A House is a Home:
reconciling design and energy performance
in three Toronto laneway houses

by

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A thesis submitted to the Faculty of Graduate and Postdoctoral
Affairs in partial fulfillment of the requirements for the degree of

Master of Architecture

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: BY Brigitte Martins
: WITH Johan Voordouw & Scott Bucking

: A THESIS SUBMITTED TO THE FACULTY OF GRADUATE
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ABSTRACT

Residential construction and operation account for a great percentage of Ontario's energy usage. Dwellings are undoubtedly indispensable, yet their necessity is not enough to justify the considerable energy this sector expends. In architectural education and practice, energy efficiency tends to assume a secondary role, one subordinate to aesthetic considerations. This divide jeopardizes the industry as increasing societal pressure demands that the profession respond to sustainability expectations. This thesis proposes an alternative workflow for architects that places energy performance considerations on par with design decisions. Through energy and daylighting simulations that consider quantitative and qualitative interventions, the analysis of two existing Toronto laneway homes uncovers a close relationship between aesthetic and performance considerations, demonstrating that design choices directly impact a home's performance. The evaluation results in a methodology to guide the design process of a new laneway home to ensure that a balance is continuously struck between design and efficiency.

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PREAMBLE

laneway house: an independent dwelling unit residing at the rear of the same lot as a principal dwelling (whether detached, semi-detached, or a townhouse) and accessed by a laneway, or secondary road >>

This thesis examines the energy use and design of two Toronto houses to develop a new design methodology. It aims to balance qualitative and quantitative factors in residential architectural design in order to produce a conscious, thoughtful, and responsible house. The energy and daylighting analyses of two existing laneway houses uncover this methodology, which will then be practically demonstrated through the design of a new **LANEWAY HOUSE**.

INQUIRY

The primary concern defining twenty-first century subsistence involves the question of sustainability, an ethos attempting to respond to the veil of mystery shrouding the future of our planet. Statistics condemn modern lifestyles and habits, fixating on the energy they demand and the toll they take on resources. The largest offender regarding energy use in Canada – and therefore a significant target for change – is the building sector.¹ Throughout a building's life, from its construction phase through to its operation, its energy demands do not falter. This notion is unsurprising, as we spend most of our lives indoors. While this is an intuitive correlation, concern regarding these statistics may not be amply reflected in the early stages of design and construction.

As a student of architecture, my personal experience has shown that university teachings recognize two dominating characteristics of architectural education and practice: design and sustainability. My education has suggested that beautiful and responsible spaces exist, that buildings can successfully marry design and environmental excellence – examples include Renzo Piano's California Academy of Sciences and Peter Busby's VanDusen Botanical Garden Visitor Centre. However, while modern curricula, technology, and research are attempting to rectify this distinction, the two pedagogies still largely exist as separate entities with some overlap. Where an overlap does occur, it can be argued that one of these prevailing ideas is compromised in favour of the other – an exceptionally sustainable building can be simply labelled as highly functional, while beautiful buildings can read as objects in space with limited practicality and response to site conditions.

This divide is further strengthened by popular attitudes. Aesthetic considerations are tremendously valued in the architectural sphere, emphasized by the desirability of 'starchitects' and their signature works. The prevalence of celebrity architects in the profession and their public perception underline the importance of design, leading to a type of practice where

our architecture arguably responds first and foremost to aesthetic considerations while energy performance becomes a secondary responsibility, an obligatory, often uninspired add-on.

Due to the necessity of shelter, the field of architecture has no choice but to respond to the current social climate and its growing expectations. While we may spend a great deal of our time in public buildings – offices in which to work, stores in which to shop, institutional buildings in which to interact – the home is the constant to which we return and escape at the end of the day. It is where we shape daily habits and exercise lifestyle decisions. Because of its pivotal role in the everyday lives of millions and its ranking as the third highest energy consumer in Canada after the industrial and transportation sectors,² the house cannot be disregarded in its contribution to the discussion of energy. It is here, in the urban residential sector, that a change will be proposed.

According to Natural Resources Canada, between 1990 and 2016 there was a 51% improvement in energy efficiency in Canada's residential sector. Overall trends revealed a 2.4% rise in residential energy use since 1990 due to the increased number and volume of households, and increased use of appliances and air conditioning; without any improvements in energy efficiency, however, usage would have increased 53.0%. The majority of energy was expended heating interior spaces (61.0%), followed by water heating (19.0%), appliances (14.0%), lighting (4.0%), and space cooling (2.0%).³ In Ontario, the **SECONDARY ENERGY** use for single detached homes showed a downwards trend: in 2017, energy use decreased by 1.3% from 2016, and 11.1% from 2015.⁴

secondary energy: the
byproduct – in the form of
electricity or heat – of raw
fuel (primary energy) >>

This data shows great improvement in energy use and efficiency in recent years, as numbers peaked in 2014 and have since been declining.⁵ A crucial consideration for architects is that statistics from over twenty-five years show that there has been a 16.1% increase in the average size of a single detached home (from 137 m² per house in 1990 to 160 m² per house in 2016).⁶ These facts highlight that energy efficiency is an important factor in the modern-day design and occupation of homes, and that improved design, reduced average area, and continued improvements to performance can further reduce these numbers.

If residential construction and operation account for the majority of Ontario's energy use, why does the architectural design process separate aesthetic and efficiency considerations instead of using performance as a design tool to demonstrate that design choices directly impact the overall performance and efficiency of a home? This thesis aims to uncover the relationship between different kinds of design decisions, namely those considering aesthetics

and those concerning energy performance and occupant comfort.

If a relationship does exist, perhaps the most impactful way to address it is through the altering of the workflow of architects, home builders, and designers. Typical practice suggests that a design is developed to a certain level of completion before its performance is assessed, usually by an energy simulation software; depending on the results, energy considerations will be incorporated into the design with various degrees of success. The result is a thoughtfully conceived design that must bend to the will of efficiency, a compromise that usually precipitates the addition of a 'green' building technology as a Band-Aid solution that fails to address the bigger problem. This approach of design first, performance later discourages holistic thinking – in considering design and performance together, the true root of the problem is unveiled, as complex issues such as these demand unconventional and imaginative solutions that consider design and performance in tandem. An adjustment to this architectural workflow would bring design and performance into a more intimate relationship, allowing performance to come to the forefront of the design discussion in the early stages of a project's acquisition.

This research intends to investigate how more responsibility can be placed on the designer in residential design. The ensuing explorations aim to direct practitioners intent on considering performance in tandem with design to become more aware of how simple design choices, like the initial moves made during a project's conception, can account for notable improvements to the efficiency of a home, and encourage ongoing dialogue between design and efficiency considerations throughout the design process.

TERMINOLOGY

The following terms and their definitions are adapted to align with and frame the goals of the research.

The research operates under the umbrella term of sustainability, the principal motive behind considering the impact of design on performance. In 2015, the United Nations Division for Sustainable Development Goals adopted seventeen goals to guide global practice; their broad definition for sustainability includes ending poverty and hunger, ensuring inclusivity, health, and equality for all, and creating environments and habits that promote safety, preservation, and the reduction of climate change. While these goals touch on resiliency, resource management, and consumption,⁷ in a general sense that is specifically applicable to the building sector, sustainability refers to the ability to live where one's present needs are reasonably met without jeopardizing the ability of future generations to do the same.⁸ With

sustainability: the conscious practice of living within one's means without jeopardizing the ability of future generations to do the same

>> this in mind, **SUSTAINABILITY** is defined as the mindset that the current state of affairs needs to change because if the status quo is unchallenged, the quality of life (reflected in the physical environment and the well-being of all living things) will irreversibly suffer. In response, the motivation of this thesis is to suggest a course of action that could improve both the efficiency and quality of residential building stock. The effects of such improvements include the thoughtful use and consumption of resources and the creation of healthier living environments.

Energy usage in the residential industry encompasses the numerous aspects of building and living in a home and their impacts, including transportation of resources, people, labour, materials (their acquisition, installation, disposal), and operation (heating, cooling, ventilation, water usage). While all are important to consider when discussing energy, this thesis is simply concerned with end-use energy, namely what is required by the occupant to run the home. The

single-family home: a dwelling type that stands apart from other buildings or units and intended to house one or more people

>> dwelling type in question for this study is the **SINGLE-FAMILY HOME**, a free-standing volume with at least four exterior walls that is occupied by one or more people⁹ in an urban environment, and most likely surrounded by similar housing units.

Energy demand, or energy loading, is the requirements and pressures placed on a building and its systems in order to operate. As long as the house is in operation, it is always drawing energy and placing a demand on the grid or other energy sources. Demand is directly

energy performance: describes how well energy supply is matched with energy demand; the result of a home's inputs and outputs

>> related to **PERFORMANCE**, the evaluation of the home's inputs and outputs determined by the supply of resources, occupant usage, demand, and environmental factors. It is affected by the efficiency, quantity, and quality of these sources and is mainly concerned with the operational

phase of design. These factors are inversely related – increased energy performance will lower energy demand, while a poorly performing building draws excessive energy. The product

energy efficiency: when energy is saved due to a decrease in its demand by occupant behaviour or equipment

>> of this relationship is **ENERGY EFFICIENCY** or conservation, where the energy used at its final destination is saved because less of it is required to meet mechanical and lifestyle demands.¹⁰

design: the formal result of a number of factors pertaining to taste, restrictions, and realities

The question of **DESIGN** is in both contrast and collaboration with these concerns for considerate consumption. In this research, the definition of design pertains to the aesthetic appearance and formal, spatial, and programmatic decisions that establish the as-built houses, the product of the client's needs and wishes, their budget and the economy, existing trends and conventions, and structural requirements. The multi-faceted design is the outcome of

workflow: the architectural design process

>> a **WORKFLOW**, the process of arriving at a proposed design through careful consideration of competing factors and their consequences. In the application of the research, design is placed in parallel with the concept of performance in the hopes that a close relationship can be uncovered through careful analysis and parsing of the architectural method.

The investigation will evaluate and attempt to balance quantitative and qualitative

quantitative: relating to something measured in terms of its number or amount

>> decisions. **QUANTITATIVE** denotes something that is measured in terms of its number or amount – in this application, it refers to decisions that target efficiency in a numerical and directly tangible way. For example, reducing a home's energy usage through the addition of more insulation is a quantitative action; the addition of the new material resulting in a reduced load on the mechanical heating system directly impacts the efficiency of the home, but it has very little

qualitative: relating to something measured in terms of its character or composition

>> implications on the formal arrangement of the space. Conversely, **QUALITATIVE** denotes something that is measured in terms of its character and composition – in this application, it refers to decisions that target efficiency in an intangible way. For example, the placement of windows will affect the activity within a space; direct sunlight may be more desirable in some spaces, whereas reduced or diffused lighting might be better suited in others. Both quantitative and qualitative decisions affect occupant use and comfort to different extents and degrees. The research aims to demonstrate that thoughtful design is the result of the marriage between quantity and quality, harmoniously achieving design and performance excellence.

METHOD

The principal method of inquiry of the thesis is research-by-design. Using realized and built examples, it is a process that emphasizes rigour, detail, and logic to arrive at empirical results that can be observed and quantified.

The relationship between design and performance was explored through the analysis of two case studies of existing single-family, detached homes in Toronto, Canada. Due to their scale, the variables were fewer and easier to isolate than in a multi-unit residential building. The detached home provided an isolated study of the life and habits of a single families in urban Toronto. A close reading of the as-built design was followed by quantitative and qualitative investigations that revealed the roles and relationships of design and performance in the homes. This process and its results were then used to develop a methodology to guide the workflow for designing other single-family homes; as a conclusion to the research, the method was tested by designing an urban laneway home.

The initial investigations were conducted through a comparative analysis of two different architectural design and evaluation tools, BEopt (Building Energy Optimization) and Autodesk Revit. BEopt allows users to optimize the design of a new or existing house to achieve

net-zero energy: a high standard of construction that dictates that the building must generate as much or more renewable energy than it consumes so that its overall impact is neutral >> **NET-ZERO ENERGY.** The user defines the floor plan of the house and categorizes the spaces by use and construction type. The building's assembly, construction, mechanical, electrical and

system: the network of various parts, mechanisms, and equipment that allow a building to function >> miscellaneous **SYSTEMS** are selected from a list of predefined options that reflect realistic standards, products, regulated practices, and cost. The existing scheme is then evaluated while referencing a base point of the user's choice, such as a net-zero model, and the program projects a path that can be followed to achieve the aforementioned reference point.¹¹

Autodesk Revit is a Building Information Modelling (BIM) software. It is an interdisciplinary tool that aims to define a complete picture of a building with a high level of detail (including the architectural, structural, and mechanical designs) before construction begins to save time, money, and resources. While its primary function is to communicate clearly across different Architecture, Engineering, & Construction (AEC) disciplines, it also features an analysis plug-in – supported by EnergyPlus, an industry-standard software for energy simulation – that can calculate a design's efficiency and impact at any stage of its process. Though it is commonly used for larger buildings, it can be used at a smaller scale for the design and construction of single-family homes.

These two programs were evaluated according to their varying strengths and weaknesses regarding the ease and accuracy of design and analysis. This was achieved by running the two case studies, plus several generic models, through the programs, isolating variables in both the designs and programs. This identified the overarching trends, issues, and strengths of the two softwares. Once the inner workings of the programs were understood and evaluated, Revit was selected to advance the research and delve into a more detailed analysis of the case studies.

This comparative analysis gave way to the study of the home's quantitative and qualitative attributes. The existing homes were thoroughly studied to determine what design changes could achieve notable performance improvements. This study was executed in two parts, one isolating quantitative decisions and the other focusing on qualitative design moves. The *quantitative* evaluation determined a new, more efficient base model based on numerical and measurable variables. This was achieved through the manipulation of a series of

envelope: the element separating interior space from the exterior, sheltering the inhabited space from the elements, and consisting of walls, roofs, foundations, floors, windows, and doors

>> performance upgrades targeting the building **ENVELOPE** and systems, including upgrades to the interior and exterior insulation, windows, appliances, light fixtures, and heating, ventilation, and air conditioning (HVAC) systems. The upgrades were studied first in isolation to quantify the extent of their impact on the base home's overall efficiency and were then gathered into one evaluation to determine their collective impact. An improved prototype for each case study was then defined, reflecting the most optimized option from a series of quantitative changes.

daylighting: a study concerned with optimizing the use of natural light to decrease dependency on and use of artificial lighting

>> Subsequently, this prototype was evaluated *qualitatively* through **DAYLIGHTING** analysis, which determines the amount of quality natural lighting a space receives throughout a predetermined time (usually annually). The purpose of the daylighting analysis was to determine if the quantitative model could be reevaluated in terms that are more sympathetic to conventional design choices, like occupant comfort and brightness of the space. The analysis proposed the reevaluation of the existing windows and their placements to improve the optimized design in a more intangible way.

