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Final Report Team Hadati Road:

Integrated Structural and Solar Performance Analysis of a Monopitch-to-Flat Roof for a 24-Unit Townhouse Development (located at 140 Hadati Road, Guelph)

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GENE 404 - Interdisciplinary Design Project 2

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Executive Summary

This report presented the final capstone analysis for the project titled Integrated Structural and Solar Performance Analysis of a Monopitch-to-Flat Roof for a 24-Unit Townhouse Development at 140 Hadati Road, Guelph, Ontario. The work investigated how roof geometry affected structural demand, photovoltaic potential, zoning feasibility, and overall project value for a proposed low-rise multi-unit residential development. The central problem was that a conventional roof choice could not be evaluated on appearance alone. On this project, the roof had to satisfy several competing requirements at the same time. It had to remain feasible within the site's height constraints, perform safely under local snow and wind conditions, support rooftop solar generation, and create value for the owner, Dotty Lake Retreats, without introducing unnecessary detailing risk. The project had compared five different roof forms: a full monopitch roof, a multi-gable roof, a butterfly roof, a flat roof, and a monopitch roof that transitions to flat at the zoning height limit.

The project used a comparative engineering design approach supported by preliminary structural calculations, load-path reasoning, photovoltaic sizing, energy-yield estimation, bracing analysis, and an interior-volume ROI assessment. The common basis for comparison was drawn from the project footprint and climate assumptions. This involved a building length of approximately 38.521 m, a span direction of approximately 14.200 m, a roof dead load of 0.65 kPa including PV, Guelph climatic values of ground snow Ss = 1.9 kPa, associated rain Sr = 0.4 kPa, and hourly wind pressure q1/50 = 0.36 kPa. These assumptions were used to generate comparison metrics across different roof options, including baseline snow load, drift-sensitive hotspot load, beam-equivalent factored moment, PV system size, annual energy yield, and bracing demand.

The study found that the full monopitch roof delivered the strongest solar and average structural performance, but it was the least compatible with the zoning height constraints. The flat roof was the simplest option from a zoning and massing perspective, but carried the highest baseline snow load and lower solar upside. The multi-gable and butterfly roofs were both disadvantaged by fragmented drainage, more complicated detailing, reduced continuous PV coverage, and more severe localized drift conditions. The monopitch-to-flat roof emerged as the best overall concept because it retained most of the solar and spatial advantages of a sloped roof while respecting the site envelope. This option produced approximately 90.1 kWdc and 99–113 MWh/year, while the preliminary package's conservative mixed-roof estimate produced approximately 80.4 kWdc and 92,500 kWh/year depending on coverage assumptions.

Overall, the recommended direction to my clients and stakeholders was to proceed with the monopitch-to-flat concept as the preferred design, while using a flat roof as the fallback option if simplified permitting, massing, or cost certainty became the dominant consideration.

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1 Introduction

Low-rise multi-unit residential developments are often evaluated primarily through unit mix, site efficiency, façade treatment, and cost per square foot, while the roof is treated as a secondary architectural decision. For the proposed 24-unit townhouse development at 140 Hadati Road in Guelph, Ontario, that approach would have been inadequate. The roof was not simply an enclosure element. It influenced structural demand, allowable building form under the zoning height cap, solar generation potential, constructability, maintenance risk, and the possible value of additional volume at the top of the building. Because of those interacting effects, the project treated roof selection as an integrated engineering and business development decision.

The project context was defined by a long building footprint of approximately 38.521 m by 14.200 m and by the intention to place solar panels across as much of the roof as practical. Ontario snow and wind loading were central to the design problem. Research indicates that roof design is rarely determined by snow load alone. They are also affected by roof shape, snow drifting, sliding, wind exposure, roof levels, and local climate [1]. In Ontario, a winter season can involve both significant uniform snow loads and snow drift loads.[2]. This was very important, despite that the most attractive design option from a zoning and solar perspective was not a pure flat roof or a pure sloped roof, but a hybrid roof that rose at 35° and then became flat at the allowable height limit. This geometry created a promising overall solution, but it also introduced the possibility that the slope-to-flat transition could become a place for accumulated snow drift and exceed local structural demand [1].

The project was also shaped by energy and sustainability considerations. Rooftop solar panels were treated as a core design element. Using National Resource Canada's solar resource tools, it shows that the location supports project-level PV planning [3], while CMHC guidance for residential renewable energy notes that multi-unit residential buildings can benefit from rooftop renewable installations when roof area, sun exposure, and mounting conditions are favourable [4]. The site and massing of the Hadati Road development made the roof geometry especially relevant to energy yield because changes in slope, interruptions, valleys, and setbacks directly affect usable PV area, orientation, racking strategy, and wind attachment loads. A roof that was structurally acceptable but poor for continuous PV coverage would underperform against the project's broader goals.

The stakeholders for the project extended beyond a structural reviewer. They include the future residents, the municipal authority having jurisdiction, engineers responsible for permit-ready design, contractors, rooftop PV installers, building operators, and importantly the client, property management Dotty Lake Retreats, who are also the decision-makers concerned with long-term maintenance and asset value. The preferred design had to function for each of these groups. For the client and development team, the main question was which roof created the best total project value under realistic constraints. For structural reviewers, the question was whether the roof

could be justified safely under snow, wind, and bracing demands. For future occupants, the roof influenced top-floor space quality, risk of ice shedding, and building energy performance. For the AHJ (Authority Having Jurisdiction responsible for construction project's building codes, safety standards, and regulations), the roof had to remain inside the applicable code and zoning framework [6]. For contractors and operators, the roof had to remain buildable and maintainable over time.

The central research and design question therefore became which roof configuration provided the best overall balance of structural performance, photovoltaic potential, zoning feasibility, and practical project value for the proposed 24-unit townhouse development? To answer that question, the project investigated five alternatives: the original multi-gable roof, a flat roof, a full monopitch roof, a butterfly roof, and a monopitch roof that transitions to flat at the zoning height limit. The project did not seek to produce a stamped design package. Instead, it aimed to provide a rigorous, engineering-grounded comparison that could justify a preferred concept and identify the technical issues that would have to be resolved before permit submission.

The scope of the report was intentionally limited to roof-form selection and the consequences that flow from that. It did not redesign the entire building structure, complete a full energy model, or replace code-compliant permit drawings prepared by a licensed professional. It used preliminary engineering calculations, parametric comparison, and development-oriented reasoning to narrow the design space and provide evidence for a preferred direction. The report began with a review of relevant literature and standards, then defined measurable engineering requirements, described the analytical approach, documented the prototype and comparison framework, presented verification and validation results, and concluded with recommendations for decision-makers.

2 Literature Review

A review of the literature and technical standards showed that the main challenge in this project was not identifying one "best" roof shape in the abstract, but choosing a roof form that balanced several objectives under real Canadian and central Ontario (snow belt) design conditions. Four bodies of literature were especially relevant: Canadian roof snow loading and drifting, wind and rooftop attachment design, solar resource and rooftop renewable energy guidance, and multi-unit residential development guidance emphasizing climate resilience and professional adaptation to actual site conditions.

The first and most important body of literature concerned snow loading. NRC publications and Ontario provincial code-related materials consistently showed that roof failures are often driven not by average uniform snow, but by local drift accumulation caused by geometry, wind exposure, and level changes [1], [2], [6], [10]. NRC's guidance on snow loads on roofs described

central Ontario regions as areas where both significant uniform snow loads and high drift loads can occur. [2] Additional NRC guidance on estimating roof snow loads explained that the basic roof load in the code is not a complete design answer; designers must still account for shape and exposure rather than applying a single generalized uniform value without judgment. [7] More recent structural code explanatory material from NRC emphasized that the National Building Code of Canada directly addresses drifting at roof steps, projections, and corners, and explicitly notes that snow drift on lower roof portions can substantially increase load if it is not considered in design [1]. Research on multi-level flat roofs in Canada also reinforced the importance of drift-sensitive conditions by showing that stepped roofs and roof level changes can produce heavy local drift accumulations that must be captured by design provisions rather than averaged away[1], [7].

This research was relevant to the Hadati Road project because the most promising concept was a stepped roof where a sloped monopitch plane terminated into a flat portion at the zoning limit. That geometry matched the type of condition the literature flags as drift-sensitive. It also justified why the project did not stop at comparing average snow loads. Instead, the work explicitly evaluated the slope-to-flat break as a local hotspot where accumulation factor, bending demand, top-chord compression, and bracing force could all increase materially above the baseline case. In other words, the literature supported the methodological choice to treat the transition zone as the governing design issue rather than as a secondary detail. [1],[2], [3], [5]

A second relevant body of literature concerned wind loading and the behavior of rooftop components. NRC's guidance explained that pressure coefficients, exposure effects, geometry, and attachment conditions all influence wind demand, and that the code differentiates between overall building response and local cladding-type pressures. [1] For a long low-rise building, this was especially important because local roof corners, edges, parapet-like transitions, and PV attachment zones can behave more critically than the average roof field. The project's preliminary engineering package therefore modeled wind uplift not as a single deterministic value but as an envelope of uplift suction cases from 0.6 to 1.5 kPa to represent field, edge, and corner behavior. The literature does not remove the need for a project-specific wind design by a qualified engineer, but it strongly supports the decision to treat wind uplift, bearing hold-downs, and PV attachment pull-out as design-critical topics for any preferred roof concept [8].

