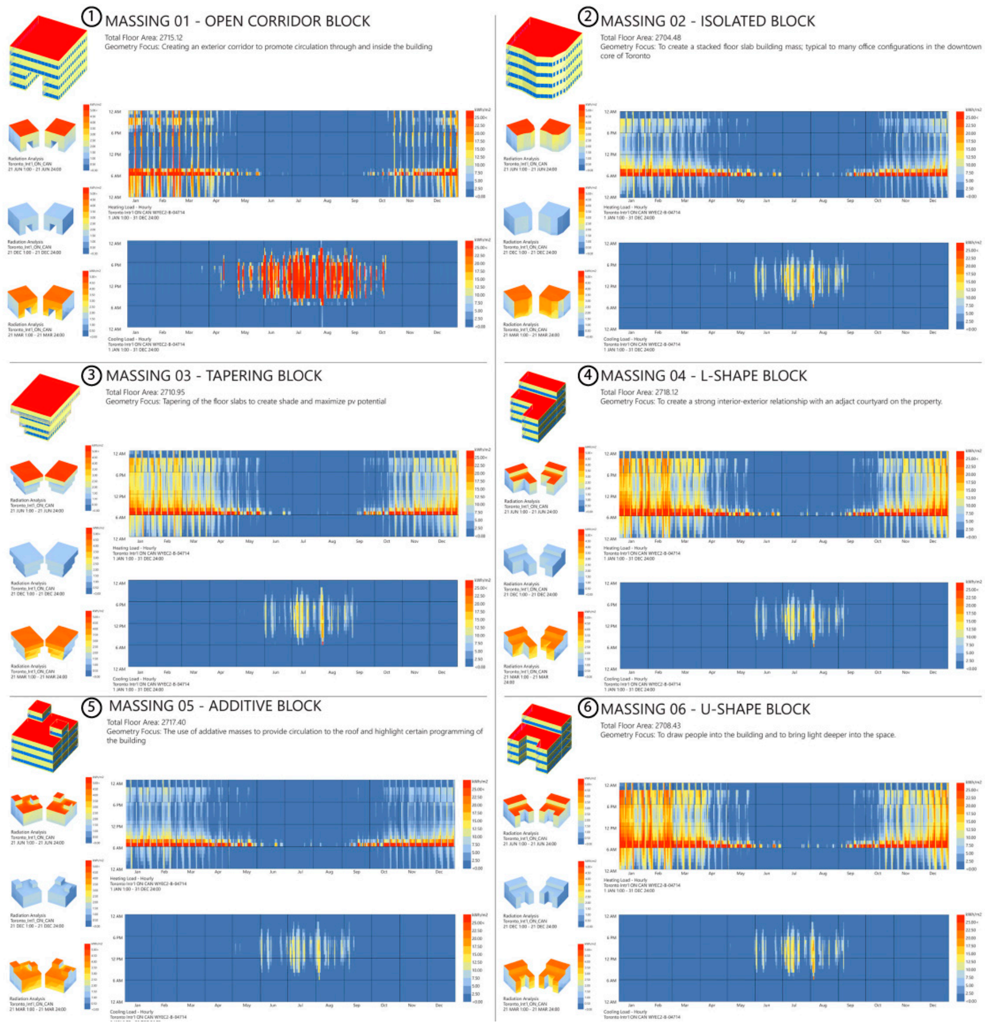

Figure 9. Competition entry: Radiation analysis evaluating heat gains on different building geometries.

(1) "Massing 01 – Open Corridor Block; Total Floor Area: 2715.12m²; Geometry Focus: Creating an exterior corridor to promote circulation through and inside the building."
(2) "Massing 02 – Isolated Block; Total Floor Area: 2704.48m²; Geometry Focus: To create a stacked floor slab building mass; typical to many office configurations in the downtown core of Toronto."
(3) "Massing 03 – Tapering Block; Total Floor Area: 2710.95m²; Geometry Focus: Tapering of the floor slabs to create shade and maximize pv potential."
(4) "Massing 04 – L-Shaped Block; Total Floor Area: 2718.12m²; Geometry Focus: To create a strong interior-exterior relationship with an adjacent courtyard on the property."
(5) "Massing 05 – Additive Block; Total Floor Area: 2717.40m²; Geometry Focus: The use of additive masses to provide circulation to the roof and highlight certain programming of the building."
(6) "Massing 06 – U-Shape Block; Total Floor Area: 2708.43m²; Geometry Focus: To draw people into the building and to bring light deeper into the space."