The daylighting studies were produced by DIVA (Design Iterate Validate Adapt), a plug-in for the modelling program Rhinoceros that provides sun path diagrams, radiation maps, climate data, and glare and shading analyses.¹² The three-dimensional Revit model – with floors, roofs, walls, windows, and doors – was imported into Rhinoceros; here, the geographical location of the project was defined to get an accurate reading of the site's yearly weather conditions based on the software's internal data. Thermal and material properties

were applied to the model layers to ensure that it interacts appropriately with the climate and daylighting data, allowing analyses concerning light transmittance to be run.

Based on the data accumulated over numerous studies and design iterations, the results established a workflow for performance-based architecture, one that front-loads performance and places it with design as a primary step in the design process. The method involves four steps, each requiring a continuous dialogue between quantitative (Revit energy analysis) and qualitative (DIVA daylighting analysis) decisions to arrive at the final design for a new laneway house.

figure 1: context plan, 1:50000

figure 2: Elle site plan, 1:1250

CASE STUDIES

The two case studies were selected from *Canadian Architect* magazine, a publication showcasing Canadian architecture of varying scales and uses. The selection of case studies from the magazine ensured that every project was designed by an architect. It can be argued that this qualification, and having been featured in a design publication, implies that these homes have achieved a certain standard of design quality and validity, and that both the client and the architectural profession have approved of the finished project.

Narrowing the choices down to homes built between 1990 and present-day ensured the sample was relatively modern in terms of construction techniques, building technologies and systems, envelope treatment, and more.

The two homes selected for study are both laneway homes located in metropolitan Toronto. Laneways are a defining feature of the city's traditional residential fabric. These homes face the street on the outer sides of a city block and have rear yards abutting at the centre of the block. The yards are separated by a laneway, a shared semi-public road used by the residences for parking or storage. This housing typology composed most of the city's neighbourhoods in the late nineteenth and early twentieth centuries and are still highly desirable today. Recently, the laneway has become a popular site for new construction, especially in urban areas where property parcels are scarce and land prices are high. These properties are often difficult to design due to their lot size and/or shape and logistical requirements. It is therefore presumed that site restrictions influenced the design of the case studies, and that these constraints would have resulted in a more considerate, and the most suitable, solution for the sites.

ELLE is a laneway house with an L-shaped floor plan located at 1 Ways Lane in the Trinity Bellwoods neighbourhood [Figure 2]. Completed by Diamond + Schmidt Architects in 1997, the public living spaces, including the living room, dining room, powder room, and kitchen, are located on the ground floor, with access to a secluded outdoor patio via a large glass door. On the second floor is the bedroom, adjacent to a large, open studio space that can also serve as a secondary bedroom. The home is configured on the nine-by-thirteen metre lot to create a yard at the back and allow the entrance to face the laneway. The backyard is the focal point of the house, drawing a clear connection between exterior and interior spaces through the placement and size of the windows along its back façade. A rooftop patio is accessible from an exterior stair [Figure 4, 5].¹³ Its configuration and internal arrangement allow the house to take full advantage of its small lot.

figure 3: Lungo site plan, 1:1250

LUNGO is a laneway house with an elongated rectangular floor plan located at 40R Shaftesbury Avenue, in the Rosedale-Moore Park neighbourhood [Figure 3]. The building dates back to the 1880s, when it began its life as a blacksmith shop. Since then, it has served as a horse shed, a storehouse, and a sculptor's home and studio. The new home was completed in 2008 by Superkül Architect. The home, measuring three by twelve metres, has extreme site constraints: three of the walls were already built up to the property line and no new openings were allowed on any wall except the north façade. As a result, a primary concern was to introduce more light into the existing building; this was achieved through the creation of two lightwells at the back of the home. The accessible rooftop terrace is highly desirable because there is no private outdoor space at grade level [Figure 6, 7].¹⁴ Within a small footprint, this long and linear volume appropriately responds to its site and program.

These two case studies form the foundation of the ensuing research and its conclusions.

CASE STUDY #1: ELLE

1 Ways Lane, Toronto, ON
completed 1997
Diamond + Schmitt Architects
single family, urban, laneway
115 m² / 1243 ft²

figure 4: Elle plans, 1:200

figure 5: Elle, exterior and interior photos

CASE STUDY #2: LUNGO

40R Shaftesbury Avenue, Toronto, ON
completed 2008
Superkül Inc., Architect
single family, urban, laneway
39 m² / 420 ft²

figure 6: Lungo plans, 1:200

figure 7: Lungo, exterior and interior photos

COMPARATIVE

The empirical analysis began by comparing the energy performance of both case studies in BEopt and Revit. The purpose was to uncover trends in data entry and acquisition, thereby determining the preferred tool for evaluating homes in a cold, northern climate. A further consideration was to uncover which program would best highlight a general relationship between design and performance decisions and synthesize these decisions at a detailed level of performance analysis.

The comparative analysis was largely concerned with simple formal moves to highlight very broad connections between inputs and results. These separate analyses were organized into six different iterations, the first three involving the laneway houses, and the second three analyzing a very basic volume. The first investigation into a relationship between form and performance involved comparing the general shape of the footprint of each home, namely Elle's L-shaped plan and Lungo's rectangular plan. Secondly, the materiality of the homes was isolated to determine the impact finishes had on performance; each base case was compared to an entirely solid box (no openings and entirely opaque) of the same dimensions, and to a glass box where every wall was composed of full height glass to find both the range and normative condition of models of the case studies.

The second half of the investigation manipulated basic formal variables on a cubic model, referred to as the CubeHaus. In three simulations, the CubeHaus was altered to isolate its area, volume, and orientation. The first iteration was concerned with area and involved doubling and halving the area of the base model while volume and orientation remained consistent across models. The second iteration was concerned with volume and involved doubling and halving the volume in relation to the base while area and orientation were consistent. Finally, in the third iteration a base model with a consistent area and volume was assigned a singular wall with a fixed percentage of glazing; this wall was then rotated across the four cardinal directions

passive solar gain: the amount of heat introduced into a space through the admission of solar radiation through windows, doors, and other glazing

>> to record **PASSIVE SOLAR GAIN**. The result of these studies was an understanding of how different formal variables affected the outputs of both BEopt and Revit.

The Cubehaus results and trends were necessary to aid in the interpretation of the existing homes. Given the limited information obtained from the *Canadian Architect* articles, some general assumptions were made in order to maintain consistency between the case studies and the programs. Only above-grade, interior spaces were modelled — basements and roof terraces, and any related elements like exterior staircases, were omitted. Partitions

were excluded from all models, leaving the exterior shell to be evaluated in isolation. Unknown values were given standard dimensions: wall heights were set to 2.50 metres, door heights to 2.10 metres, and windowsill heights were set to 0.90 metres.

All of these models were evaluated and compared to one another by their annual

site energy: a measurement of energy at its end destination, excluding the energy expended to produce and transport it

>> **SITE ENERGY** usage [Figure 8]. Measured in kilowatt-hours (kWh), site energy represents the raw and processed energy that is purchased and used in a building. It is a metric used to describe the end use of energy at its final destination and excluding all of the energy demands prior to arriving at the site, including losses in acquisition, transportation, and processing. Conversely, *source energy* considers the entire spectrum of energy use from beginning to consumer – it is the combination of site energy consumption with production and delivery losses.¹⁵

figure 8: source versus site energy

When discussing energy efficiency and performance, site energy is the most common metric because of the lack of certainty surrounding the conversion of source to site energy. Energy efficiency codes also favour site energy to separate end use from the energy expended before arriving at the site.¹⁶

In these analyses, the resulting number is the sum of the energy demand of five factors: heating, represented by a natural gas furnace; cooling, represented by an electric air conditioner; appliances, represented by both electrical plug loads and fixtures, like a refrigerator or dishwasher; lights, represented by electric interior lighting; and a heating fan, represented by a unit that uses an electric fan to warm the air. Together, these elements paint an accurate picture of the average annual energy demand based on a residential occupancy schedule, before and after work hours in both the mornings and evenings when the home is primarily used and exerting the majority of its demand.

figure 9: Elle and Lungo models

The first analysis conducted, 1A, compared Elle and Lungo directly to one another [Figure 9]. Given the discrepancy in area — with Elle’s area 66% greater than that of Lungo — in order to properly compare the two homes, the metric of comparison was site energy use per square metre (kWh/m²). The results from both programs demonstrated that Elle was a more efficient house in terms of its energy use per square metre, while Lungo was 16% less efficient in BEopt and 45% less efficient in Revit [Figures 11, 12]. Heating accounted for the majority of the homes’ energy use, ranging from about half to 86% of the total energy usage. In both cases, equipment and lights occupy the second and third highest demands respectively, with cooling and heating fans as the lowest demands. Though the overall trends were similar across both platforms, there was a 20% difference between the results from Revit and BEopt, demonstrating that there are in fact dissimilarities between the programs and their interfaces, namely inconsistencies in modelling or output selections that are reflected in the results. This iteration demonstrated that in this scenario, the L-shape yielded results that favour a more efficient design per area than the rectangle because of the relationship between its larger area and larger energy output.

figure 10: Elle base model with solid and glass box models

1B, the second iteration, compared the as-built Elle as the base model to a solid and an all-glass model to demonstrate how opacity could alter performance [Figure 10]. In both programs, the solid boxes outperformed the base and the glass box — in BEopt, the solid box was 11% more efficient than the base, and in Revit, the difference was 13% [see Appendix C for the full results of all iterations]. The glass boxes yielded more drastic results, with a 30% increase in site energy use from the base in BEopt and a 66% drop in Revit. The solid box incurred the lowest numbers, but the biggest change in overall, and heating, demand was seen when

figure 11: Iteration 1A, BEopt results

figure 12: Iteration 1A, Revit results

comparing the glass to the as-built model – a more meaningful impact or change was observed when the house was converted from a glass box to its as-built state, rather than converting the base to the solid box. While heating still accounted for the majority of the energy demand, in the glass box design cooling accounted for a considerable amount of the total, given glass' tendency to cause overheating. In this scenario, an opaque box with no openings performed more favourably than an entirely transparent box, though both scenarios do not favour realistic or desirable living conditions. Both programs demonstrated similar trends, but the difference between cases across programs was 25% for the solid box and 36% for the glass box.

figure 13: Lungo base model with solid and glass box models

1C, an analysis of the solid, glass, and as-built models for Lungo, produced similar trends as those of 1B [Figure 13]. The BEopt solid box was 12% more efficient than the base, whereas the Revit solid box was 7% more efficient. Conversely, the BEopt glass box was 32% less efficient than the base compared to the Revit glass box that was 70% less efficient. Heating accounted for around 70% to 80% of the total demand across all models. The conclusions echoed those of 1B, where the solid box outperformed the other models but the change from the glass box to the as-built was the most substantial. The difference between the solid model results from BEopt and Revit was 33%, while those for the glass box across programs differed by 30%.

figure 14: CubeHaus, area models

To isolate formal variables further, the CubeHaus iterations investigated the effects of area, volume, and orientation [Table 1]. Iteration 2A used a simple cube model with an area of 1,024 ft², measuring thirty-two feet in width, length, and height [Figure 14]. Its area was then halved in one case and doubled in another, the dimensions changing accordingly to keep the volume consistent across each model. The area of each southern façade was 40% glazing, while the remaining three walls were entirely opaque.

AREA:

CASE #	SCALE	AREA (FT ²)	VOLUME (FT ³)	X (FT)	Y (FT)	Z (FT)	FRONT ORIENTATION	GLAZING AREA (%)
1	1.0	1,024	16,384	32	32	16	S	40
2	0.5	529	16,399	23	23	32	S	40
3	2.0	2,025	16,200	45	45	8	S	40

VOLUME:

CASE #	SCALE	AREA (FT ²)	VOLUME (FT ³)	X (FT)	Y (FT)	Z (FT)	FRONT ORIENTATION	GLAZING AREA (%)
1	1.0	1,024	16,384	32	32	16	S	40
2	0.5	1,024	8,192	32	32	8	S	40
3	2.0	1,024	32,768	32	32	32	S	40

ORIENTATION:

CASE #	SCALE	AREA (FT ²)	VOLUME (FT ³)	X (FT)	Y (FT)	Z (FT)	FRONT ORIENTATION	GLAZING AREA (%)
1	1.0	1,024	16,384	32	32	16	S	40
2	1.0	1,024	16,384	32	32	16	N	40
3	1.0	1,024	16,384	32	32	16	E	40
4	1.0	1,024	16,384	32	32	16	W	40

table 1: CubeHaus model variables

In both Revit and BEopt, the halved area yielded the highest overall demand, corresponding to the increased surface area needed to accommodate the increased area. A form with more surface area not only requires more materials to enclose the interior spaces, it also results in more heat loss because of the increased area of envelope through which heat can flow and escape, placing more pressure on the heating and cooling systems.¹⁷ The model with the smallest area awarded the highest results because of its slender, elongated form – a compact form is more economical in shape and materials, and intuitively more efficient, explaining the low numbers of the doubled-area model.