A third body of literature related to rooftop solar on residential buildings. NRCan's solar resource mapping identifies Canada's mean daily global insolation and global horizontal irradiance resource and provides an authoritative basis for planning-level solar assessment. [3] CMHC guidance for residential renewable energy options notes that rooftop solar on multi-unit residential buildings is most appropriate when sufficient roof area with solar exposure is available and when mounting, electrical, and maintenance conditions are addressed [4]. CMHC also notes that rooftop panels are commonly mounted on angled support frames or directly on sloped roofs, and that the project team must account for wind resistance, electrical requirements,

and utility interconnection conditions. [4] These sources did not provide a single “correct” roof form, but they did show that uninterrupted area, favorable orientation, and manageable attachment conditions matter. That justified the project’s use of PV coverage, module density, and yield range as formal comparison metrics rather than as secondary sustainability commentary.

A fourth body of literature concerned development practice and the translation of prototypical concepts into permit-ready design. The CMHC Housing Design Catalogue User Guide makes clear that prototypical housing designs are not permit ready and must be adapted by qualified professionals to actual site, code, climate, and authority requirements. [4] The work was not a stamped engineering package. It was a structured preliminary evaluation intended to guide the next design phase. The literature therefore supported a report structure that distinguished between comparative concept selection and final project implementation.

Canadian and Ontario guidance clearly discusses snow drift, wind effects, rooftop solar, and site-specific professional review. The project’s contribution was to combine these and other literature into a single roof-form decision for a real development scenario. A purely structural perspective might favour a clean full monopitch or a flat roof. A purely zoning perspective might favour a flat roof. A purely solar perspective might favor the largest uninterrupted sloped plane. A purely architectural perspective might keep the original multi-gable form. The literature did not automatically reconcile those objectives. That gap justified the integrated comparative framework used in this capstone. [2], [6], [7], [9]

Feedback incorporated from prior project milestones shaped the literature review emphasis in two ways. First, the project moved away from discussing the preferred roof primarily in descriptive terms and instead grounded the discussion in the literature on drift, uplift, and design adaptation. Second, the review broadened beyond structural performance alone to include energy generation, development practicality, and implementation maturity. That refinement improved the report’s relevance to both engineering evaluation and real-world decision-making.

3 Engineering Specifications

Because this project was completed within an engineering capstone framework, the preferred concept had to be evaluated against measurable requirements rather than aesthetic preference alone. The requirements were derived from the uploaded engineering package, the poster objectives, the assignment brief, and applicable Canadian and Ontario technical guidance on structural and rooftop renewable design.

At the highest level, the project required a roof form that could remain feasible within the building’s zoning height limit while still supporting rooftop solar generation and acceptable

structural performance. That immediately ruled out any solution that produced excellent average structural behavior but clearly exceeded the project envelope. The roof also had to remain compatible with a low-rise, multi-unit wood-framed or hybrid framed building strategy and with a practical truss span of approximately 14.2 m repeated along the building length. The preferred concept therefore needed not only to "work" structurally in theory, but also to map to a buildable framing and bracing strategy.

A second major requirement concerned climatic loading. The design basis adopted in the project used Guelph climatic values of ground snow Ss = 1.9 kPa, associated rain Sr = 0.4 kPa, and hourly wind pressure q1/50 = 0.36 kPa, in alignment with the preliminary package. Even though final permit design would require confirmation under the governing code and by a qualified professional, the capstone treated these values as the controlling environmental inputs for concept comparison. Any roof option that created severe local drift conditions, excessive uplift hotspots, or disproportionate bracing demand relative to its project value was considered weaker, even if it remained theoretically solvable.

A third requirement involved rooftop solar performance. The project treated solar production as a project objective, not a marketing add-on. The preferred roof needed to support large contiguous PV coverage with reasonable module layout efficiency, manageable racking strategy, and acceptable attachment risk. From the literature, uninterrupted south-oriented or solar-favourable roof area with clear access and manageable wind anchorage is important for multi-unit residential rooftop renewable systems. [5], [7] For the capstone, that principle was translated into measurable targets through PV capacity, energy yield range, and continuity of usable roof surface.

A fourth requirement concerned safety and risk concentration. The design was not allowed to shift too much hidden complexity into one unresolved detail. A roof that looked acceptable in a plan view but created major ice-shedding risk, internal drainage dependence, or drift amplification at valleys and steps was treated as inferior unless it delivered clearly superior project value elsewhere. This requirement strongly penalized concepts with interior valleys, repeated geometry interruptions, or a large number of local detailing transitions. It also meant that the preferred concept needed an identifiable strategy for snow guards, porticos, uplift connections, member bracing, and diaphragm continuity. [1]

A fifth requirement involved value creation. The poster and preliminary package both framed the roof not only as a structural shell but also as a potential source of added interior value. The selected concept therefore needed to be evaluated against possible uses of the extra roof volume, including cathedral ceilings, loft/storage or mezzanine space, and a potential additional storey or row of units. Because the site was already constrained by the zoning height limit, the practical requirement became maximizing the value of volume inside the existing envelope rather than assuming height increases would be permitted.

The following engineering specifications governed the concept selection process:

1. The roof must remain feasible within the existing zoning height limit.
2. The roof must be capable of supporting a practical rooftop PV strategy with strong relative yield.
3. The roof must not create unacceptable drift-sensitive zones without a credible mitigation path.
4. The roof must remain compatible with a practical truss or hybrid framing strategy over a 14.2 m span.
5. The roof must allow a continuous and understandable load path for gravity, uplift, and diaphragm actions.
6. The roof must not create unnecessary waterproofing or drainage complexity.
7. The roof must provide the best total balance of performance and value, not simply the best score in one category.

To operationalize those requirements, the project used comparison criteria and threshold logic rather than a single-weight optimization equation. A concept was considered strong if it satisfied the zoning requirement, produced strong PV output relative to alternatives, maintained average and local structural demands within a manageable design envelope, and offered either improved top-floor spatial value or materially lower project risk. A concept was considered weak if it failed the zoning condition, produced the highest local snow hotspot without offsetting advantages, or fragmented the roof into many risk-prone conditions. This engineering specification framework enabled the later verification matrix and final recommendation.

Table 1. Primary design requirements used to evaluate roof alternatives.

Requirement	Why it mattered	Target / acceptance logic	Implication for concept selection
Zoning feasibility	The building was already constrained by height.	Roof had to remain within the site envelope.	Ruled out the full monopitch as the preferred actual-project option.
Structural manageability	Ontario snow and drift could govern the roof.	Average loads acceptable and local hotspots clearly designable.	Penalized valley-heavy and drift-sensitive forms without mitigation.
Solar performance	PV was a core project objective.	Strong usable roof area and favorable relative yield.	Favored continuous sloped or hybrid planes over fragmented roofs.

Buildability and drainage	Repeated valleys and interruptions increase risk.	The roof needed understandable drainage and detailing.	Penalized butterfly and multi-gable concepts.
Value creation	Roof geometry affected top-floor utility.	The preferred concept had to create usable value.	Supported loft/storage use in the selected concept.

4 Methods, Frameworks, and Analytical Approach

The project used an engineering design and comparative simulation framework. Rather than producing one detailed design from the outset, the work first defined the problem, then established consistent comparison assumptions, generated and screened roof alternatives, quantified their relative performance, and finally selected the concept that provided the best balance of structural behavior, photovoltaic opportunity, zoning feasibility, and value creation. This approach aligned well with the assignment requirement to connect context, methods, verification and validation, empirical interpretation, and recommendations into one coherent report.

The analytical basis began with geometry drawn from the project site plan and concept drawings. The main building footprint was taken as approximately 38.521 m in length and 14.200 m in span direction, with the project described as a proposed three-storey, 24-unit townhouse building. These dimensions were used to establish the plan area, likely truss span, likely repetition of framing along the building length, and the feasible roof surface available for photovoltaic coverage. For the monopitch-to-flat concept, the project modeled roof truncation using a 35° slope and a variable rise-to-cap H, which generated a sloped run $x = H/\tan(35°)$, a flat run $f = L - x$, and a sloped surface length $s = x/\cos(35°)$. The project tested H values from 2.0 to 5.0 m to understand how the zoning cap could change the balance between sloped and flat roof area.