Rubric

Criteria	Level 5 – Outstanding 10 points	Level 4 – Excellent 8.5 points	Level 3 – Good (not great) 7 points	Level 2 – Satisfactory 6 points	Level 1 – Unacceptable 3 points	Missing 0 points
Energy Analysis for first two iterations (Individual -marked for each partner separately)	Level 4 achieved, AND Student demonstrates awareness of implication of their results for design development and/or massing selections.	Energy study provides output for both massing options and is reasonably presented; no irrelevant information (e.g. generic weather analysis output). Analysis of the data is provided and clearly explains the findings of the results and any issues arising in the process.	Energy study provides output for both glazing iterations and is reasonably presented; no irrelevant information (e.g. generic weather analysis output). A good degree of analysis of the data is provided and clearly explains the findings of the results and any issues arising in the proces	Energy study provides output for both massing iterations but does not discuss them (feels more like a "show and tell" presentation of findings, rather than an **analysis**).	Any of the Level 2 elements are missing or unsatisfactory	This element was missing
Cost Analysis for first two iterations (Individual)	Level 4 achieved, AND Analysis provides insight on the relative cost of the	Level 3 achieved, AND There is some discussion of factors that may	Level 2 achieved, and the student mentions at least one factor that may justify	Cost estimates are provided for both glazing iterations. Student	Any of the Level 2 elements are missing or unsatisfactory	This element was missing OR citations are not

	four options and how this might affect design choices. There is thoughtful discussion of factors that may justify higher initial costs, including aesthetics, and site context.	justify higher initial costs, including aesthetics, and site context.	higher initial costs, including aesthetics, and site context.	analysis mentions the relative cost of the four options and notes which are the highest and lowest options.		provided as required in this course.
Refined Design – Performance Achievement (Pair)	An EUI <120 kWh/m^2/yr (and at least 10% less than the lowest EUI of Massings 1A, 1B, 2A, and 2B) has been achieved. There is no evidence of incorrect modeling.	The building has a maximum EUI of 120kWh/m^2/yr. There is no evidence of incorrect modeling.	The building has a maximum EUI of 150kWh/m^2/yr. Modeling errors, if any, are minor	Student makes a reasonable attempt to both reduce energy and/or cost in the revised design, but does not achieve Level 3 outcomes. There may be moderate modeling issues but these are noted by	The refined design is trivial and/or there is little-to-no analysis provided regarding the decisions made in its creation. Evidence of moderate+ model errors that have not been acknowledged.	This element was missing

				the students.		
Refined Design – Quality of Analysis, Evaluation, and Synthesis	Narrative demonstrate exceptional of understanding of building cost and energy performance based on a comprehensive analysis of the previous massing options.	Design and associated narrative show a high degree of understanding of building cost and energy performance based on a comprehensive analysis of the previous massing options	Design and associated narrative show a good degree of understanding of building cost and energy performance based on a strong analysis of the previous massing options.	Student makes a reasonable attempt to discuss the revised design, but does not achieve Level 3 outcomes.	The refined design is trivial and/or there is little-to-no analysis provided regarding the decisions made in its creation	This element was missing
Quality of Presentation	Excellent presentation - clear both graphically and in terms of written content.	Very good presentation - clear both graphically and in terms of written content but minor errors are present.	Good presentation - some errors present either graphically or in terms of written content.	Satisfactory presentation but noticeable errors present either graphically or in terms of written content.	Students have made an effort but not achieved Level 2 expectations.	This element was missing