The halved area was 60% less efficient than the base model in BEopt and 65% less efficient in Revit. A great difference between the base and the doubled area was also apparent in both programs – a 51% increase in efficiency in BEopt and a 39% increase in Revit. The greatest difference in performance was afforded to the change from the halved area to the base model. Across the board, heating was the largest demand except in the doubled area Revit model, where the appliances and lights equally accounted for the greatest demand, with

heating as the third highest. There was a 26% difference between the halved areas in both programs and a 20% difference between the doubled areas. This iteration suggested that a tall, slender figure with a smaller area is less efficient than a wide, stout form with a larger area.

figure 15: CubeHaus, volume models

Iteration 2B manipulated the volume while maintaining a consistent area, length and width, and orientation [Figure 15]. The highest numbers were yielded by the doubled area, which again corresponded with a tall form with a large surface area. This model was 52% less efficient than the base in BEopt, and 39% less efficient in Revit. Conversely, the squat, halved-volume model had the lowest results: 40% more efficient than the base in BEopt and 30% more efficient than the base in Revit. Heating was the highest demand. The halved volume resulted in a 31% difference between programs while the doubled volume saw a 54% difference. The conclusion that can be drawn in this scenario is that the tallest figure – the doubled volume – with the greatest surface area was the least efficient.

figure 16: CubeHaus, orientation models

In the last iteration, 2C, the base model in both 2A and 2B – with a fixed area and volume – was rotated so that its glazed façade faced each of the four directions, with the southern orientation as the base [Figure 16]. This iteration produced the smallest differences between results. In each case, the southern orientation performed the best, followed by the east, west, and north. In BEopt, the difference between case studies and the base varied between 2% and 5%, whereas the range in Revit was 10% to 12%. Heating was the highest demand across all examples, but it is worth noting that cooling is proportionately higher on the southern model and lower on the northern model, directly corresponding to the amount of direct sunlight – and potential for overheating – each elevation receives. The southern model

was the highest performing with a 35% variance between programs, while the northern model yielded a 36% difference. These examples demonstrated that the orientation of a simple cube played a small role in its overall efficiency.

Overarching trends in inputs and outputs, and strengths and weaknesses, were uncovered through these iterations and their side-by-side comparisons. While the programs performed well in providing a general overview of all models, with relatively consistent trends between both platforms, there were several limitations to both that affected the ease of modelling and generating results.

BEopt is admirable for its highly-detailed list of presets. It is easy to select an option that best suits the project, and equally as simple to create a user-defined option if one of the standard ones does not suit. Its accurate performance evaluation and reporting are refined, however it is very limited in terms of defining the home's formal aspects. The interface employs a fixed, square grid, restricting itself to ninety-degree angles — any plan that varies from this form is nearly impossible to model accurately.

Revit is primarily used for the design of large-scale buildings and, accordingly, its settings and interface are best suited for projects of this scale. For this reason, there are very limited options that accommodate single-family homes. To define a mechanical system for the building, one must select a predetermined option from a drop-down list; without the ability to edit the properties of the equipment, one must select an option that best suits a small-scale residential occupancy. However, its greatest advantage is its high level of precision regarding the modelling and detailing of the building. Wall assemblies, thermal and spatial properties, and the drawing tools are very flexible and editable, which makes Revit an easy-to-use design program.

In conclusion, BEopt is better suited for studying the degree of impact between equipment types within a relatively simple floor plan and for evaluating very general design moves, while Revit is better suited for scenarios that require a more detailed study of specific design moves. It is easier to trace the impact of more subtle formal changes in Revit than in BEopt and, accordingly, it became the evaluation tool for the next investigations. Despite the highly adaptable nature of Revit's modelling interface, it was made evident through the minor result differences in formal changes reflected by both programs that a comparative analysis only begins to skim the surface of the question of design in relation to performance.

QUANTITATIVE

This investigation was concerned with a series of quantitative moves targeting the performance of the envelopes of Elle and Lungo. It was a direct result of the inability of both programs' performance results to show sensitivity to detailed formal changes. This analysis was a necessary foundation upon which a qualitative investigation into the design of both case studies could be developed.

The ensuing quantitative research used the shell Revit models from the previous comparative analysis and adapted them to more accurately reflect the as-built homes; the interior partitions, staircases, doors, and vertical shafts and voids were added. Assumptions from the previous models – including omitting below-grade or exterior living spaces, and standard dimensions for wall heights, doors, and windows – were maintained for consistency.

Further assumptions were added at this stage to provide details that would directly impact energy performance. All elements of the envelope were detailed – exterior and interior walls, flat roof, and floor – according to the building codes and guidelines in place at their time of construction. The assemblies were detailed according to a 1999 publication by the Canadian Mortgage and Housing Corporation (CMHC) that provided best practices at the turn of the century.¹⁸ The exterior walls for both houses followed a simple **RAINSCREEN** approach and were finished on the exterior with metal cladding.

raainscreen: wall
construction approach
where a cavity is added
between the exterior finish
and the rest of the wall
assembly to protect it from
any unwanted moisture
penetrating the finish,
allowing the precipitation
to evaporate or drain
down and out of the
bottom of the cavity

Each quantitative change was simulated in isolation and in relation to the base model. General performance settings were affected according to the variable being tested, including the HVAC system (a gas furnace), the electrical demand (appliances and lighting) per square metre, and the double-glazed windows [Table 2]. Like the comparative analysis, the results were given in terms of annual site energy usage.

	EQUIPMENT	HEAT PUMP	INSULATION (EX)	INSULATION (IN)	LIGHTS	WINDOWS
base	10.76 W/m ²	none	none	none	10.76 W/m ²	x2 glaze
equipment	3.88 W/m ²	none	none	none	10.76 W/m ²	x2 glaze
heat pump	10.76 W/m ²	yes	none	none	10.76 W/m ²	x2 glaze
insulation (exterior)	10.76 W/m ²	none	38 mm extra	none	10.76 W/m ²	x2 glaze
insulation (interior)	10.76 W/m ²	none	none	38 mm extra	10.76 W/m ²	x2 glaze
lights	10.76 W/m ²	none	none	none	5.38 W/m ²	x2 glaze
windows	10.76 W/m ²	none	none	none	10.76 W/m ²	x3 glaze, low-e
all (furnace)	3.88 W/m ²	none	none	38 mm extra	5.38 W/m ²	x3 glaze, low-e
all (heat pump)	3.88 W/m ²	yes	none	38 mm extra	5.38 W/m ²	x3 glaze, low-e

table 2: settings for upgrade models

This analysis is justified by Natural Resources Canada's studies regarding increased energy efficiency. The data revealed that improvements in energy efficiency from 1990 to

2013 were the result of improvements to the building envelope and the use of more efficient appliances and heating and cooling units.¹⁹ These factors are therefore the variables of the following investigations.

The first iteration ran the base model through Revit's EnergyPlus energy simulation to establish a baseline. Secondly, the equipment (interior plug loads and appliances) settings

EnergyStar: a rating system and program that establishes a high level of energy efficiency for products

>> were altered to reflect if all units were updated to **ENERGYSTAR** appliances. The third and fourth iterations targeted the envelope with the addition of an extra 38 mm of rigid insulation. The exterior insulation case involved the insertion of the new layer on the extreme exterior side of the structure, between the cladding and the existing layer of exterior rigid insulation. The interior insulation case addressed the extreme interior side of the structure, placing the new layer between the interior gypsum board finish and the plywood sheathing. The fifth iteration addressed lighting; similar to the equipment iteration, all fixtures were updated to efficient light-emitting diode (LED) fixtures. The windows were upgraded in the sixth case to triple-pane units with a low-emissivity coating to help improve their thermal retention, a critical feature in cold climates. The seventh scenario replaced the gas furnace with a more efficient electric

air source heat pump: an exterior unit that transfers warm air between the interior and exterior according to the season, serving both heating and cooling requirements

>> **AIR SOURCE HEAT PUMP**. Substituting a furnace for a heat pump is a relatively easy intervention because it uses the existing unit's cooling coil and only requires the addition of a heating coil. Finally, two iterations were run with all of these upgrades – one case used the existing furnace and all the upgrades, while another swapped the furnace for the heat pump in addition to the other changes. Both cases employed the interior insulation approach rather than exterior insulation approach [Figure 17].

For both Elle and Lungo, the combined upgrades with the heat pump produced the most efficient model; in fact, upgrading simply to a heat pump was the second-most efficient case, yielding better results than the iteration with all the upgrades and furnace [Figures 18, 19]. The results demonstrated that the heat pump was an efficient upgrade that created relatively little disturbance to the existing home. Further, the heating demand was significantly reduced in the heat pump models; in these cases, the fans drew the most energy, followed by heating, compared to heating dominating the energy demand in the remaining iterations. For both homes, all of the upgrades plus the furnace placed third in most efficient results, followed by upgrading the windows; though a fairly effective and relatively unobtrusive intervention, replacing every window unit with triple-glazed would be quite costly.

figure 17: description of
quantitative upgrades

figure 18: Elle, quantitative results

figure 19: Lungo, quantitative results

Lungo performed more intuitively in that every iteration was more effective than the base model [Figure 19]. The next most-effective upgrade involved insulation – the interior insulation marginally outperformed the exterior insulation and is arguably an easier intervention because only the gypsum board would need to be replaced rather than removing the exterior cladding. The simplest solutions – upgrading light fixtures and appliances – had the smallest impact but were still worthwhile undertakings as they improved upon the base model.

Elle generally followed the same trends, except the addition of insulation was slightly more energy intensive than the base model [Figure 18]. This could be attributed to the home's more complicated envelope – its L-shape has more surface area, requiring more material and expending more energy through heat loss across the larger surface area. Both insulation models did reduce the overall heating load, however, as the material addition improved the heat retention of the envelope, relieving some of the pressure from the mechanical systems to heat the space.

ELLE (1 WAYS LANE)													
AREA (M ²) = 115.51							AREA PER PERSON = 38.5 M ² (3 PEOPLE)						
VARIABLE	HEATING (KWH/YR)	% OF TOTAL	COOLING (KWH/YR)	% OF TOTAL	LIGHTS (KWH/YR)	% OF TOTAL	EQUIPMENT (KWH/YR)	% OF TOTAL	FANS (KWH/YR)	% OF TOTAL	TOTAL (KWH/YR)	OVERALL RANK	
all (heat pump)	1,753	26	569	9	1,486	22	1,072	16	1,783	27	6,663	1	
HVAC	1,639	21	1,350	17	1,497	19	1,497	19	1,956	25	7,939	2	
all (A/C)	15,239	81	975	5	1,486	8	1,072	6	103	1	18,875	3	
windows	13,650	71	2,353	12	1,497	8	1,497	8	150	1	19,147	4	
equipment	15,861	79	1,986	10	1,497	7	542	3	144	1	20,030	5	
lights	15,633	78	2,031	10	750	4	1,497	7	144	1	20,055	6	
base	14,831	74	2,194	11	1,497	7	1,497	7	147	1	20,166	7	
insulation (interior)	12,636	62	1,567	8	2,969	15	2,969	15	114	1	20,255	8	
insulation (exterior)	12,642	62	1,567	8	2,969	15	2,969	15	114	1	20,261	9	

LUNGO (40R SHAFESBURY AVENUE)													
AREA (M ²) = 38.99							AREA PER PERSON = 13.0 M ² (3 PEOPLE)						
VARIABLE	HEATING (KWH/YR)	% OF TOTAL	COOLING (KWH/YR)	% OF TOTAL	LIGHTS (KWH/YR)	% OF TOTAL	INT. EQUIPMENT (KWH/YR)	% OF TOTAL	FANS (KWH/YR)	% OF TOTAL	TOTAL (KWH/YR)	OVERALL RANK	
all (heat pump)	1,756	28	1,183	19	739	12	581	9	1,917	31	6,176	1	
HVAC	1,728	28	1,314	17	1,308	17	1,308	17	1,961	26	7,619	2	
all (A/C)	15,394	81	2,050	11	739	4	581	3	144	1	18,908	3	
windows	14,489	74	2,344	12	1,308	7	1,308	7	153	1	19,602	4	
insulation (interior)	14,839	75	2,217	11	1,306	7	1,306	7	150	1	19,818	5	
insulation (exterior)	14,847	75	2,219	11	1,306	7	1,306	7	150	1	19,828	6	
equipment	16,125	80	2,106	10	1,308	6	583	3	150	1	20,272	7	
lights	15,950	79	2,136	11	742	4	1,308	6	150	1	20,286	8	
base	15,333	75	2,250	11	1,308	6	1,308	6	153	1	20,352	9	

table 3: quantitative analysis results

This exercise produced a highly optimized version of the base model that considered several potential upgrades and their attributed factors and effects [Table 3]. Cumulatively, the new house models employed high performance triple-pane windows, efficient appliances and light fixtures, insulated, **AIRTIGHT** envelopes, and new heat pumps. These upgrades addressed the energy efficiency of both case studies in a quantifiable way through a number of changes ranging in cost, effectiveness, and intrusiveness. While substantial in their effect on performance, they have very little impact on the formal qualities of the homes. A third, qualitative study is necessary to address and compare its effects relative to those of a quantitative nature. The most effective model – all upgrades plus a heat pump – became the new base model for the qualitative performance improvements that followed.

airtightness: a quality measured in air changes per hour (ACH) that describes the degree to which the building envelope resists the movement of air

>>

QUALITATIVE

The next phase targeted qualitative design choices, those that directly impact intangible sensations like comfort and enjoyment. This phase of research aimed to demonstrate how these types of decisions influence the energy performance of a home. Qualitative design is addressed through daylighting analysis to discover how a space's relationship with natural light could affect the habits and use of the occupants. There are many factors associated with natural light, including its intensity, colour, and location; all vary over the course of a day and season and have a direct impact on people's well-being.²⁰

Preliminary daylighting studies of Elle and Lungo suggested that there was potential for improvement in order to respond to the sites' sunlight patterns and to improve the quality of the interior spaces. The results further highlighted how the windows — including their placements and sizes — serve the interior spaces and cater to the user activities. In response, the following studies uncovered to what extent the reorganization of window placements and the use of natural light affected energy use and performance.