The loading model was built from project-level assumptions rather than from a full finite element structural model. A dead load of 0.65 kPa was used, including approximately 0.20 kPa for PV modules and racking, and Guelph climatic values of Ss = 1.9 kPa, Sr = 0.4 kPa, and q1/50 = 0.36 kPa were adopted from the preliminary package. [10] Baseline roof snow loads were then calculated using the standard roof snow form $S = Is[Ss(Cb\ Cw\ Cs\ Ca) + Sr]$, with baseline assumptions of Is = 1.0, Cb = 0.8, Cw = 1.0, Ca = 1.0, and a placeholder slope factor of Cs = 0.8 for the 35° sloped roof area. This yielded baseline snow loads of approximately 1.92 kPa on flat areas and 1.62 kPa on the sloped portion. Because the project's preferred concept involved a roof step, drift was not treated as a secondary issue. Instead, the analysis explicitly simulated

accumulation factors Ca from 1.0 to 2.5 to generate a drift-sensitive demand envelope for the break condition.

For structural comparison, the project used beam-equivalent line-load calculations to estimate order-of-magnitude reactions, moments, and chord-force demands. With a representative truss spacing of 0.6 m on center and a 14.2 m span, factored downward roof pressure was calculated using a typical ULS combination qu = 1.25D + 1.5S. This approach does not replace a true truss analysis, but it provides a transparent and comparable basis for identifying which roof forms generate more or less gravity demand and for estimating how drift at the transition zone amplifies the problem. The same philosophy was applied to uplift, where the preliminary package modeled net uplift using qu = 0.9D - 1.4W over a range of uplift suction cases from 0.6 to 1.5 kPa. The project used these results to evaluate not only member demand but also likely implications for hold-downs, bearing connections, and PV attachment.

The PV analysis was intentionally planning-grade rather than software-intensive. The project used the roof plan area of approximately 547 m², assumed 65–80% practical coverage depending on geometry and access constraints, and used a representative module power density of approximately 0.210 kW/m². Energy yield was then estimated using a Southern Ontario planning range of approximately 1,100–1,250 kWh/kWdc-year, with 1,150 kWh/kWdc-year used as a central planning value in the preliminary package. This allowed the project to compare each roof form on a consistent basis without overstating the certainty of the energy model. The method was appropriate for concept screening because the project question was comparative rather than interconnection-ready.

A development-value sub-method was added to avoid selecting a roof that was technically strong but economically indifferent. The additional interior volume created by a sloped or hybrid roof was assessed qualitatively across three reuse scenarios: cathedral ceilings, loft/storage or mezzanine space, and an additional full storey or row of units. The analysis compared each scenario against probable rent/value upside, code and zoning difficulty, structural implications, and implementation risk. Because the project already operated at the zoning height limit, the added-storey option was treated as lowest-feasibility despite its theoretical revenue upside.

The project’s research design was therefore mixed in a modest but appropriate sense. It combined quantitative comparison (loads, moments, PV capacity, energy range, bracing force) with qualitative engineering judgment (waterproofing complexity, drainage risk, zoning practicality, and implementation maturity). The “data” for the project were generated from project geometry, code-style loading equations, published technical guidance, and the comparative simulation logic documented in the uploaded files. Acceptance criteria were defined at the concept level: the preferred concept had to remain zoning-feasible, relatively strong in solar performance, structurally manageable under baseline and drift-sensitive cases, and superior in total value to the other options.

Midterm feedback changed the analytical approach in two important ways. First, it pushed the project away from treating the monopitch-to-flat roof as a predetermined answer and toward comparing several roof forms on the same basis. That change improved the credibility of the final recommendation because the chosen concept had to win the comparison rather than simply be described positively. Second, feedback encouraged broader justification beyond structure alone. As a result, the final method incorporated solar performance, zoning practicality, and value-creation analysis alongside structural demand. These changes produced a final analytical framework that was more integrated, more decision-oriented, and more aligned with a real development process.

Table 2. Core analytical inputs and comparison basis.

Input	Value / assumption	Source / purpose
Building length	38.521 m	Project geometry from uploaded engineering package.
Building span direction	14.200 m	Used for likely truss span and roof area.
Dead load, D	0.65 kPa including PV	Common basis for comparative roof calculations.
Ground snow, Ss	1.9 kPa	Guelph climatic assumption in preliminary package.
Associated rain, Sr	0.4 kPa	Included in the roof-snow equation.
Hourly wind pressure, q1/50	0.36 kPa	Planning-level wind basis for Guelph.
Truss spacing	0.6 m o/c	Representative comparison assumption.
PV module density	0.210 kW/m²	Used to convert usable area to system size.
Planning yield	1,100–1,250 kWh/kWdc-year	Used for preliminary annual energy envelopes.

5 Prototype Development

The prototype development phase of the project was analytical rather than physical. No full-scale built roof mock-up was constructed, and no permit-ready truss package was issued. Instead, the project developed a sequence of design prototypes that increased in specificity and usefulness over time. This level of prototype maturity was appropriate for a capstone investigation whose goal was to select and justify a preferred concept rather than to produce final construction documents.

The first prototype was the concept-level roof comparison itself. At the beginning of the project, the roof problem existed primarily as a set of alternatives: keep the original multi-gable roof, simplify to flat, move to a full monopitch, create a butterfly roof, or use a monopitch that transitions to flat at the zoning limit. Each of these alternatives represented a low-fidelity design prototype. Their purpose was not to finalize member sizes or details, but to reveal what kinds of risks and opportunities each geometry created. The multi-gable option preserved a familiar residential appearance, the flat roof simplified height and massing, the full monopitch maximized the sloped solar plane, the butterfly roof explored a more dramatic architectural option, and the monopitch-to-flat concept attempted to reconcile slope benefits with zoning constraints.

The second prototype was a medium-fidelity analytical model of the preferred concept. Once the monopitch-to-flat option began to emerge as a likely candidate, the project developed a more detailed representation of its geometry, loading, PV area, and bracing implications. This prototype used the actual footprint dimensions, a 35° slope, a variable rise-to-cap sensitivity analysis, a dead-load estimate including PV, and code-style snow and uplift combinations. It was advanced enough to reveal the governing issue at the slope-to-flat transition and to support a meaningful verification exercise. At the same time, it remained deliberately preliminary. It did not claim final code compliance or replace the need for a licensed structural review.

The third prototype was the decision-support package itself: a combination of comparison tables, structural demand maps, PV output comparisons, and a narrative recommendation. The research poster condensed this package into an accessible visual artifact. [9] In the context of the final report, that poster served as evidence that the project had matured from early alternative ideation to a synthesized decision artifact capable of being presented to academic and stakeholder audiences. The poster was not simply a communication deliverable; it was part of the prototype development pathway because it forced the project to clarify what the real outputs of the capstone were. Those outputs were not truss shop drawings. They were a preferred roof concept, a justification framework, and a prioritized list of technical issues for next-stage design.

The main prototyping goals were tied to risk reduction. Functionally, the project needed to determine which roof geometry best served the project's combined goals. From a reliability standpoint, it needed to identify whether the selected concept contained a hidden governing

failure mechanism such as severe drift accumulation at a roof step. From a safety standpoint, it needed to identify implications for snow retention, ice shedding, uplift anchorage, and bracing continuity. From a value standpoint, it needed to establish whether the extra roof volume created by the selected concept was materially useful or merely visually appealing. Each prototype stage reduced uncertainty in one or more of these categories.

The main tools and materials used in prototype development were calculations, geometric sensitivity analysis, decision matrices, and presentational synthesis rather than fabrication materials. In effect, the project used computational and representational prototypes rather than physical ones. That choice was reasonable because the dominant uncertainties at this stage were not about material finish or user interface; they were about comparative performance and design direction. A physical roof mock-up would not have answered the central project question as effectively as a disciplined alternative-screening framework.

Traceability was maintained by mapping design inputs directly to prototype features. The key design inputs were: site geometry, zoning height limit, Ontario climatic loading, rooftop solar intent, structural span logic, and owner value considerations. These mapped to prototype features as follows:

- ➢ Site geometry mapped to roof plan area, span assumptions, and PV coverage potential.
- ➢ Height limit mapped to the truncation logic in the monopitch-to-flat concept.
- ➢ Climatic loading mapped to snow, drift, uplift, and bracing calculations.
- ➢ Solar intent mapped to uninterrupted roof plane evaluation and energy-yield estimates.
- ➢ Structural span logic mapped to truss spacing assumptions, moment calculations, and chord-force estimates.
- ➢ Value considerations mapped to the ROI analysis of attic volume use.

This traceability mattered because it enabled later verification. The report could test whether each input requirement had been addressed by a corresponding analytical output. For example, the input “must remain inside the zoning envelope” mapped to truncation geometry; the input “must support meaningful rooftop PV” mapped to system size and yield range; and the input “must remain structurally manageable under drift” mapped to factored moment, chord force, and bracing calculations. In this sense, the prototype development phase also created the skeleton of the verification matrix presented later in the report.

The main limitations of the prototype phase were design maturity and scope. The preferred concept was not advanced to a final truss configuration, a detailed waterproofing design, or a permit-ready photovoltaic layout. That was acceptable for the scope of a capstone concept-selection project, but is acknowledged explicitly. The prototype answered the question “Which roof should be advanced?” much more confidently than it answered the question “Exactly how should every detail of that roof be built?” That boundary was maintained throughout the report to keep the work honest and professionally credible.

6 Verification & Validation (V&V)

Verification and validation were treated as distinct activities in this project. Verification addressed whether the project's analytical outputs were internally consistent with its stated design inputs and assumptions. Validation addressed whether the selected concept was the right solution for the actual project context and stakeholder priorities. This distinction followed the assignment brief and was especially important because the capstone was a concept-selection exercise rather than a final construction package.

Verification focused on design correctness relative to the project framework. The main question was: did the analytical package accurately reflect the defined geometry, loading assumptions, photovoltaic intent, and decision criteria? The project completed verification through a series of calculations, sensitivity checks, cross-comparisons, and consistency reviews. The geometry was verified by referencing the building footprint used across the poster and the preliminary package. The load cases were verified by using a consistent dead load, snow basis, wind basis, and truss spacing throughout the comparison. The beam-equivalent moment calculations were checked against the stated span and line load equations, and the bracing model was checked using a consistent 2% brace-force rule across baseline and drift cases. The PV calculations were verified by applying the same roof area, coverage-factor logic, and module density basis across the alternatives, and the energy estimates were reviewed against reasonable central Ontario planning yields rather than ad hoc values. [6]

Verification also included internal comparative logic. For example, the full monopitch roof was expected to outperform the flat roof in solar potential because its continuous sloped surface created a more favorable usable module area, and the project results reflected that expectation. The butterfly roof was expected to suffer in localized snow and drainage performance because of its internal valley, and the comparison results likewise showed the strongest local snow hotspot for that option. The selected monopitch-to-flat concept was expected to outperform a flat roof on solar and interior-value potential while introducing a risk concentration at the break line, and the verification results also aligned with that reasoning. These consistency checks did not replace final engineering, but they increased confidence that the comparative model was directionally sound.

The most important verification output was the identification of the slope-to-flat transition as the governing design zone in the preferred concept. Under baseline flat conditions, the beam-equivalent factored moment was approximately 55.84 kN·m, but under stronger drift assumptions the same zone increased to approximately 90.32 kN·m. At a representative truss depth of 1.6 m, the corresponding top-chord compression increased from about 34.9 kN to about 56.5 kN. When the bracing model converted those compression forces into brace demand using a 2% rule, the permanent top-chord bracing diagonal demand increased from about 9.87 kN to about 15.98 kN per 6 m bay. This chain of results verified that the project was not simply

choosing the preferred roof based on average behavior; it was identifying and checking the actual local condition likely to govern the next design phase.

Validation addressed whether the project had selected the right concept for the site and stakeholders. Because no built prototype or occupied building existed, validation could not take the form of post-occupancy monitoring or experimental load testing. Instead, validation was completed at the concept level using stakeholder-relevant acceptance criteria. The selected concept had to satisfy five validation questions:

1. Did it remain feasible inside the zoning envelope?
2. Did it preserve strong solar potential relative to alternatives?
3. Did it avoid the worst drainage and local-drift risks seen in other options?
4. Did it create a practical path for structural detailing rather than a structurally opaque concept?
5. Did it improve total project value by creating useful top-floor volume?

Against these criteria, the monopitch-to-flat option validated strongly, but conditionally. It passed the zoning-feasibility criterion because it was explicitly defined by truncation at the height limit. It passed the solar criterion because it outperformed the flat roof and the fragmented roofs while remaining feasible in the envelope. It passed the drainage and constructability criterion relative to the butterfly and multi-gable roofs because it avoided an internal valley and reduced the number of repeated roof interruptions. It passed the value criterion because the added roof volume had a clear recommended use as loft or storage/mezzanine space. However, it only conditionally passed the structural-risk criterion, because the report found that the break line concentrated snow drift, uplift, and bracing demand. That conditional result did not disqualify the concept; rather, it clarified the exact issue that had to be engineered in the next stage.

The timing and maturity of V&V activities should also be stated clearly. Verification occurred during analytical model development and after the comparative tables were assembled. Validation occurred at the end of the concept-selection process, when the preferred roof form could be judged against the project's integrated goals. Both activities were completed at a preliminary design maturity level. That means the V&V results are highly useful for concept selection but not sufficient for permit sign-off.

The project also developed a simple validation protocol for future continuation. In a next-stage design process, the preferred roof concept should be reviewed by the client/developer, architect, structural engineer, and PV consultant against explicit acceptance criteria: height compliance, structural feasibility, roof-access strategy, drainage logic, PV layout efficiency, snow-retention safety, and maintainability. The outcome of this capstone was therefore both a validated concept and a validation roadmap for the next design stage.

Overall, the V&V process strengthened the report in two ways. It prevented the work from overstating analytical certainty, and it translated technical findings into stakeholder-relevant decision language. The project did not conclude merely that the monopitch-to-flat roof had "good numbers." It concluded that the concept was the right direction for the actual Hadati Road project, provided that the break line is treated as the central engineering task in detailed design.

Table 3. Verification matrix summary.

Design input / spec	Verification method	Result / data	Pass / condition	Notes
Remain within height limit	Geometry truncation sensitivity	Preferred concept explicitly truncates at zoning cap.	Pass	Core rationale for hybrid roof.
Support strong PV performance	Area + module density + yield comparison	Monopitch-to-flat retained strong relative output.	Pass	Outperformed flat and fragmented forms.
Manage structural demand	Beam-equivalent load and moment comparison	Average demand manageable; break line governs.	Conditional pass	Detailed engineering required at transition.
Avoid worst drift / drainage risk	Hotspot and roof-form comparison	Butterfly and multi-gable performed worse locally.	Pass	Supports rejection of those options.
Create practical value	ROI assessment of roof volume	Loft/storage was the strongest use of added space.	Pass	Better than cathedral-only or extra storey.

Table 4. Validation protocol and outcomes used at concept-selection stage.

Stakeholder / lens	Question	Acceptance criterion	Outcome	Interpretation
Planning / AHJ	Does the roof fit the site envelope?	The concept remains within the height limit.	Met	Preferred concept retained feasibility.
Owner / developer	Does the roof improve total project value?	Adds usable volume and preserves solar upside.	Met	Loft/storage use strengthened recommendation.

Structural reviewer	Is demand understandable and designable?	No hidden global failure mode.	Conditionally met	Break line governs and must be engineered.
Solar designer	Is there enough good roof area?	Strong contiguous usable PV zones.	Met	Hybrid roof preserved strong relative output.
Operations / maintenance	Is long-term detailing manageable?	Avoid excessive valleys and drainage traps.	Met	Hybrid simpler than butterfly and multi-gable.

7 Results and Discussion

The results of the comparative analysis showed that roof performance on this project was governed by trade-offs, not by a single dominant metric. No single option was best in every category. The full monopitch roof performed best in pure solar and average structural terms, the flat roof performed best in zoning simplicity, and the hybrid monopitch-to-flat roof performed best in overall project balance. The multi-gable and butterfly roofs were both weaker once local snow, drainage, and detailing risk were considered.

The full monopitch roof produced the strongest theoretical engineering and solar result. In the project comparison, it achieved approximately 109.4 kWdc and 120–137 MWh/year, with the lowest baseline snow load of the main alternatives at approximately 1.62 kPa and an average beam-equivalent moment of about 48.95 kN·m. This result is intuitive. A continuous 35° roof plane makes excellent use of the roof surface for flush-mounted PV, avoids stepped drift complications, and retains a relatively clean structural load path. If the project had not been constrained by height, this option would likely have been the preferred engineering concept. The reason it was not selected was not performance weakness, but infeasibility under the zoning envelope. The project's geometry calculations showed that a full 35° slope across the entire 14.2 m run would require substantially more rise than the truncated design and would therefore struggle to remain inside the available height. The discussion consequence is important: the best abstract engineering roof was not the best actual project roof.

The flat roof represented the opposite trade-off. It was the simplest option for zoning and massing, and it likely offered the cleanest permitting path because it minimized concerns about building height and large visible roof form changes. However, it performed worse in the project's technical and value metrics. It carried the highest baseline snow load at about 1.92 kPa and an average factored moment of about 55.84 kN·m, while delivering only about 80.4 kWdc and 88–101 MWh/year in the comparative table. The flat roof was not a poor concept overall; in fact, it remained the recommended fallback if simplified compliance became the dominant priority. But it gave up several advantages simultaneously: favorable solar tilt on the sloped portion, added top-floor volume, and some of the architectural distinctions that the project sought to

preserve. In other words, the flat roof solved the zoning problem cleanly, but it solved it by surrendering value.