Firstly, each independent living space — living/family room, dining room, kitchen, bedrooms — was analyzed in isolation [Figure 20]. The purpose was to discover the direct and independent relationship of each space to daylight before considering each room as a part of the whole. Though modelled in isolation, surrounding buildings were included to depict the existing conditions. The outputs were measured in **DAYLIGHT AUTONOMY** (DA) to determine the amount of sufficient light being admitted, where sufficient refers to the amount or quality of light that is conducive to performing tasks. This 'useful' light has a value of 300 **LUX** — a number falling far below this median describes a very dark space while a number greatly exceeding this median describes an excessively bright space. The results revealed how much of the floor area received at least 300 lux over the course of the year during the residential hours of occupation, namely between 7:00 and 10:00 AM and 4:00 and 7:00 PM.

daylight autonomy: a metric that denotes a percentage of time that an area receives sufficient daylight over the course of a year >>

lux: the metric unit of illuminance >>

The results, produced in DIVA, were visually graded on a scale from blue to red, where blue denotes an under-lit area and red an over-lit area; general rules of thumb concerning daylight and orientation helped interpret the visual results [Figure 21]. Elle is bordered on three sides by neighbouring houses, leaving the eastern, street-side face relatively unobstructed [Figure 22]. Its entire southern façade is devoid of openings. The living/dining room benefitted from little direct light because its windows exclusively face north; it was the second darkest room, receiving useful light for 9.9% of the year. The design of the kitchen implies cooking

figure 20: Elle and Lungo, spatial divisions for qualitative analysis

was of minimal importance to the clients – the closed-off space outfitted with small appliances primarily acts as a hallway between the front and back of the house.²¹ Appropriately, the kitchen was the most insufficiently lit room, subjected to useful light for 8.8% of the year. The family room faces west and received a fair amount of sunlight in the late afternoon and early evening, when entertaining guests might occur. The studio space – doubling as a potential second bedroom – on the second floor was consistently well lit, a desirable quality for a work space.

¹ Avi Friedman, *Fundamentals of Sustainable Dwellings* (Washington, DC: Island Press, 2012), 17.

² John Carmody et al., *Window Systems for High-Performance Buildings* (New York, NY: W.W. Norton & Company, Inc., 2004), 45.

³ U.S. Department of Energy, "Daylighting," accessed February 12, 2020, <https://www.energy.gov/energysaver/daylighting>.

figure 21: daylighting rules of thumb

The brightest room in the home was the master bedroom, inviting in a great amount of eastern light through its corner window to naturally awaken sleepers in the mornings. Its mean DA is 18.2% for the time occupied annually. On average, Elle's five spaces received useful daylight 12.7% of the year during occupied hours.

figure 22: Elle, daylighting results before, 1:200

figure 23: Lungo, daylighting results before, 1:200

Lungo, too, is framed on three sides by neighbours, its western wall facing the street. The house is an interesting daylighting study because of its two lightwells. These skylights bring additional light to the living room and the combined kitchen and dining room on the first floor. The results indicated that both spaces benefitted from a considerable amount of diffused sunlight from above [Figure 23]. The living room was the brightest room, lit by useful light for 14.9% of the year due to a corner window facing southeast.

At the northern end of the house, the kitchen/dining room did not receive a lot of light during operational hours, namely in the evening to prepare and eat dinner. The kitchen was mostly shaded, tucked away in its corner, while the dining area benefitted from two full-height windows. Upstairs, the bedroom faces north and east while the master bedroom is exposed only to the east. Both rooms were lit considerably from the east, rousing slumberers in the early morning. Both spaces saw 13.0% of the year exposed to useful light. All four spaces received daylight on average 14.0% of the year during occupied hours.

The results demonstrated that Lungo marginally received more useful daylight than Elle, suggesting that in this comparison its long, narrow shape is more conducive to the introduction of natural light compared to Elle's L-shape [Table 4]. The design intention of Elle's floor plan was to favour the exterior courtyard, explaining why the plan's two legs flank the backyard, however the orientation of this configuration is not receptive to daylight [Figure 24]. Considering the impact of the skylights on the daylighting results, perhaps the lightwells are under-utilized in Lungo's existing design, as neither of the rooms on the second floor take advantage of this feature [Figure 25].

ELLE (1 WAYS LANE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
kitchen	3.50	3.20	11.20	8.75
living/dining	5.60	4.00	22.40	9.92
bedroom/studio	9.20	5.30	48.76	10.70
family room	4.50	5.90	26.55	16.19
master bedroom	4.50	5.90	26.55	18.23
average				12.76

LUNGO (40R SHAFTESBURY AVENUE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
bedroom	3.00	2.40	7.20	13.13
master bedroom	3.00	3.90	11.70	13.32
kitchen/dining	3.10	4.50	13.95	14.72
living	3.10	3.90	12.09	14.89
average				14.02

table 4: Elle and Lungo, daylighting results before

Next, analysis for individual rooms was continued by isolating the existing windows. Each original window was reconsidered through three different window types: full height (floor-to-ceiling glazing), high ribbon (short unit height and placed near the top of the wall), and standard sill (three foot tall unit with a standard three foot sill height). The sill height and overall height of the windows were manipulated, while their width and placements on the walls remained as-built. These three cases address views and daylight penetration, quantity, and quality with varying degrees of success.

figure 24: Elle, full house daylighting results before, 1:250

figure 25: Lungo, full house daylighting results before, 1:250

The full height introduces natural heat into the space and lets in the greatest amount of light, but it is more direct and intense. While it promotes uninterrupted views, it may not always be appropriate in relation to the use of the room. The amount of daylight that is admitted into a room is proportional to the amount of sky viewed through the window, therefore high, horizontal windows are most effective at introducing light into the space than low, wide windows.²² If full height and high windows are two extremes, the standard sill serves as the middle of the spectrum.

Once these different conditions were established for each room, it was considered how these windows might affect interior organization. Furniture layouts were modified for each space; as the photographs of Lungo show it furnished, the as-designed arrangement was deemed the base, whereas an existing condition was imagined for Elle as it was photographed in an unfurnished state [Figure 26, see Appendix E for the full results of all rooms]. This step explored how the established light patterns might affect activity and comfort as inferred by furniture layouts, and how these qualities might be adjusted to respond to the daylighting results. The investigation was highly subjective because it is hard to objectively quantify the DA results as individual tolerances can vary greatly. The quantitative results – with the help of criteria like comfort, use, and the flow of and between the spaces – were qualitatively interpreted through personal opinions and the accompanying *Canadian Architect* articles describing the clients' desires and needs.

The result of these studies was a final window layout based on this qualitative reading. Several iterations were explored, comparing their energy performance to that of the base model in order to uncover the relationship of improved daylighting to energy usage. The first scenario of the most objectively 'ideal' windows involved selecting which of the three window types yielded the lowest energy demand by room. For instance, when run through Revit's analysis engine, Elle's master bedroom produced the lowest numbers when all of the existing windows were converted to high ribbons; this too was the case with the bedroom and living/dining room. Full height windows was the most energy efficient scenario for the kitchen. The family room's existing layout was the most effective because its heating load was substantially smaller than those of the other three cases due to the solar heat gain from the existing larger windows. All of Lungo's rooms favoured high ribbons save for the master bedroom, which benefitted most from standard sill. When these conditions were combined into the base model, the energy performance saw a 1.7% increase from the base for Elle and a 2.0% decrease for Lungo. While producing attractive energy performance results, the arrangement of windows was rather impractical; the almost exclusive use of high ribbon windows limits visibility and therefore does not produce a comfortable home.

Comparatively, a second iteration evaluated the numerical results to strike a balance between their quantitative and qualitative values. The windows were reorganized according to the window type condition which best suited each individual window and its relationship to the room and the other windows in the space. This iteration was conscious of keeping the original window-to-wall ratio of the base model consistent to avoid drastically altering the intent of the original design.

figure 26: Elle bedroom/studio, three window variations results, 1:200

As opposed to previous studies, the sill height, width, and overall height of the units were manipulated, and in some cases the placement of some of the units was changed to achieve more desirable daylighting results. On Elle's east face, a tall window was removed from the kitchen and placed in the family room, and the northern family room window's position was shifted on the same façade to provide an even distribution of lighting [Figure 27]. Regarding layout, the original kitchen plan remained untouched because it was the best use for the space. Different furniture layouts were afforded in the entertainment spaces of the family, living, and dining room to respond to lighting conditions and improve flow. Upstairs, the bed placements suited the spaces while the studio design allowed flexibility depending on desired use while remaining separate from the sleeping area [Figure 28].

figure 27: Elle elevations, before and after, 1:200

figure 28: Elle, daylighting results after, 1:200

On Lungo's east face, both of the first-floor windows shifted their positions to adjust light admission into both the living room and the kitchen [Figure 29]. The kitchen opened up to take advantage of the room's length, providing more working space and freeing it from the darkest corner of the room while still accommodating room for dining. The living room layout was subtly adjusted to support flow around the staircase. While the bedroom layouts remained untouched, the addition of two windows took advantage of the lightwell to provide, along with some changes to the existing windows, a more even light distribution to both rooms [Figure 30].

figure 29: Lungo elevations, before and after, 1:200

figure 30: Lungo, daylighting results after, 1:200

figure 31: Elle, full house daylighting results after, 1:250

figure 32: Lungo, full house daylighting results after, 1:250

The individual rooms and overall homes were then brought back into Revit to see if the qualitative improvements yielded quantitative energy performance improvements. The results revealed no general consensus, highlighting the delicate balance between designing for efficiency and for delight [Figures 31, 32]. In some cases, the new rooms performed better than their bases while the opposite was true in other cases. Elle's new window model was 5% less energy efficient than its base from the quantitative study while Lungo was 1% more efficient than its base. Considering that both houses with quantitative

ELLE (1 WAYS LANE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
kitchen	3.50	3.20	11.20	3.57
bedroom/studio	9.20	5.30	48.76	7.99
living/dining	5.60	4.00	22.40	9.92
master bedroom	4.50	5.90	26.55	18.28
family room	4.50	5.90	26.55	26.41
average				13.23

LUNGO (40R SHAFTESBURY AVENUE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
kitchen/dining	3.10	4.50	13.95	10.07
bedroom	3.00	2.40	7.20	11.86
living	3.10	3.90	12.09	16.09
master bedroom	3.00	3.90	11.70	17.88
average				13.98

table 5: Elle and Lungo, daylighting results after

upgrades saw about a 60% decrease in energy usage from their as-built conditions, a 5% increase in use for Elle can be considered negligible, though not an ideal outcome [Table 5].

A simple conclusion to draw from these final studies is that quantitative and qualitative decisions directly impact one another, and a compromise will always result when trying to balance the two. Design decisions overlap and exist in a grey area – a choice cannot be singularly qualitative or quantitative, as all aspects of design to a degree address and affect both realms. However, the investigations have illustrated that these decisions produce substantial effects to delight, comfort, and performance, and that even small changes can directly impact a home's design in terms of efficiency, use, and appeal. The two phases of investigation targeting the envelope and daylighting have proven that both case studies could objectively benefit from a renovation to implement these changes or, more ideally, these issues could have been considered and implemented during the design and construction phase to save time, money, resources, and energy. The results have revealed that improvements could generally be made through rather subtle and unobtrusive means that do not alter the character or design intent of the homes, but the subtlety of these adjustments serve also to highlight the architectural strength and excellence of the designs.

This concludes the quantity and quality investigations of the case studies; while additional analysis could further explore the relationships, the thorough investigations and their substantial results have sufficiently proved that a new, balanced workflow can be adopted from the methods and conclusions outlined thus far. This research has helped to identify trends

and qualities present in the design and execution of the two homes, and has been validated through the research's comprehensive workflow.

The final section introduces a new methodology that will be demonstrated by designing a new laneway house. This process will guide architectural workflow by affirming what the research has verified in a tangible, practical way, and ensuring that design and performance are balanced throughout the entire process.

figure 33: context plan, 1:50000

SITE AND CLIENT

The proposed methodology follows a similar course of action to the preceding studies. To ensure design and performance remain in equilibrium, each stage of the four-step process informs one another through continuous energy and daylighting analyses; ongoing translation between models and analysis tools in both Revit and DIVA establishes an uninterrupted dialogue between their respective design discussions. As with conventional workflow, the method guides the design from its initial stages through to the detailed, complete home model by using performance data to justify qualitative decisions.

The workflow's foundation – upon which all decisions and impressions are built – is the site and client. Once both are established, the first phase of design involves simple massing, where qualities like shape, volume, area, and orientation are determined and when the first energy and daylighting analyses occur. A massing is selected to advance into phase two, which introduces program and internal arrangement. Spaces and interior partitions are placed and evaluated in Revit and DIVA. The best option is selected to move into the third phase regarding openings and window placement. Similar to the qualitative study, different spaces and their relationships to windows are assessed. A final prototype emerges from this phase, where the design is brought to fulfilment through minor revisions and additions [Figure 34].

The fictitious client requirements were based on a questionnaire [Figure 35]. These questions became the

figure 34: proposed methodology

reference point for subsequent decisions, allowing the decision-making to remain objective and producing a finished product tailored to a clear set of requirements and desires. The client was defined as a young professional seeking to build a starter home for themselves and a partner, with the potential to eventually expand their family and host guests. The primary spaces included an area to entertain and a bright, functional kitchen, while a studio/office and bedrooms were secondary in importance and size.