The multi-gable roof, which represented the original proposed roof design, proved less attractive once evaluated analytically. In the comparison, it delivered about 81.3 kWdc and 89–102 MWh/year, with an average snow load of about 1.77 kPa, a local snow hotspot of about 2.59 kPa, and an average moment of about 52.39 kN·m. Those average results appear reasonable at first glance, but the local behavior and detailing implications were significantly worse. The multiple gables and valleys reduced uninterrupted PV area, multiplied flashing and waterproofing interfaces, and created more locations where snow could accumulate irregularly. The multi-gable roof therefore underperformed the selected concept not because it catastrophically failed one calculation, but because it introduced too many medium-sized problems without producing a meaningful strategic advantage elsewhere. From a decision-making perspective, it was an inefficient compromise.

The butterfly roof was the weakest option in the comparison. It delivered middling PV performance at about 84.1 kWdc and 93–105 MWh/year, but it created the highest localized snow hotspot at about 3.00 kPa and a high local moment in the valley region. Its central inward valley also made it the riskiest option for drainage and waterproofing on this project. The butterfly roof was the clearest example of why average metrics alone cannot guide roof selection. Its average structural demand did not look dramatically worse than other alternatives, but the geometry concentrated the most serious problems into the exact area that would be hardest to waterproof, inspect, and maintain. For a Guelph townhouse building with winter snow exposure and rooftop solar intent, that result made the butterfly roof a poor candidate despite its architectural distinctiveness.

The monopitch-to-flat roof produced the strongest overall balance. In the comparative simulation using the H = 4 m mid-case, it generated approximately 90.1 kWdc and 99–113 MWh/year, with an average snow load of about 1.80 kPa, a local hotspot of about 2.68 kPa, and an average moment of about 53.07 kN·m. The research poster and the preliminary package also presented a more conservative first-pass estimate of about 80.4 kWdc and 92,500 kWh/year for the mixed roof concept depending on coverage assumptions. Taken together, these results suggest that the preferred concept retained strong solar performance and remained meaningfully better than a flat roof, while also staying feasible within the site envelope. It did not outperform the full monopitch in pure engineering or pure solar terms, but it did not need to. It only needed to outperform all other options once zoning feasibility was included in the objective function.

The key discussion point is that the selected concept won because it balanced system-level outcomes. It preserved a sloped solar surface, produced useful top-floor volume, respected the height limit, and avoided the valley-driven drainage risks of a butterfly or repeated interruption risks of a multi-gable roof. At the same time, it exposed the central technical challenge of the

project: the break line. The drift simulation in the preliminary package showed that when the accumulation factor increased from Ca = 1.0 to Ca = 2.0, the factored moment at the break increased from 55.84 to 90.32 kN·m. The associated top-chord compression at 1.6 m truss depth increased from about 34.9 kN to about 56.5 kN, and the corresponding permanent top-chord bracing demand increased to approximately 10–16 kN axial per 6 m bay depending on the severity of drift. These results are critical because they convert a vague warning about the roof step into a specific engineering agenda for the next phase.

The ROI analysis sharpened the interpretation further. The project did not treat the extra roof volume as automatically valuable. Instead, it compared three uses: cathedral ceilings, loft/storage or mezzanine space, and an additional full storey. Cathedral ceilings offered some premium spatial quality but little direct area gain. An additional full storey promised the highest revenue in theory but was least feasible because the design already truncated at the zoning cap and a fourth level would trigger broader structural, fire, and planning implications. Loft or storage/mezzanine space emerged as the strongest value strategy because it created real usable space without requiring rezoning or a fundamentally different building class. This finding materially supported the selected roof concept by showing that the geometry's additional volume had a realistic use case rather than being merely an aesthetic by-product.

Several limitations must be acknowledged. First, the study was comparative and preliminary. It did not produce a stamped structural design, a full CFD or wind tunnel analysis, or a software-based PV production model using hourly meteorological data. Second, some inputs were intentionally generalized for first-pass concept comparison, such as the representative truss spacing, placeholder slope factor, and uplift envelope. Third, the report did not have access to complete permit-level architectural, mechanical, and drainage drawings, which means some implementation details remain unresolved. Fourth, the project's validation was concept-level rather than post-construction. These limitations do not invalidate the results, but they define their appropriate use: concept selection, not final sign-off.

The project nonetheless achieved reproducibility at the analytical level. A future reviewer could reproduce the comparison by using the stated footprint dimensions, loading assumptions, slope geometry formulas, PV area calculations, energy-yield ranges, and beam-equivalent line-load method provided in the report and appendices. For the purposes of a capstone final report, that level of reproducibility is appropriate and transparent.

In summary, the results showed that the selected monopitch-to-flat concept was not the lowest-risk roof in every local sense, nor the strongest single-metric performer. It was the strongest project-level solution. Its success depended on acknowledging and then deliberately engineering the break condition, rather than pretending that the hybrid roof behaved like a simple uniform plane. That is precisely why it emerged as the most credible recommendation.

Table 5. Comparative roof-form results used in final ranking.

Roof type	PV size / energy	Avg. snow load (kPa)	Local hotspot (kPa)	Avg. moment (kN·m)	Discussion summary
Full monopitch	109.4 kWdc / 120–137 MWh/yr	1.62	1.80	48.95	Best pure engineering and solar result, but weakest zoning fit.
Multi-gable	81.3 kWdc / 89–102 MWh/yr	1.77	2.59	52.39	Acceptable average case, but too many valleys and fragmented PV zones.
Butterfly	84.1 kWdc / 93–105 MWh/yr	1.84	3.00	54.12	Most severe local snow and drainage risk; poorest overall option.
Flat	80.4 kWdc / 88–101 MWh/yr	1.92	2.30	55.84	Best fallback for zoning simplicity; lower solar and value upside.
Monopitch to flat	90.1 kWdc / 99–113 MWh/yr	1.80	2.68	53.07	Best overall compromise for this site; break line governs detailing.

8 Safety, Ethics, Standards, and Societal Impact

Safety, ethics, standards, and societal impact were all material to this project because the roof decision affects not only engineering calculations, but also resident safety, long-term asset durability, and the responsible communication of technical conclusions. The report therefore treated this section as more than a formality.

From a safety perspective, the most immediate issues were snow, ice, wind uplift, and rooftop equipment attachment. Canadian structural design guidance and NRC commentary make clear that drifted snow at roof steps and lower roofs can materially increase local loads and must be addressed in design. [1], [2], [3], [5] For the selected concept, that issue was central rather than peripheral. The slope-to-flat transition can accumulate drifted snow, amplify local member demand, and increase required bracing. The preferred concept also introduced the possibility of sliding or retained snow on the sloped portion, which is why the preliminary package called for snow guards at the low eave and porticos over entrances. In a real building, failing to design these details appropriately could affect both structural safety and public safety at points of entry.

The report therefore recommended that snow retention, entrance protection, and roof-access detailing be treated as mandatory next-stage design tasks rather than deferred accessories.

Wind safety is similarly important. The project's uplift envelope showed that PV improves downward dead load but also creates more demanding attachment design and local uplift considerations, especially near edges and transitions. Ethical engineering communication requires stating clearly that a planning-level uplift envelope is not equivalent to a permit-ready wind design. The report therefore did not claim that the preferred roof was already fully resolved; it stated instead that the concept was preferred provided that detailed uplift, hold-down, and PV anchorage design are completed by qualified professionals. This is consistent with CMHC's guidance that prototypical or conceptual housing designs must be adapted and verified by qualified professionals before permit submission. [4]

The standards context for the report included the Ontario Building Code framework, the National Building Code structural design approach, and supplementary climatic and seismic data used for building design in Ontario. [1], [6] The work did not attempt to supersede those standards. Instead, it used them as the basis for concept-level evaluation. The project also relied on code-style load combinations and code-style snow-load logic rather than ad hoc rules, which improved the integrity of the comparison. At the same time, the report recognized the limitations of applying standards at an early project phase. One ethical risk in capstone work is implying that a concept-level study is equivalent to final professional design. The report intentionally avoided that error by repeatedly distinguishing between comparative analysis and stamped design.

The ethical dimension of the project also involved decision-making under uncertainty. A misleading report could have selected the full monopitch roof because it posted the strongest solar numbers, or the flat roof because it minimized visible complexity. Instead, the project presented trade-offs honestly, including the fact that the preferred hybrid roof concentrates its risk at one location. This matters ethically because stakeholders deserve to understand not just what is recommended, but why it is recommended and where the remaining uncertainty lies. The capstone therefore treated transparency as part of the design quality.

On the societal side, the roof decision influences housing performance and resilience. A roof that supports rooftop solar and uses roof area productively can contribute to lower operating-energy demand and improved long-term building value. A roof that manages snow, drainage, and maintenance risk properly also contributes to more durable housing stock, which has broader implications for housing quality and affordability over the building lifecycle. Conversely, a roof chosen for appearance alone but prone to higher maintenance or repeated failure points would impose future social and economic costs on owners and residents. The selected concept supports societal benefit only if it is executed responsibly: strong solar potential, practical top-floor use,

and deliberate detailing at the transition zone are what convert the concept from a visually appealing idea into a resilient housing strategy.

Because the project did not involve human-subject research, privacy and TCPS 2 considerations were minimal compared with a survey- or interview-based capstone. Still, the broader principle of responsible research remained relevant. The report used de-identified technical reasoning and published sources, did not fabricate stakeholder outcomes, and did not claim performance beyond what the analytical model could defend. That approach is ethically appropriate for an engineering capstone and should remain the basis for any future continuation of the work.

9 Sustainability Analysis

The sustainability implications of the roof decision were assessed using an environmental, social, and economic lens. This triple-bottom-line view was important because the project's recommended roof could not be justified purely on solar output or purely on construction simplicity. A sustainable solution had to perform reasonably well across energy, resilience, usability, and long-term asset value.

Environmentally, the primary sustainability benefit of the project was the integration of rooftop photovoltaic generation into the building concept. NRCan's solar resource information confirms that Canada has an identifiable solar resource base suitable for project-level planning, and CMHC guidance notes that multi-unit residential buildings can reduce purchased energy when roof area and mounting conditions are favorable for solar systems. [3], [9] Within that context, roof geometry matters. A more continuous and appropriately oriented roof plane supports better module layout, fewer obstructions, and potentially higher yield. The selected monopitch-to-flat concept outperformed the flat roof and fragmented roof forms in expected solar production while remaining feasible within the site envelope. That improved the environmental case for the project because it increased the building's potential to offset a portion of its operational electricity demand.

Environmental sustainability also includes durability, not just energy production. A roof that produces slightly more electricity but creates materially higher waterproofing or snow-management risk may not be the better lifecycle choice. The butterfly roof illustrated this issue clearly: despite acceptable average metrics, its internal valley concentrated drainage and snow accumulation risk. The multi-gable roof created multiple interruptions that would likely add flashing points and long-term maintenance complexity. By comparison, the selected monopitch-to-flat roof retained a relatively clean drainage and waterproofing logic while avoiding the central valley issue of the butterfly roof. Its main lifecycle risk was concentrated at a single transition zone that can be deliberately designed, inspected, and reinforced. That kind of

localized, understood risk is generally more manageable over a building life than a roof form that distributes many smaller risk points across the whole plan.

Social sustainability in this project was tied to housing quality, resident experience, and resilience. The selected roof concept offers a better top-floor spatial opportunity than a flat roof because it creates additional interior volume that can be used as loft or storage/mezzanine space. While this is partly an economic benefit, it is also social: improved storage or flexible mezzanine space can make units more usable and more adaptable for residents. In addition, a well-designed solar-capable roof can contribute to a building identity associated with energy performance and future readiness. Social sustainability also includes safety and climate resilience. A roof that is carefully designed for snow retention, entrance protection, and concentrated drift control is more resilient for residents than one that appears simple but underperforms in winter conditions.

Economic sustainability was perhaps the strongest differentiator among roof alternatives. The project's ROI analysis found that loft/storage or mezzanine use of the added roof volume was the most practical value-generation strategy within the existing envelope, while an additional full storey was least feasible and cathedral ceilings provided only moderate value. This result matters because it shows the selected roof can create measurable long-term value rather than simply adding capital cost. A sustainable development strategy is not only about minimizing upfront cost; it is about allocating capital toward features that continue to produce value over the asset lifecycle. In this project, that meant favouring a roof geometry that could support both solar generation and usable upper-level volume.

The main sustainability trade-off in the preferred concept is embodied complexity at the break line. The monopitch-to-flat roof is more complex than a pure flat roof and requires more deliberate structural and waterproofing detailing. That additional complexity carries some material, coordination, and potentially cost implications. However, the report found that the total lifecycle balance still favors the selected concept, because the extra detailing burden is concentrated and purposeful rather than diffuse and repetitive. The concept uses complexity strategically to unlock better energy performance and better interior value. That is a more sustainable kind of complexity than the fragmented complexity of multi-gables or the maintenance-sensitive complexity of a butterfly roof.

The report therefore concludes that the selected roof performs best from a sustainability standpoint when the three sustainability dimensions are considered together. It is environmentally stronger than a flat roof because it supports better solar performance; socially stronger because it creates more useful top-floor conditions and can be designed for winter safety; and economically stronger because it creates more practical value within the existing envelope than the other feasible options. The sustainability case is not unconditional. It depends on detailed design at the transition zone and on a disciplined implementation strategy. But among the evaluated options, it remains the most balanced and most defensible sustainable choice.

Table 6. Triple-bottom-line sustainability comparison of the preferred concept.

Dimension	Key benefit	Main trade-off	Overall assessment
Environmental	Higher relative rooftop PV potential and useful solar geometry.	More detailing than a pure flat roof.	Positive
Social	Better top-floor utility and strong potential for resilient housing performance.	Requires careful snow-retention and entrance safety design.	Positive
Economic	Best practical value from loft/storage in existing envelope.	Transition detailing may add some upfront cost.	Positive

10 Recommendations to Decision-Makers

Based on the comparative analysis, the primary recommendation to decision-makers is to advance the monopitch-to-flat roof as the preferred design basis for the Hadati Road development. This recommendation is supported by the evidence that the concept remains feasible within the zoning envelope, preserves strong relative solar performance, creates useful interior volume, and avoids the major drainage and fragmentation penalties of the multi-gable and butterfly alternatives.

However, the recommendation should be implemented with conditions. The project team should not treat the preferred roof as "already solved." Instead, the next design phase should be structured around the transition line as the principal engineering task. The first recommendation is therefore to commission a permit-stage structural review focused specifically on snow drift at the slope-to-flat break, local member forces, bearing reactions, uplift effects, and permanent bracing design. The capstone has already identified the governing issue and quantified its likely magnitude at a concept level. The role of the next-stage engineer is to turn that knowledge into final truss geometry, member sizes, hold-downs, and detailing.

The second recommendation is to integrate the PV strategy early rather than after structural design is complete. Because the selected roof's value depends partly on rooftop solar performance, the PV layout, mounting method, access paths, snow-retention strategy, and uplift attachment assumptions should be coordinated before the roof is finalized. NRCan and CMHC guidance both support planning-grade solar analysis at an early stage, but final system efficiency and attachment design depend on coordinated architectural and structural decisions. [5], [9] For this project, that means the sloped portion, the flat portion, the break line, and the roof-access requirements should all be considered together.

The third recommendation is to use loft/storage or mezzanine space as the preferred programmatic use of the additional roof volume created by the selected concept. The analysis showed that this use offers the strongest value within the existing height limit while avoiding the much larger approval and redesign burden associated with an additional full storey. Decision-makers should therefore treat the added volume as a functional asset and incorporate it into unit planning early in the next design phase.

The fourth recommendation is to keep the flat roof as the formal fallback option. This is important from a project-risk standpoint. If the next-stage design review shows that the transition detailing, bracing, or cost premium of the monopitch-to-flat concept outweighs its solar and value benefits, the flat roof remains the strongest simplified alternative. Establishing a fallback now improves decision resilience later and avoids forcing the team into a binary all-or-nothing design path.

The fifth recommendation is to document implementation risks explicitly for the owner and design team. Those risks include: drift concentration at the break, local uplift and PV attachment design, snow guard load transfer, entrance protection, diaphragm continuity, drainage detailing at the mixed roof system, and coordination among architecture, structure, and solar layout. Converting these issues into an action list will help the project team preserve the benefits of the selected concept while avoiding preventable coordination failures.

Finally, decision-makers should use the capstone results appropriately. The report should be used to justify concept selection, support discussion with consultants, and frame next-stage design priorities. It should not be used as a substitute for final structural or code review. That is not a weakness of the project; it is the correct professional use of a concept-selection study. [8]

11 Conclusion

This report set out to determine which roof configuration provided the best overall balance of structural performance, photovoltaic potential, zoning feasibility, and project value for a proposed 24-unit townhouse development in Guelph, Ontario. Using a comparative engineering framework, the project evaluated five roof options and concluded that the monopitch roof that transitions to flat at the zoning height limit is the strongest overall solution for the actual site conditions.

The main reason for this conclusion is that the selected concept performs well across the categories that matter most simultaneously. It retains strong solar potential, remains feasible within the allowable envelope, creates useful additional interior volume, and avoids the major drainage and fragmentation problems associated with more interrupted roof forms. At the same time, the report did not hide the roof's main weakness. The slope-to-flat transition is the governing zone and must be deliberately engineered for snow drift, uplift, and bracing demand.

Recognizing that issue was not a failure of the concept. It was the project's most important technical insight.

The work also changed the project team's understanding of what constitutes a "good" roof on a development like this. Early in the problem, it would have been easy to assume that the roof with the best average structural numbers or the simplest zoning profile would automatically be the right answer. The final analysis showed that neither assumption was sufficient. The best roof was the one that balanced system-wide outcomes. That is why the full monopitch roof remained the best abstract engineering option, the flat roof remained the best simplified fallback, and the monopitch-to-flat roof became the best real project option.