CLIENT QUESTIONNAIRE

CLIENT INFORMATION

age 18-25 26-35 36-45 46-55 56-65 66+
 status single in a relationship engaged married separated/divorced widowed other _____
 do you live alone? Y N if no, how many people do you live with? 1
 do you have children? Y N # _____ do you have pets? Y N # _____
 job Structural Designer do you ever work from home? Y N describe how home office, large plan table
 personal tastes (materials, style, furnishing, etc.) wood, contemporary modern, dark + light (contrast)

IDEAL HOME DESCRIPTION

what goals are you hoping to achieve? _____
 longterm plan for the home starter home forever home other _____
 # of above ground storeys 2 car(s) Y N # 1 storage garage carport none (driveway)
 hobbies/activities that might take place at the home woodworking studio, or multi-purpose studio room
 ideal # of bedrooms 2+ ideal # of bathrooms 2.5
 additional must-have rooms kitchen dining room living room family room office/studio
 other _____
 is entertaining important? Y N do you require formal and informal spaces? Y N
 describe needs for entertainment spaces TV, Fireplace, open space but not too open, division/separation
 ideal kitchen, any must-haves pasta filler, uninterrupted center space, natural light
 ideal bedroom, any must-haves ensuite, natural light
 ideal bathroom, any must-haves bidet, shower w rainfall, combo., double sink?, center space.
 important connections/adjacencies between rooms master bedroom w ensuite, kitchen w adjacent living room
 how should spaces accommodate your daily routine? where do you spend the most time? most time in living room, and kitchen, minimal time in office and bedroom studio time would vary on free time available
 hierarchy of rooms and importance in terms of size, use, privacy, etc. 1) Kitchen and living room to have most space, privacy not a concern for these spaces, 2) Studio: second largest space 3) Master bedroom: 3rd most space
 any privacy concerns? balance between privacy and natural light
 is outdoor living important? Y N if yes, describe Outdoor entertaining area, w pizza oven, low maintenance green space.
 describe to what extent natural light is important to you, and any views you wish to enhance or obstruct natural light around kitchen sink, morning light in bedroom, afternoon/evening light in entertaining areas.
 do you ever host guests? Y N if yes, how many guests at a time? 2
 mobility/accessibility concerns Y N if yes, describe _____
 desired design features (pitched ceiling, fireplace, etc.) rustic brick wall/feature wall, wood elements
 desired exterior design features (elevations, landscaping, etc.) brick, wood, stucco, Flat/angular roof
 non-negotiable features N/A

figure 35: completed client questionnaire

figure 36: site plan, 1:1250

Located in Little Portugal at 62A Moustray Street, the site was selected from a real estate website; it is currently vacant and for sale, making it a desirable blank slate for development. Occupying 525 m², the lot is located at the centre of the residential block, off a laneway accessed from Moustray Street [Figure 36]. It is equidistant from the surrounding homes on all sides and separated by their backyards, providing a respectable distance and privacy from the neighbours. Two existing structures on the site are included in the property sale. These sheds could easily be converted to a garage or workshop to extend their lifespans; alternatively, they could be demolished if the extra space is not needed.

As it is a laneway house, the project is subject to a number of restrictions and zoning bylaws as mandated by the City of Toronto [Figure 37]. In June 2018, the city introduced By-law 810-2018 to allow the construction of laneway homes as ancillary, independent structures accessed by a lane in areas zoned for residential use. These suites are independent, principal dwelling units with facilities for food preparation and bathing, and physically separated from the street-front home on the same lot. They are only allowed to be constructed in an urban zone defined by Lake Ontario to the south, Parkside Drive to the west, Eglinton Avenue to the north, and Victoria Park Avenue to the east. Several regulations are outlined to direct development, including maximum footprint, height, width, and length, lot coverage and landscaping, and setbacks [Table 6]..²³

REQUIREMENTS (COURTESY OF CITY OF TORONTO BY-LAW 810-2018)

62 Moutray
site area: 138 m²
footprint: 74.2 m²

62A Moutray
site area: 122 m²
footprint: 41.46 m²

CATEGORY	DESCRIPTION
rear yard setback (150.8.60.20)	min 0.0 m if rear wall has no openings or does not abut a street or lane min 1.5 m for all other cases
side yard setback (150.8.60.20)	min 0.0 m if side wall has no openings or does not abut a street or lane min 1.5 m for all other cases
minimum separation (150.8.60.30)	5.0 m from main dwelling if height does not exceed 4.0 m 7.5 m from main dwelling if height exceeds 4.0 m
maximum length (150.8.60.30)	10.0 m
maximum width (150.8.60.30)	8.0 m
maximum height (150.8.60.30)	4.0 m if located 5.0 m to 7.5 m from main dwelling 6.0 m if located more than 7.5 m from main dwelling
maximum storeys (150.8.60.30)	2
interior floor area (150.8.60.50)	must be less than the gross floor area of the main dwelling
lot coverage (150.8.60.70)	cannot exceed 30% of main dwelling lot area
decks and platforms (150.8.60.60)	< 10% of interior floor area, complies with setbacks, heights, etc. and not including green roof required opaque screen no less than 1.5 m in height on the side yard no higher than 0.2 m above storey from which it is accessed can encroach on the limiting distance from main dwelling by 1.5 m if not greater than 0.3 m in height
landscaping (150.8.50.10)	≤ 6.0 m, min 60% soft landscaping between front and back units < 6.0 m, min 85% soft landscaping between front and back units
car parking (150.8.80)	not required
bike parking (150.8.80)	2 spaces required within suite or yard setbacks

table 6: zoning regulations

figure 37: zoning site plan, 1:400

MASSING

Within the regulations of bylaws and the nature of the site, six massing iterations were explored, each variation addressing orientation, adjacencies, and other relationships to the site and client in different ways [Figure 38]. Though the entire irregularly-shaped lot is for sale, a rectangular section was selected because of its direct adjacency to the house at 62 Moutray, the principal dwelling unit to which the bylaw refers, and its relationship to the laneway and the existing shed.

figure 38: massing models

Massing 01 represents the most straightforward relationship between setbacks and site restrictions: with the maximum footprint of forty-one square metres, it is a rectangle with space for an outdoor living area at either the northern or southern end of the site [Figure 39, see Appendix F for all six site plans]. Massing 02 is a compressed L-shaped plan designed to shelter a backyard at the rear, east side of the site, away from the laneway. Similarly, massing 03 is an L-shape that is more introspective, creating a pocket for outdoor space that is turned inward, towards the laneway and away from the neighbours. Massing 04 is a rotated L that turns away from the neighbours to the north and east; like massing 03, it creates a sheltered space at the core of the site. Massing 05 breaks free from the linear site constraints to open itself up to the laneway

figure 39: massing 01 site plan, 1:300

and the centre of the site, leaving ample space at the back for outdoor living. Finally, massing 06 is a broken and rotated L-shape that engages the laneway and provides a backyard at the north.

To ensure continuity across models of varying surface areas and volumes, a window-to-wall ratio of 20% was allocated to each façade of each model in order to observe general lighting patterns when brought into DIVA and to provide a baseline for Revit's energy analysis. The same parameters from the quantitative study were applied to these Revit models: triple pane windows with corresponding thermal and material properties, appliances and lighting loads, an additional layer of interior insulation to wall assemblies, and a heat pump HVAC system.

Revit recorded a 12.0% difference in annual site energy use between the highest and lowest performing models [Figure 40]. In all cases, heating accounted for the greatest energy use, followed by lighting. Fans drew the smallest demand while the equipment and cooling loads varied across models for third and fourth place. Massing 03 was the most efficient model at the lower end of 5,000 kWh/yr. Its efficiency is likely credited to the east-west orientation of its longest façades; these exposures introduce less solar heat gain and are less likely to cause overheating than with a southern orientation, while still providing comfortable levels of daylight. Next was massing 02 followed by massing 04, 05, and 01, which produced similar results to one another. Massing 06 was the least efficient, likely due to its complicated envelope and surface area.

In DIVA, two storeys for each massing were modelled. A range of 8.9% existed between the averaged results from both floors of all models. The highest average mean DA is from massing 03, while massing 05 was awarded the lowest. Generally, all spaces were lit relatively well and evenly [Figure 41].

Without specific window placements and program allocation in plan, it is difficult to pinpoint a particular massing that yields the most ideal daylighting results. However, it is easier to evaluate daylighting in relation to the energy analysis results and the client's desires. The client expressed the importance of outdoor living space in conjunction with other entertainment spaces and described a preference for morning light in the bedrooms and afternoon/evening light in the public spaces. When considering these general criteria, massing 03 is the most appealing option. Its daylighting results are promising due to its primary east-west exposure and it yielded the best energy results. While the other models have their own merits regarding orientation, site, and energy usage, massing 03 was selected as the best option to advance into the planning stages.

figure 40: massing models, quantitative results

MASSING 01

level 1: 30.95%

level 2: 47.04%

MASSING 04

level 1: 23.39%

level 2: 46.96%

MASSING 02

level 1: 34.42%

level 2: 46.86%

MASSING 05

level 1: 27.07%

level 2: 38.53%

MASSING 03

level 1: 33.87%

level 2: 49.70%

MASSING 06

level 1: 26.54%

level 2: 41.53%

figure 41: massing models, qualitative results, 1:200

PLAN

With the footprint established by the massing investigations, the planning phase involved resolving the internal organization of program according to the client's habits and wishes; as a result, two final options were determined. Central to both options was the arrangement of public and private spaces. The spaces used for entertaining, namely the kitchen and living room, were grouped together in an open concept plan that encourages interaction and overflow between the two spaces, which will likely be used together and at the same time of day. Conversely, the bedrooms were kept together and in proximity of a full bathroom. Additional and secondary rooms, including mechanical, storage, and laundry, were grouped in the basement.

figure 42: option 1 plans, 1:150

Option 1 reserved the ground floor for public use and located the bedrooms on the second floor [Figure 42]. The levels are joined by a staircase, with the idea that this continuous volume could introduce light into both storeys through windows or skylights. An entry nook, with room for a bench and closet, leads into the main living space that is centred around a fireplace adjacent to the stairwell. The kitchen opens up onto an outdoor patio. On the second level, both bedrooms are served by a central bathroom. The master bedroom is located at the southern end of the plan, while the second bedroom can accommodate a queen-size bed or can be used as an office. This configuration satisfied many of the client's programmatic wishes, including the relationship of certain rooms to particular natural lighting conditions, a fireplace, uninterrupted kitchen counter space, the size of rooms, and the number of bathrooms and bedrooms.

figure 43: option 2 plans, 1:150

Option 2 similarly addressed these requests but reversed the spatial arrangement – the public space was shifted to the brighter, more open second floor while the main floor hosted the bedrooms [Figure 43]. Upon entry, guests can access the second floor by the adjacent stair. A ground floor patio is still accessible from the main floor hallway, before the master bedroom, which is separated from a smaller bedroom by the shared bathroom. The second floor welcomes one to a very open space for entertaining. The kitchen remains the same as the first iteration, but opens onto a smaller, elevated balcony rather than a garden patio. The living room, complete with fireplace, becomes more spacious; its openness allows it to benefit from western exposure via the stairwell.

Regarding annual energy analysis, option 2 outperformed option 1 by a small margin, just under 2.0% [Figure 44, Table 7]. Heating and fan demands were close between the two cases. The biggest difference existed in cooling loads – option 1's cooling load was closer to 1,000 kWh/yr while option 2's was closer to 600 kWh/yr. This could be explained by the greater number of openings on option 1's southern façade, more likely to promote overheating by solar radiation. Similarly, option 2 has fewer openings on its eastern and western walls.

Overall, the difference between the average daylighting results for both cases and both storeys was 3.4%, however option 2's daylighting results exceeded those of option 1, especially when comparing the second floors [Figure 45, Table 8]. Both first storeys yielded lower results, likely because their position closer to the ground and their relation to neighbouring structures does not allow as much light to penetrate. The difference between the second storeys was

13.2%, with option 1's mean DA at 6.6% and option 2's mean DA at 19.8%. The increase can be attributed to the openness of option 2's second storey plan – the open concept plan encourages more even daylighting than that of option 1, which is composed of closed-off rooms [Table 8].

figure 44: planning models, quantitative results

Iteration	Heating (kWh/yr)	Cooling (kWh/yr)	Lights (kWh/yr)	Int. Equipment (kWh/yr)	Fans (kWh/yr)	Total (kWh/yr)	
Option 01	1,953	936	561	528	289	4,267	2
Option 02	1,925	553	792	711	233	4,214	1

table 7: planning models, quantitative results

figure 45: planning models, qualitative results, 1:150

ITERATION	LEVEL 1 MEAN DA (%)	LEVEL 2 MEAN DA (%)	AVERAGE DA (%)	
Option 01	9.59	6.60	8.10	2
Option 02	3.22	19.77	11.50	1

table 8: planning models, qualitative results

Both the quantitative energy results and the qualitative daylighting results point to option 2 as the superior choice in terms of performance. However, discretion was required to justify that option 1 was the preferable option. The second configuration was less desirable spatially and in addressing the needs of the client. The first-floor arrangement of bedrooms was less ideal than that of option 1; it resulted in smaller bedrooms and a closed-off first floor that would feel cramped and less inviting. Additionally, a ground floor outdoor space is less attractive when it is accessed on a separate floor than the entertaining spaces. One of the few redeeming qualities of option 2's plan was the bigger, more spacious living room.

Option 1's arrangement is more intuitive and conducive to the client's lifestyle. Despite its lower performance by a small margin, it was selected to continue into the openings phase. This decision is yet another aspect of rectifying design and performance and achieving balance — had option 2 been selected, other sacrifices relating to design and occupation of the space would have to be made to accommodate the weaker, yet better performing, design.

OPENINGS

Like the quantitative daylighting studies, the house was first divided into four rooms to analyze daylighting conditions independently. Preliminary window locations were placed to accommodate views and to respond to lighting conditions expressed by the client. On the main floor, natural light was important around kitchen workspaces and to support connections to the outdoor patio. Windows in the living room were meant to compliment the layout of furniture and different activities that could take place there. In the bedrooms, windows allowed for views and eastern light exposure to wake inhabitants in the mornings.

When window placements were established, the three window types – full height, high ribbon, and standard sill – were implemented to provide three possible cases for each room. According to the DIVA results, the bedroom was extremely well lit by full height and standard windows, but conversely could offer too much light considering softer lighting could be more desirable if the space was used as an office or studio [Figure 46]. In the master bedroom, full height windows evenly distributed light while ribbon windows softened and limited the amount of light. Standard sill offered a happy balance and suggested prioritizing eastern openings over southern ones.

In the kitchen, full height and standard sill let in a substantial amount of light. It was a well-lit room in all three cases due to the full height glass sliding door; shading devices would be useful to limit the amount of direct sunlight while still allowing views to the backyard.

Similarly, full height windows covered the majority of the floor area in the living room; standard sill performed similarly but would provide a more concentrated spotlight in seating areas rather than in both seating and traffic areas. Ribbon windows offered softer, more diffused light to the space.