Uncertainty remains, as it should at this stage. Final snow-drift calculations, permit-stage wind design, PV attachment detailing, diaphragm design, and full construction coordination were outside the scope of the capstone and still require qualified professional review. [8] But the project significantly reduced uncertainty at the concept-selection level. It provided a justified recommendation, defined the next engineering questions, and translated a broad design idea into a disciplined decision framework.

In that sense, the capstone achieved more than a roof comparison. It demonstrated how engineering analysis, solar planning, zoning awareness, and development-value reasoning can be combined to support a better building decision. The recommended next step is clear: advance the monopitch-to-flat concept into detailed design, while treating the break line as the central technical focus and preserving a flat-roof fallback if implementation conditions change.

Acknowledgments

The person I would like to sincerely acknowledge is Dr. Derek Rayside, P.Eng., PhD, Associate Dean of Co-operative Education and Professional Affairs, for his guidance, support, and mentorship throughout the development of this capstone project.

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Appendix A: Verification Matrix

Spec	Verification method	Result / data	Pass / fail	Notes
Height compliance	Truncation geometry with H sensitivity	Preferred concept defined by break at zoning cap.	Pass	Core design requirement.
Baseline snow load basis	NBCC-style snow calculation	Flat baseline 1.92 kPa; 35° slope 1.62 kPa.	Pass	Used consistently across comparisons.
Drift sensitivity captured	Accumulation-factor simulation	Moment increased to 90.32 kN·m at Ca = 2.0.	Pass	Identified governing local conditions.
Chord-force demand	Beam-equivalent + F ≈ M/d	34.9 kN baseline at d = 1.6 m; 56.5 kN under drift.	Pass	Appropriate first-pass sizing logic.
Bracing demand	2% brace-force rule + 6 m segments	~10–16 kN axial per diagonal bay.	Pass	Used to define next-stage detailing issues.
PV sizing logic	Area × coverage × module density	The selected concept remained a strong relative performer.	Pass	Planning-level but transparent.

Value creation logic	ROI scenario comparison	Loft/storage ranked highest practical use.	Pass	Supports owner/developer recommendation.

Appendix B: Validation Protocol and Outcomes

Stakeholder	Context / scenario	Acceptance criterion	Measure	Outcome	Notes
Developer	Preferred roof for real project site	Best total project value in envelope	Comparative ranking	Met	Hybrid concept recommended.
AHJ / planning	Compliance with height intent	Roof does not exceed zoning limit	Geometry review	Met	Truncation is explicit.
Structural engineer	Concept suitable for detailed design	Risks identifiable and designable	Demand hotspot analysis	Conditional	Break line governs.
PV designer	Roof supports efficient solar deployment	Strong usable PV area	Capacity + yield estimate	Met	Better than flat and gables.
Operations	Roof remains maintainable	No excessive valley / internal drain dependence	Qualitative risk review	Met	Hybrid simpler than butterfly.

Appendix C: Reproducibility and Data Package Summary

The project is reproducible at the concept-analysis level. A reviewer can reproduce the principal findings by using the following inputs and steps:

1. Use building geometry of 38.521 m × 14.200 m.
2. Use dead load D = 0.65 kPa including PV.
3. Use climatic assumptions of Ss = 1.9 kPa, Sr = 0.4 kPa, and q1/50 = 0.36 kPa.
4. Apply the roof snow expression and compare flat versus sloped roof cases.
5. Simulate drift at the slope-to-flat break using accumulation-factor cases from Ca = 1.0 to 2.5.
6. Convert roof pressure to line load using truss spacing of 0.6 m and estimate beam-equivalent moments over a 14.2 m span.
7. Estimate chord force using F ≈ M/d for representative truss depth.

8. Estimate brace force using 2% of compression force and collect force into 6 m bracing segments.
9. Estimate PV capacity using plan area, practical coverage factor, and 0.210 kW/m² module density.
10. Estimate annual energy using a Southern Ontario planning yield range of roughly 1,100–1,250 kWh/kWdc-year.