ROOM	VARIABLE	HEATING (kWh/yr)	COOLING (kWh/yr)	LIGHTS (kWh/yr)	INT. EQUIPMENT (kWh/yr)	FANS (kWh/yr)	TOTAL (kWh/yr)	RANK	DAYLIGHT AUTONOMY (%)
bedroom	full height	1,983	286	217	156	175	2,817	2	31.01
	high ribbon	2,153	164	217	156	136	2,826	3	4.86
	standard sill	2,081	200	217	156	147	2,801	1	20.30
master	full height	1,661	731	250	214	225	3,081	3	19.07
	high ribbon	1,642	608	250	214	206	2,920	1	3.77
	standard sill	1,647	647	250	214	211	2,969	2	11.20
kitchen	full height	2,447	292	264	192	225	3,420	1	38.61
	high ribbon	2,558	222	264	192	203	3,439	3	23.61
	standard sill	2,522	239	264	192	208	3,425	2	30.10
living	full height	2,800	422	264	192	281	3,959	3	21.65
	high ribbon	2,811	336	264	192	264	3,867	1	9.15
	standard sill	2,808	361	264	192	269	3,894	2	20.37

table 9: individual rooms, quantitative and qualitative results

Energy analysis revealed that the best performing cases involved standard in the bedroom, high ribbon in the master bedroom and living room, and full height in the kitchen [Table 9]. As noted, the standard sill provided a happy medium in a room with predominately northeastern exposure, allowing in controlled, more diffused lighting early in the day.

figure 46: individual rooms, three window variations results, 1,200

High ribbons are logical in rooms facing south to take advantage of daylighting without introducing too much light and heat gain. Full height in the kitchen introduced western light at the end of the day when its strength is beginning to diminish but its low position in the sky still allows it to reach deep into spaces.

Between the three cases for each room, a great difference did not exist between the best and worst cases, averaging about a 1.0% to 2.0% difference. This small margin suggested that variations in options do not significantly impact the performances. As noted in the quantitative analysis, heating demands were higher in the high ribbon configurations because they admit the least amount of light, while cooling was highest in the rooms with southern exposure, like the master bedroom, when the sun is at its highest intensity.

After reflecting once more on the results and needs of the client, each room was analyzed again in isolation with final window arrangements. In the bedroom, a standard sill was placed on the east and west façades, and a high ribbon window on the north wall to introduce diffused light [Figure 47]. This configuration yielded the lowest energy efficiency numbers, outranking the other three iterations; its DA number fell just below the average of the three cases [Table 10].

ROOM	VARIABLE	HEATING (KWH/YR)	COOLING (KWH/YR)	LIGHTS (KWH/YR)	INT. EQUIPMENT (KWH/YR)	FANS (KWH/YR)	TOTAL (KWH/YR)	RANK	DAYLIGHT AUTONOMY (%)
bedroom	full height	1,983	286	217	156	175	2,817	3	31.01
	high ribbon	2,153	164	217	156	136	2,826	4	4.86
	standard sill	2,081	200	217	156	147	2,801	2	20.30
	final	2,019	214	217	156	153	2,759	1	16.46
master	full height	1,661	731	250	214	225	3,081	4	19.07
	high ribbon	1,642	608	250	214	206	2,920	1	3.77
	standard sill	1,647	647	250	214	211	2,969	2	11.20
	final	1,642	697	250	214	219	3,022	3	13.69
kitchen	full height	2,447	292	264	192	225	3,420	2	38.61
	high ribbon	2,558	222	264	192	203	3,439	4	23.61
	standard sill	2,522	239	264	192	208	3,425	3	30.10
	final	2,483	244	264	192	214	3,397	1	27.71
living	full height	2,800	422	264	192	281	3,959	4	21.65
	high ribbon	2,811	336	264	192	264	3,867	1	9.15
	standard sill	2,808	361	264	192	269	3,894	2	20.57
	final	2,792	381	264	192	272	3,901	3	16.80

table 10: individual rooms, final quantitative and qualitative results

The master bedroom had two standard windows on the eastern wall, as well as a skinny full height southern window to let in some midday sun. A ribbon window punctuating the stairwell takes advantage of the light it introduces. This arrangement ranked third of all four, exceeding the most efficient high ribbon case by 102 kWh/yr, while its DA was the second highest of the four.

In the kitchen, employing a narrow, full height window alongside the patio doors and a standard window at counter height to provide natural task lighting was the best performing case of four variations, its DA rating just below the average.

In the living room, a large standard window was used on the eastern wall to provide lighting in the seating area, and a tall, narrow window was placed at the entry to allow in a controlled amount of southern light. This configuration placed third, and the DA fell at the average of all four.

figure 47: individual rooms, final window results, 1:200

Shading features (vertical and horizontal fins, roof overhangs) were considered. Testing revealed that shading devices positively influenced the DA by reducing the admission of strong sunlight – a 13.5% improvement for the ground floor and a 1.0% improvement for the second floor were recorded when using shading devices [Figure 48, Table 11].

These window placements and treatments were carried into the last phase, where the design was refined before its concluding analysis.

figure 48: openings models, qualitative results with and without shading devices, 1:50

ITERATION	LEVEL 1 MEAN DA (%)	LEVEL 2 MEAN DA (%)	AVERAGE DA (%)
final, shading	19.26	16.09	17.68
final, no shading	22.27	16.23	19.25

table 11: openings models, qualitative results with and without shading devices

FINAL DESIGN

an additional guest bedroom or office [Figure 50-62].

figure 49: site plan, 1:300

figure 50: plans, 1:150

figure 51: elevations, 1:200

figure 52: longitudinal and cross sections, 1:200

figure 53: exterior view, looking towards the house from the laneway approach

figure 54: exterior view, looking towards the house from the driveway

figure 55: exterior view, patio

figure 56: exterior view, front door

figure 57: exterior view, address

figure 58: interior view, living room looking towards the kitchen

figure 59: interior view, kitchen

figure 60: interior view, upstairs office in second bedroom

figure 61: interior view, looking down the stairs

light floor, ceiling, and walls

dark floor, wood ceiling

dark floor, wood ceiling, and dark kitchen cabinets

Three images of the living room serve to highlight how materials might affect the interpretation of the space; three material palettes show how various conditions can be qualitatively perceived differently despite the living room's quantifiable daylighting results remaining the same.

figure 62: living room, comparing material palettes

The final design had an energy demand of 7,689 kWh/yr. It was also modelled as a two-storey house without a basement to compare it to the two case studies, where basements were excluded from modelling [Figure 63]. Its demand, then, was 5,692 kWh/yr, in comparison to Elle's demand of 7,039 kWh (19.2% difference) and Lungo's demand of 6,164 kWh/yr (7.7% difference).

The average DA for both levels was 17.7% [Figure 64]. This average is similar to those of Elle and Lungo, however the new home's numbers were more moderate and comparable between levels. A difference exists where the ground floors of Elle and Lungo yielded far lower numbers, with a large difference existing between Lungo's first and second floors.

This house was a product of a defined methodology that collapses performance and aesthetics into one. The result is home that is bright and efficient (in both energy usage and scale), maximizes its small site, equally acknowledges quality and quantity, and appropriately communicates the client's wishes. While there is always room for improvement – for instance, the bedrooms and living room could be bigger – the home is the best solution to result from following the methodology, which has exhibited that alternative architectural practices can be successfully tested and implemented on residential projects.

figure 63: comparing quantitative results across three houses

figure 64: comparing qualitative results across three houses

CONCLUSION

This thesis' intent was to arm myself with useful tools of practice; these tools — whether in the form of a rules of thumbs handbook, a checklist, or, what would become the most viable option, a workflow method — would provide me with practical skills and knowledge when entering the profession. Guiding these ideas were my personal inclinations towards residential architecture, namely that a home should respond to its occupants, site, and environment in a thoughtful and deliberate fashion. The question I sought to answer was, how might design and, by extension, architecture respond to and strike a balance between these quantitative and qualitative demands?

This personal search produced these various studies, culminating in a design methodology. They offer a scrutinizing lens through which to view the practice of architecture, one that stresses rigour and consciousness by providing a distinctive work and thought process for designers. The research, and its application in the tangible form of the concluding design project, has demonstrated how my practice might become more accountable. Most notably, the methodical study of quantitative and qualitative aspects has highlighted the effects and interconnectedness of these decisions on overall design and performance; what might appear as disparate elements are quite intertwined.

There is no simple, straightforward answer to achieving a perfect equilibrium between design and efficiency — as a reflection of our own lives, there is always compromise. My personal task, then, is to find the best compromise that inspires delight and fulfilment in both occupation and performance, and the other implications of these decisions, including the quantity of energy expended, internal flow, the introduction of useful light, and other factors that have been explored. In order for architectural practice to combat the numerous local, national, and global issues I have personally come to view, compromise — or perhaps stability or balance — is key, because I think exorbitance in any regard will simply result in deficiency in another.

In this vein, I hope that this methodology and research will be my springboard into the profession and the foundation upon which I can build the knowledge and expertise that will be added to this toolkit. Any type of change is first enacted on a small scale, therefore this document will certainly serve as my guide and will hopefully affect valuable change in my personal architectural vocation. If its influence might move beyond my sphere and into the broader field, I believe that there is always room for positive change, no matter the size of the action.

POSTSCRIPT

The objectives and scope of the thesis evolved several times to acknowledge changing expectations. At its inception, my goal was to uncover trends that would place more responsibility on the architect in the early design phases; ideally, the research would support the claim that design choices – both simple and complex moves – could have an equal or greater impact on energy efficiency than green technologies. The comparative analysis revealed that modelling programs were not very sensitive to such changes; for instance, a change in numbers occurs if the façade's window-to-wall ratio is altered, but no difference is indicated if a window were to shift its position on the same wall. This conclusion, paired with the quantitative analysis' substantial reductions in energy efficiency, called for a shift in scope, one that expanded to include qualitative considerations to weight their effects (and, therefore, notions more concerned with design rather than technology) against the previous, more technical studies.

My expectation that the onus should mainly be placed on the architect, rather than technology, was adjusted in light of the findings – the qualitative and quantitative research, then, attempted to address the question of design versus technology in a new fashion, one different from the initial goals of the thesis to tackle these questions through more general formal design means. While my expectations were altered, and there was some disappointment in arriving at that realization, I am glad that they changed, because the result was an interesting study that balanced two different but complimentary aspects. Similar to the conclusions of this thesis, I was met with compromise and discussion but, in the end, this negotiation resulted in balance.

Envelope upgrades and daylighting analysis are simply two of many variables in the equation of energy efficiency. While these studies begin to delve into the complex nature of efficiency (and, in contrast and cooperation, effectiveness), there are many other avenues worth exploring, including:

- the use of healthy materials and considering their impact over their lifecycles;
- the lifecycle of inhabitants: aging-in-place, accessibility, and how the house might adapt to its owners' changing needs and expectations;
- green technology and the harnessing and use of renewable energies, including solar panel integration, geothermal heating, and green construction practices like double skin façades and thermal storage walls;

- manufacturing approaches, including prefabrication, tilt-up structures, and modular construction, and the implications of their use of resources, labour, and transportation;
- advanced fabrication including 3D printing, computer numerical control (CNC), and laser cutting;
- parametric design, responsive façades, and 'smart' technologies.

Additional investigation would certainly add value to the discussion of balance in all aspects of architecture; the more variables that are considered as part of the whole, the more a comprehensive picture can be painted, and the more we can understand the connection between our inputs and outputs, and our actions and their consequences. Like with this thesis, these ideas could be also explored in terms of renovations to existing structures, thereby improving the existing building stock and reducing the amount of waste and energy produced by new builds. Conversely, as demonstrated by this thesis, these concepts would be beneficial if integrated in the very early stages of design. My personal interests lie in the realm of construction techniques and the integration of complementary technology – this might serve as the primary investigation for the next phase of study to aptly connect the findings of this thesis and further research.

As demonstrated with the ideas above, there is no shortage of innovative approaches that will undoubtedly become integral to future residential design and construction practices. Any number of these concepts could be incorporated into further research inspired by this thesis, demonstrating that the future of architectural practice is malleable and capable of positive change.

GLOSSARY AND ABBREVIATIONS

ACH

air changes per hour

AEC

Architecture, Engineering, & Construction

BIM

Building Information Modelling

CMHC

Canadian Mortgage and Housing Corporation

DA

daylighting autonomy, measured in a percentage

HVAC

heating, ventilation, and air conditioning

kWh

kilowatt-hours, unit of measurement for energy

kWh/m²

kilowatt-hours per square metre, unit of measurement for energy per area

LED

light-emitting diode

airtightness

a quality measured in air changes per hour (ACH) that describes the degree to which the building envelope resists the movement of air (Natural Resources Canada, "The EnerGuide Housing Glossary - Definitions")

air changes per hour (ACH)

the number of times in an hour the entire volume of air is replaced in a home (*Fundamentals of Residential Construction*, 703)

air source heat pump

an exterior unit that transfers warm air between the interior and exterior according to the season, serving both heating and cooling requirements (*Mechanical and Electrical Equipment*, 466)

daylight autonomy (DA)

a metric that denotes a percentage of time that an area receives sufficient daylight over the course of a year (*Dynamic Daylight Performance Metrics*, 10)

daylighting

a study concerned with optimizing the use of natural light to decrease dependency on and use of artificial lighting (*Window Systems for High-Performance Buildings*, 376)

design

the formal result of a number of factors pertaining to taste, restrictions, and realities

EnergyStar

a rating system and program that establishes a high level of energy efficiency for products

energy efficiency

when energy is saved due to a decrease in its demand by occupant behaviour or equipment (*Mechanical and Electrical Equipment*, 13)

envelope

the element separating interior space from the exterior, sheltering the inhabited space from the elements, and consisting of walls, roofs, foundations, floors, windows, and doors (*Energy Efficiency Trends*, 50)

laneway house

an independent dwelling unit residing at the rear of the same lot as a principal dwelling (whether detached, semi-detached, or a townhouse) and accessed by a laneway, or secondary road (City of Toronto, "Changing Lanes: Overview")

lux

the metric unit of illuminance

net-zero energy

a high standard of construction that dictates that the building must generate as much or more on-site renewable energy than it consumes so that its overall impact is neutral (Canadian Home Builders' Association, "Builders' Manual," 392)

passive solar gain

the amount of heat introduced into a space through the admission of solar radiation through windows, doors, and other glazing (Natural Resources Canada, "The EnerGuide Housing Glossary - Definitions")

performance

describes how well energy supply is matched with energy demand; the result of a home's inputs and outputs

qualitative

relating to something measured in terms of its character or composition

quantitative

relating to something measured in terms of its number or amount

rainscreen

wall construction approach where a cavity is added between the exterior finish and the rest of the wall assembly to protect it from any unwanted moisture penetrating the finish, allowing the precipitation to evaporate or drain down and out of the bottom of the cavity (*Wood Frame Envelopes*, 5.9.)

secondary energy

the byproduct — in the form of electricity or heat — of raw fuel (primary energy) (EnergyStar, "The difference between source and site energy")

single family home

a dwelling type that stands apart from other buildings or units and intended to house one or more people (*Energy Efficiency Trends*, 46, 49)

site energy

a measurement of energy at its end destination, excluding the energy expended to produce and transport it (EnergyStar, "The difference between source and site energy")

system

the network of various parts, mechanisms, and equipment that allow a building to function

sustainability

the conscious practice of living within one's means without jeopardizing the ability of future generations to do the same (*Fundamentals of Residential Construction*, 33)

workflow

the architectural design process

ENDNOTES

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FIGURES

figure 5:

IMAGE 1: Rieder. "Single-family house 1 Ways Lane." Accessed November 28, 2019. <https://www.rieder.cc/en/project/einfamilienhaus-1-ways-lane/>

IMAGE 2: Burley, Robert. "Life in the Fast Lane." *The Canadian Architect*, October 2004, 16.

IMAGE 3: Rieder. "Single-family house 1 Ways Lane." Accessed November 28, 2019. <https://www.rieder.cc/en/project/einfamilienhaus-1-ways-lane/>

IMAGE 4: Burley, Robert. "Life in the Fast Lane." *The Canadian Architect*, October 2004, 16.

IMAGE 5: Burley, Robert. "Life in the Fast Lane." *The Canadian Architect*, October 2004, 15.

IMAGE 6: Burley, Robert. "Life in the Fast Lane." *The Canadian Architect*, October 2004, 15.

figure 7:

IMAGE 1: Arban, Tom. "Life in the Back Lane." *The Canadian Architect*, April 2010, 22-23.

IMAGE 2: Arban, Tom. "40R Laneway House - Superkül." Accessed November 28, 2019. https://superkul.ca/projects/homes/40r_laneway-house/

IMAGE 3: Arban, Tom. "40R Laneway House - Superkül." Accessed November 28, 2019. https://superkul.ca/projects/homes/40r_laneway-house/

IMAGE 4: Arban, Tom. "40R Laneway House - Superkül." Accessed November 28, 2019. https://superkul.ca/projects/homes/40r_laneway-house/

IMAGE 5: the MASH. "40R Shaftesbury Avenue - SUMMERHILL, TORONTO." Accessed November 28, 2019. <https://themash.ca/realestategossip/2019/3/40r-shaftesbury-avenue-summerhill-toronto>

IMAGE 6: Arban, Tom. "40R Laneway House - Superkül." Accessed November 28, 2019. https://superkul.ca/projects/homes/40r_laneway-house/

Jen, Leslie. "Life in the Fast Lane." *The Canadian Architect*, October 2004, 14-16.

Ways Lane House, Toronto, Ontario
Diamond + Schmitt Architects Inc.

Life in the Fast Lane by Leslie Jen

This relatively compact residence for a landscape architect is exemplary of Toronto laneway housing in its articulation as a contextually scaled form on a tight site, accomplished without sacrificing any of the mod con requirements of contemporary urban life. Situated near the entrance of a laneway, the house is located in an enviable downtown location close to the busy intersection of Queen and Bathurst Streets. As the site measures a mere 29 by 44 feet, the front of the L-shaped house is pressed right to the lane's edge, allowing for a landscaped courtyard in the back. In this modestly sized outdoor space, provision is made for ample seating and a water garden.

Generous plantings soften the hard edges, and vines creep up the pale brick enclosure of the high wall separating the house from the adjacent property, creating a welcoming urban oasis.

Additional outdoor space is available on the roof deck, accessed via an exterior stair. The cleft in the building visible from the front elevation contains the stair, sandwiched between the two volumes of the second level of the house. Access to the stair is gained from either the bedroom or the studio on the second level, and is screened from view by horizontal mahogany strips. A tension is created in the narrow space of the stairway, with the walls of both volumes closing in on

Interior and exterior spaces flow together in this exquisite residence on a laneway site in downtown Toronto.

Clockwise from left: front elevation reveals an attractive composition of concrete panels, mahogany screens and wood-framed windows; site plan shows the appropriately scaled house in its downtown neighbourhood context; a sculptural wall screens the stairway from view; compact corridor kitchen connects front entry to rear dining area.

either side. But ascension through this potentially claustrophobic space is rewarded with increasing amounts of daylight, and upon final destination, the wide open expanse of the roof deck, from which clear views in every direction of the low-rise residential neighbourhood can be enjoyed. Even single-car parking is cleverly accommodated for and protected by a sliding mahogany screen which enhances the composition of the front façade, contributing a dynamic component to the abstract orthogonal assemblage of concrete panels, horizontal wood slats and glazed openings.

The first floor of the house contains the basic public spaces of living, dining, kitchen and powder room. Through the provision of ample glazing and pivot-door access to the courtyard, interior and exterior spaces flow seamlessly into one another. Interestingly, cooking appears not to be a priority in this household; the extremely compact linear kitchen is fitted with small-scale stainless steel appliances and a tiny bar sink only, while functioning as a corridor leading from the front of the house to the dining area at the back. The private zone of the second level contains one bedroom, one bathroom, and a generously sized studio for the owner. Handsomely scaled mahogany-framed windows, cleanly detailed plaster, and Ontario stone and natural wood floors create a tactile and warm interior. Fortunately, the house also contains a partial basement, an extremely valuable and

much coveted entity in dense urban conditions where adequate storage space is of paramount importance.

Although the siting of the house right at the border of the laneway maintains the ever-critical urban edge, no intermediary zone between the front entry and the vehicular traffic of the lane exists, creating an uncomfortably close relationship between public and private space. However, the Ways Lane residence represents an entirely satisfying solution to new housing in an urban context. Everything is accommodated for in this simple but exquisitely detailed project, and economically so, both in terms of space and expenditure. Not a single square foot is wasted anywhere in the fluid flow of living spaces. As real estate prices climb ever higher, the price of a house (more often than not a decrepit fixer-upper) on a standard lot in the downtown core is prohibitively expensive. By exploiting the availability of such residual sites as longtime Toronto practitioners Jeffery Stinson, Terence Van Elslander, Brigitte Shim and Howard Sutcliffe have done, it is possible to commission a custom-designed home for a relatively modest sum without having to endure a dreary commute to the suburbs. **CA**

Second floor

Ground floor
1. carport
2. garden
3. entrance
4. pond
5. bedroom
6. studio

Client: Claire Ironside
Architect Team: Donald Schmitt
Structural: Yolles Partnership Inc.
Landscape: Claire Ironside
Contractor: Ed Gaigas Contracting
Area: 2,175 ft² including basement
Budget: \$110,000
Completion: 1997
Photography: Robert Burley

Top left: ample glazing and pivot doors in the living and dining areas connect the interior to the light, air and space of the exterior courtyard. **Below:** dramatic night view of the L-shaped house from the courtyard.

A LANEWAY SHED IS TRANSFORMED INTO A SUBLIMELY COMPACT PIED-À-TERRE THAT RETAINS TRACES OF ITS PAST LIVES.

PROJECT 40R LANEWAY HOUSE, TORONTO, ONTARIO
ARCHITECT SUPERKÜL INC | ARCHITECT
TEXT GABRIEL FAİN

The story of laneway housing in Toronto is not a new one. It's a story that's as old as the city itself and emerges from the patterns of uneven urban growth beginning in the 19th century. Toronto's laneway system has always been a valuable resource—first serving as an important lifeline for the distribution of services and goods and accommodating a variety of uses including stables, workers' housing and commercial functions. The advent of zoning regulations and modern transportation systems dramatically impacted the fabric of the laneway network. Today, however, the

vibrant character and original uses of many of the laneways is very much kept alive because they have operated as experimental sites for architectural interventions. The project at 40R Shaftesbury Avenue—designed by Meg Graham and Andre D'Elia with the assistance of Drew Sinclair of Superkül Architects—is an exceptional example of one such experiment in adaptive reuse, urban sustainability and infill development.

Located in the historic Summerhill neighbourhood in Toronto, the building at 40R originally functioned as a blacksmith's shop and serviced

TOM ARRIAN

the North Toronto Railway Station in the early 1880s. For over 120 years, its uses continued to evolve—beginning as a smithy, then a horse shed, a storage depot and most recently, a sculptor’s live-work studio. The rich history of the building was most expressively registered on the exterior through the assemblage and overlapping of materials in various states of decay—rusted steel panelling, Insulbrick and barn board.

It takes the vision of two progressive clients—artist Elena Soni and her husband Jorge, a psychiatrist—to see the potential for a dilapidated lane-

TOM ARRIAN

way shed to have a new lease on life. In 2006 they purchased the property with the intention of downsizing and converting the building into their new home. *Having admired* the shed for over 20 years, the clients were particularly interested in preserving its unique material qualities yet re-configuring the building to accommodate their desire for daylight, outdoor space and living space.

But projects on the emerging frontier of urban laneways such as 40R are rather difficult to undertake and require a lengthy approvals pro-

OPPOSITE ARCHITECT-FRIENDLY RUSTED STEEL PANELS PROVIDE A SOFTLY TEXTURED, DYNAMICALLY PATTERNED FAÇADE THAT ENLIVEN THIS MIDTOWN LANEWAY. **ABOVE** AN AERIAL VIEW OF THE HOME REVEALS THE SKYLIGHTS AND ROOFTOP TERRACE THAT MAKE THIS 850-SQUARE-FOOT STRUCTURE FEEL MUCH BIGGER THAN ITS ACTUAL SIZE.

cess through the city and neighbourhood interests. In Toronto, laneway housing is generally excluded from provisions made in the Official Plan and its supportive zoning bylaw measures. In

TOP A BEAUTIFULLY WEATHERED STEEL DOOR FROM THE ORIGINAL BUILDING WAS REUSED AS A GRITTY URBAN SLIDING WALL THAT OPENS UP THE DINING ROOM TO THE LANEWAY. **ABOVE** THE PRIVATE ROOFTOP TERRACE. **OPPOSITE, CLOCKWISE FROM TOP RIGHT** THE FRONT AND SIDE FAÇADES OF THE HOME; NATURAL LIGHT DESCENDS INTO THE GROUND-FLOOR LIVING ROOM; A VIEW FROM THE STAIRS REVEALS THE TIGHT DIMENSIONS OF THE INTERIORS; THE DOUBLE-HEIGHT LIGHT SHAFT IN THE KITCHEN ADDS SECTIONAL DYNAMISM TO THIS COMPACT HOME; THE ROOFTOP TERRACE IN THE EVENING; THIS CORNER DETAIL ILLUSTRATES THAT SALVAGED MATERIAL FROM THE ORIGINAL BUILDING WAS REUSED WHEREVER POSSIBLE; A DETAIL OF THE SLIDING STEEL DOOR; WOOD SIDING IS USED ON TWO FAÇADES.

fact, the original building at 40R was legally non-conforming, which means that zoning for the site doesn't even allow for its current use but was permitted because it was built before the enactment of the current bylaw.

The design is as much about the architects strategically playing with city rules as it is about

the intelligent crafting of space and light. The project was both legally and technically made complicated by the building code due to the original structure being built to its property lines on three sides and with only two feet to spare on the fourth. The footprint of 40R measures about 10 feet by 40 feet and sits on an extremely tight lot.

As a result, the architects were prohibited from creating any new openings with the exception of its north façade. The building's second-floor cantilever is a result of a right-of-way at grade that provides access to the rear garage of an adjacent property. So with no available outdoor space at grade and with city restrictions on extending the building envelope, the only solution for additional space was to build upwards and on the roof. Even more complications existed in renovating the old laneway structure due to issues of site servicing and the uncertainty of whether or not the building even had foundations and a proper floor structure.

These zero-tolerance conditions, as the architects have termed it, dictated many of the formal gestures. Perhaps the legacy of this building is the manner in which Graham and D'Elia were able to seamlessly integrate issues of sustainability into the architecture. The strategy, therefore, relies heavily on drawing light, air and views from above. A series of three-foot-wide light wells are carved out of the interior and allow a soft and diffuse light from the sky to penetrate the interior spaces. These shafts also function as ventilation stacks in a passive cooling system, in which the operable venting skylights at the top of the light shafts release excess warm air. In-floor radiant heating embedded in the polished concrete floors also reduces the heating energy requirements of the house. A series of rooftop elements including a terrace and green roof are developed into a stormwater collection system used for irrigation and flushing toilets.

To make a home in a laneway with only 850 square feet of space means taking a position about minimal footprint and ecologically considered urban living. The ground floor is designed as tight as a ship and is taken up by a living room and kitchen. A simple material palette of drywall, oak panels, and cedar stairs is used. The second floor has equally well proportioned spaces consisting of a master bedroom and a guest room—each with their own compact bathroom. Small windows are strategically punched out of the walls in these spaces where light is required. A tranquil cedar-lined exterior courtyard is carved out of the second-floor volume and connects to the rooftop with galvanized metal stairs.

The skillful play and composition of materials apparent on the interior is perhaps even more refined on the exterior—becoming, perhaps, an urban spectacle. The external expression speaks about the poetics of how materials can come together almost bluntly—sharing in the rustic vernacular of the laneway. The original thin-gauge rusted-steel cladding, for example, was removed, catalogued, rehabilitated, and reapplied as a veneer in a quilted and irregular pattern on the south and west elevations.