Appendix D: Graphs and Figures

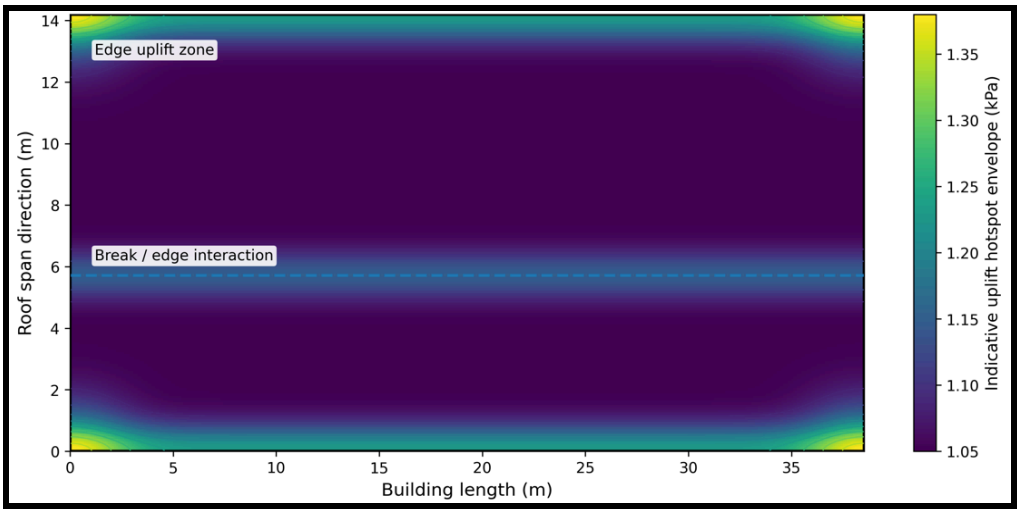


Figure 1: *Structural Demand Map By Roof Type*

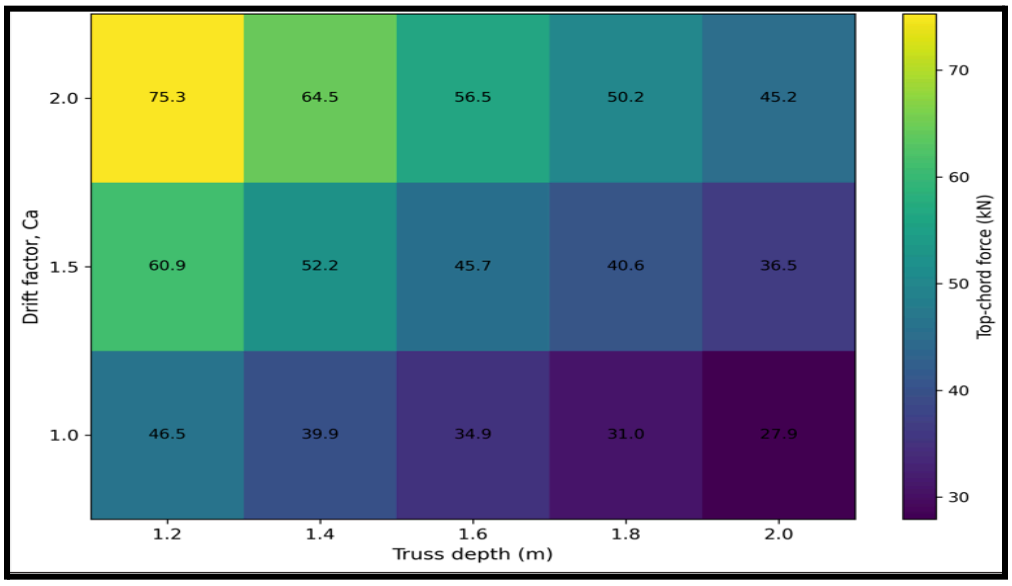


Figure 2: *Equivalent Top-Chord Force Heat Map*

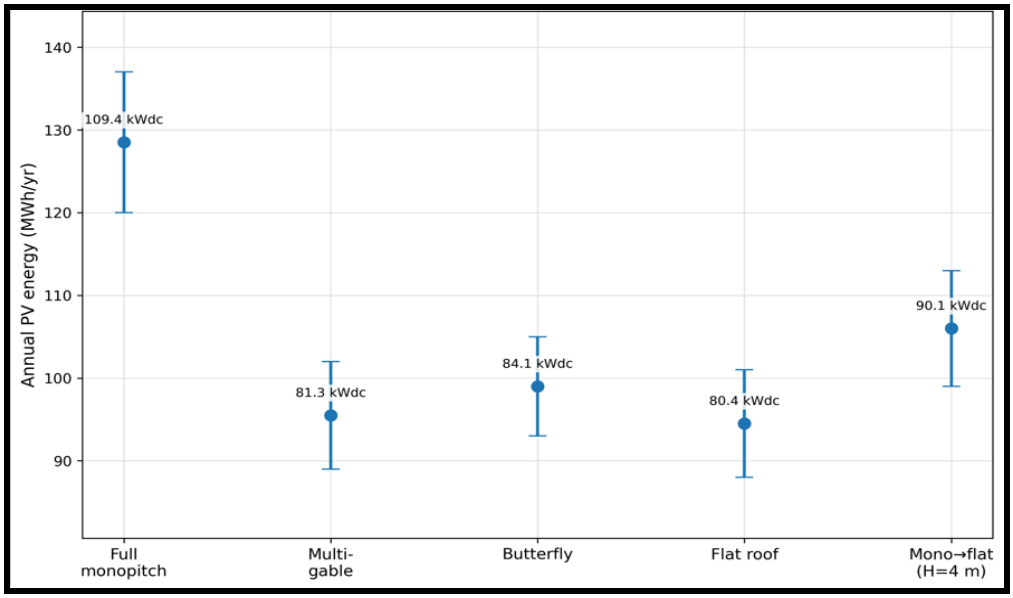


Figure 3: *Roof-Form PV Output Comparison*

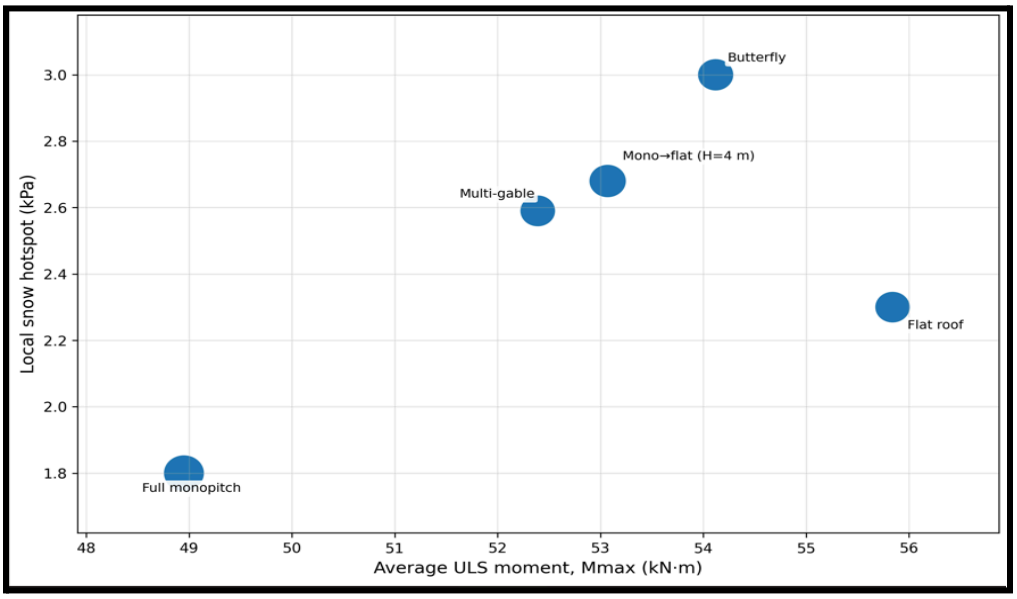


Figure 4: *Structural Demand Map By Roof Type*

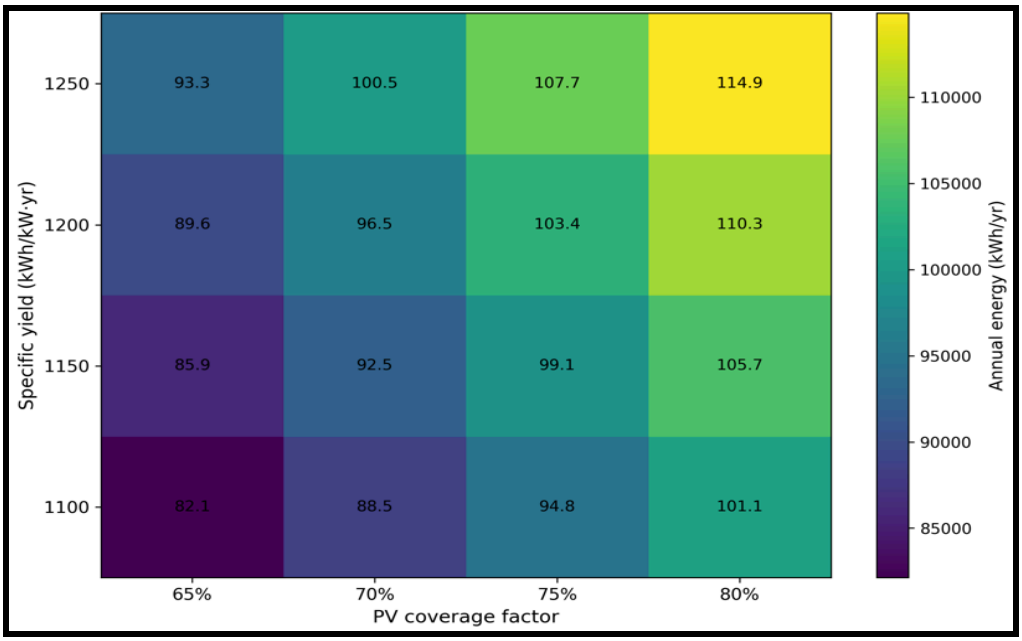


Figure 5: *Annual PV Energy Heat Map*

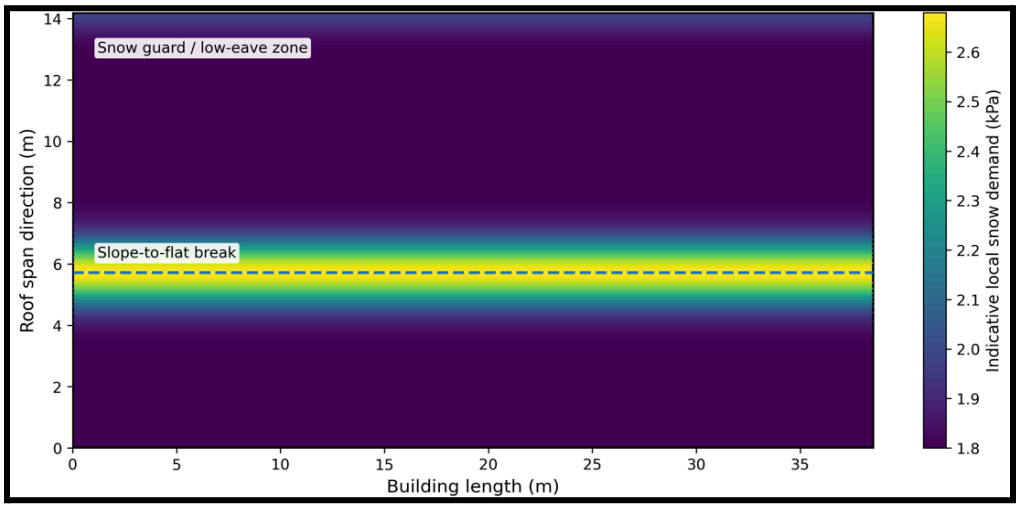


Figure 6: *Snow-Drift Hot Spot Map*

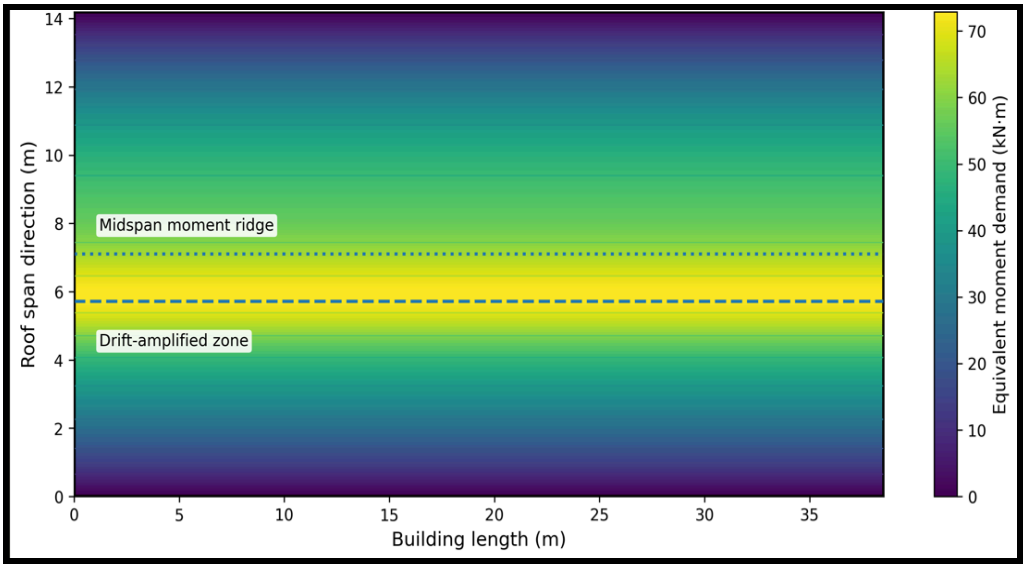


Figure 7: *Equivalent Bending-Demand Map*