SHAH GIL

GABRIEL FARNI

GABRIEL FARNI

TOM ARBAN

JORNE BRICOMAN

TOM ARBAN

TOM ARBAN

JORNE BRICOMAN

CONTEXT DIAGRAM

- 1 TTC—SUMMERHILL STATION
1954 | PASSENGER PLATFORMS
- 2 4 SHAFTESBURY PLACE
CIRCA 1924-1982 | SITE OFFICE
1982-2007 | SINGLE-FAMILY RESIDENCE
- 3 46R SHAFTESBURY AVENUE
CIRCA 1950-2007 | STONE-CLUTTER
- 4 42A SHAFTESBURY AVENUE
CIRCA 1950-1992 | AUTOBODY SHOP
1992-2007 | SINGLE-FAMILY RESIDENCE
- 5 40R SHAFTESBURY AVENUE
CIRCA 1880-1910 | BLACKSMITH
CIRCA 1910-1935 | HORSE SHED
CIRCA 1935-1965 | HOTEL STORAGE
CIRCA 1965-1970 | TAXI DEPOT
CIRCA 1970-2007 | ARTIST'S STUDIO
2007+ | SINGLE-FAMILY RESIDENCE
- 6 5-11 SHAFTESBURY PLACE
CIRCA 1930+ | FACTORY
CIRCA 1960+ | WAREHOUSE (DEMOLISHED)
1998-2007 | SINGLE-FAMILY RESIDENCES

- 1 TERRACE
- 2 GREEN ROOF
- 3 SKYLIGHT VENTS
- 4 PLANTER
- 5 LIGHT SHAFT
- 6 MASTER BEDROOM
- 7 COURTYARD
- 8 GUEST BEDROOM
- 9 LIVING
- 10 MECHANICAL
- 11 KITCHEN
- 12 DINING
- 13 HALLWAY
- 14 NEIGHBOURING GARAGE
- 15 RIGHT-OF-WAY
- 16 SHAFTESBURY PLACE

The building is highly contextual as further zoning requirements for non-combustible cladding resulted in varying materials applied to the exterior. A cedar-strip rainscreen on the second floor of the north and east façades is finished with dark Falun paint from Sweden which makes visible the subtle expressions of the natural wood grain. Marine-grade plywood sheathing is used on the ground floor and is also painted black. Superkül's collagist approach to detailing can be linked to a lineage of the so-called Toronto Style, which is arguably inspired by the work of the Venetian architect Carlo Scarpa. The most obvious manifestation of this is the decorative reintegration of the original graffiti-covered steel door onto a sliding track so that it can be used as a screen on the ground floor facing the laneway.

40R makes a convincing argument about reusing, renovating and recycling old buildings in the city's forgotten laneways and how to reactivate them as exciting places of urban life. It's been more than 30 years since Barton Myers wrote his theory on urban consolidation in *Vacant Lottery*, where he was one of the first to state that by using what we have in better ways, we can navigate through complex bylaws and fill in the voids of the city. It has taken this long for firms like Superkül to emerge, firms that can build on these urban theories and who have developed models of sustainable design with a maturity, precision and rigour that is rare among young practitioners. **CA**

Gabriel Fain is currently pursuing a Master of Architecture degree at the University of Toronto. He is an intern architect at Kuwabara Payne McKenna Blumberg Architects.

CLIENT RIFNA AND JORGE SONI
ARCHITECT TEAM ANDRE D'ELIA, MEG GRAHAM, DREW SINDIAR
STRUCTURAL ROBERT E. BROWN ASSOCIATES
MECHANICAL GRY & ASSOCIATES ENGINEERING INC.
INTERIORS SUPERKUL INC | ARCHITECT
CONTRACTOR BOSZKO & VERITY INC.
GEOTECHNICAL FORWARD ENGINEERING AND ASSOCIATES INC.
AREA 850 SF
BUDGET 100K
COMPLETION OCTOBER 2008

APPENDIX B: BEopt Settings

GROUP NAME	CATEGORY NAME	CURRENT OPTION NAME
BUILDING	Front Wall Orientation	East
	Neighbors	None
WALLS	Wood Stud	R-13 Fiberglass Batt, 2x4, 16 in o.c.
	Wall Sheathing	OSB
	Exterior Finish	Vinyl, Light
CEILINGS/ROOFS	Finished Roof	R-30C Fiberglass Batt, 2x10
	Roof Material	Asphalt Shingles, Medium
FOUNDATION/FLOORS	Slab	Uninsulated
	Interzonal Floor	R-19 Fiberglass Batt
	Carpet	0% Carpet
THERMAL MASS	Floor Mass	Wood Surface
	Exterior Wall Mass	1/2 in. Drywall
	Partition Wall Mass	1/2 in. Drywall
	Ceiling Mass	1/2 in. Drywall
WINDOWS & DOORS	Window Areas	varies by case
	Windows	Low-E, Double, Non-metal, Air, L-Gain
	Interior Shading	Summer = 0.7, Winter = 0.7
	Door Area	20 ft ²
	Doors	Fiberglass
	Eaves	2 ft
	Overhangs	None
AIRFLOW	Air Leakage	7 ACH50
	Mechanical Ventilation	2010, Exhaust
	Natural Ventilation	Year-Round, 3 days/wk
SPACE CONDITIONING	Central Air Conditioner	SEER 13
	Furnace	Gas, 78% AFUE
	Ducts	15% Leakage, R-8
	Ceiling Fan	National Average
	Dehumidifier	None
SPACE CONDITIONING SCHEDULES	Cooling Set Point	76 F
	Heating Set Point	71 F
	Humidity Set Point	None
WATER HEATING	Water Heater	Gas Standard
	Distribution	Uninsulated, Trunk/Branch, Copper
	Solar Water Heating	None
	Solar Water Heating Azimuth	Back Roof
	Solar Water Heating Tilt	Roof Pitch
LIGHTING	Lighting	34% CFL Hardwired, 34% CFL Plug-in
APPLIANCES & FIXTURES	Refrigerator	Top freezer, EF = 17.6
	Cooking Range	Electric
	Dishwasher	318 Rated kWh
	Clothes Washer	Standard
	Clothes Dryer	Electric
	Hot Water Fixtures	1
APPLIANCES & FIXTURES SCHEDULES	Refrigerator Schedule	Standard
	Cooking Range Schedule	Standard
	Clothes Dryer Schedule	Standard
MISCELLANEOUS	Plug Loads	1
	Extra Refrigerator	None
	Freezer	None
	Pool Heater	None
	Pool Pump	None
	Hot Tub/Spa Heater	None
	Hot Tub/Spa Pump	None
	Well Pump	None
	Gas Fireplace	None
	Gas Grill	None
	Gas Lighting	None
MISCELLANEOUS SCHEDULES	Plug Loads Schedule	Standard
	Extra Refrigerator Schedule	Standard
	Freezer Schedule	Standard
	Pool Heater Schedule	Standard
	Pool Pump Schedule	Standard
	Hot Tub/Spa Heater Schedule	Standard
	Hot Tub/Spa Pump Schedule	Standard
	Well Pump Schedule	Standard
	Gas Fireplace Schedule	Standard
	Gas Grill Schedule	Standard
	Gas Lighting Schedule	Standard
POWER GENERATION	PV System	None
	PV Azimuth	Back Roof
	PV Tilt	Roof, Pitch

table B1: base model settings
for Elle and Lungo

GROUP NAME	CATEGORY NAME	CURRENT OPTION NAME
BUILDING		
	Front Wall Orientation	East
	Neighbors	None
WALLS		
	Wood Stud	Uninsulated, 2x4, 16 in o.c.
	Wall Sheathing	None
	Exterior Finish	Glass
CEILINGS/ROOFS		
	Finished Roof	R-30C Fiberglass Batt, 2x10
	Roof Material	Asphalt Shingles, Medium
FOUNDATION/FLOORS		
	Slab	Uninsulated
	Interzonal Floor	R-19 Fiberglass Batt
	Carpet	0% Carpet
THERMAL MASS		
	Floor Mass	Wood Surface
	Exterior Wall Mass	None
	Partition Wall Mass	1/2 in. Drywall
	Ceiling Mass	1/2 in. Drywall
WINDOWS & DOORS		
	Window Areas	100%
	Windows	Low-E, Double, Non-metal, Air, L-Gain
	Interior Shading	None
	Door Area	None
	Doors	Fiberglass
	Eaves	2 ft
	Overhangs	None
AIRFLOW		
	Air Leakage	7 ACH50
	Mechanical Ventilation	2010, Exhaust
	Natural Ventilation	Year-Round, 3 days/wk
SPACE CONDITIONING		
	Central Air Conditioner	SEER 13
	Furnace	Gas, 78% AFUE
	Ducts	15% Leakage, R-8
	Ceiling Fan	National Average
	Dehumidifier	None
SPACE CONDITIONING SCHEDULES		
	Cooling Set Point	76 F
	Heating Set Point	71 F
	Humidity Set Point	None
WATER HEATING		
	Water Heater	Gas Standard
	Distribution	Uninsulated, Trunk/Branch, Copper
	Solar Water Heating	None
	Solar Water Heating Azimuth	Back Roof
	Solar Water Heating Tilt	Roof Pitch
LIGHTING		
	Lighting	34% CFL Hardwired, 34% CFL Plug-in
APPLIANCES & FIXTURES		
	Refrigerator	Top freezer, EF = 17.6
	Cooking Range	Electric
	Dishwasher	318 Rated kWh
	Clothes Washer	Standard
	Clothes Dryer	Electric
	Hot Water Fixtures	1
APPLIANCES & FIXTURES SCHEDULES		
	Refrigerator Schedule	Standard
	Cooking Range Schedule	Standard
	Clothes Dryer Schedule	Standard
MISCELLANEOUS		
	Plug Loads	1
	Extra Refrigerator	None
	Freezer	None
	Pool Heater	None
	Pool Pump	None
	Hot Tub/Spa Heater	None
	Hot Tub/Spa Pump	None
	Well Pump	None
	Gas Fireplace	None
	Gas Grill	None
	Gas Lighting	None
MISCELLANEOUS SCHEDULES		
	Plug Loads Schedule	Standard
	Extra Refrigerator Schedule	Standard
	Freezer Schedule	Standard
	Pool Heater Schedule	Standard
	Pool Pump Schedule	Standard
	Hot Tub/Spa Heater Schedule	Standard
	Hot Tub/Spa Pump Schedule	Standard
	Well Pump Schedule	Standard
	Gas Fireplace Schedule	Standard
	Gas Grill Schedule	Standard
	Gas Lighting Schedule	Standard
POWER GENERATION		
	PV System	None
	PV Azimuth	Back Roof
	PV Tilt	Roof, Pitch

table B2: glass model settings
for Elle and Lungo

GROUP NAME	CATEGORY NAME	CURRENT OPTION NAME
BUILDING		
	Front Wall Orientation	East
	Neighbors	None
WALLS		
	Wood Stud	R-13 Fiberglass Batt, 2x4, 16 in o.c.
	Wall Sheathing	OSB
	Exterior Finish	Vinyl, Light
CEILINGS/ROOFS		
	Finished Roof	R-30C Fiberglass Batt, 2x10
	Roof Material	Asphalt Shingles, Medium
FOUNDATION/FLOORS		
	Slab	Uninsulated
	Interzonal Floor	R-19 Fiberglass Batt
	Carpet	0% Carpet
THERMAL MASS		
	Floor Mass	Wood Surface
	Exterior Wall Mass	1/2 in. Drywall
	Partition Wall Mass	1/2 in. Drywall
	Ceiling Mass	1/2 in. Drywall
WINDOWS & DOORS		
	Window Areas	None
	Windows	Clear, Single, Metal
	Interior Shading	Summer = 0.7, Winter = 0.7
	Door Area	None
	Doors	Fiberglass
	Eaves	2 ft
	Overhangs	None
AIRFLOW		
	Air Leakage	7 ACH50
	Mechanical Ventilation	2010, Exhaust
	Natural Ventilation	Year-Round, 3 days/wk
SPACE CONDITIONING		
	Central Air Conditioner	SEER 13
	Furnace	Gas, 78% AFUE
	Ducts	15% Leakage, R-8
	Ceiling Fan	National Average
	Dehumidifier	None
SPACE CONDITIONING SCHEDULES		
	Cooling Set Point	76 F
	Heating Set Point	71 F
	Humidity Set Point	None
WATER HEATING		
	Water Heater	Gas Standard
	Distribution	Uninsulated, Trunk/Branch, Copper
	Solar Water Heating	None
	Solar Water Heating Azimuth	Back Roof
	Solar Water Heating Tilt	Roof Pitch
LIGHTING		
	Lighting	34% CFL Hardwired, 34% CFL Plug-in
APPLIANCES & FIXTURES		
	Refrigerator	Top freezer, EF = 17.6
	Cooking Range	Electric
	Dishwasher	318 Rated kWh
	Clothes Washer	Standard
	Clothes Dryer	Electric
	Hot Water Fixtures	1
APPLIANCES & FIXTURES SCHEDULES		
	Refrigerator Schedule	Standard
	Cooking Range Schedule	Standard
	Clothes Dryer Schedule	Standard
MISCELLANEOUS		
	Plug Loads	1
	Extra Refrigerator	None
	Freezer	None
	Pool Heater	None
	Pool Pump	None
	Hot Tub/Spa Heater	None
	Hot Tub/Spa Pump	None
	Well Pump	None
	Gas Fireplace	None
	Gas Grill	None
	Gas Lighting	None
MISCELLANEOUS SCHEDULES		
	Plug Loads Schedule	Standard
	Extra Refrigerator Schedule	Standard
	Freezer Schedule	Standard
	Pool Heater Schedule	Standard
	Pool Pump Schedule	Standard
	Hot Tub/Spa Heater Schedule	Standard
	Hot Tub/Spa Pump Schedule	Standard
	Well Pump Schedule	Standard
	Gas Fireplace Schedule	Standard
	Gas Grill Schedule	Standard
	Gas Lighting Schedule	Standard
POWER GENERATION		
	PV System	None
	PV Azimuth	Back Roof
	PV Tilt	Roof, Pitch

table B3: solid model settings
for Elle and Lungo

APPENDIX C: Comparative Analysis Results

BEOPT

MODEL	COOLING (KWH/YR)	EQUIPMENT (KWH/YR)	FANS (KWH/YR)	HEATING (KWH/YR)	LIGHTS (KWH/YR)	TOTAL
1A *kWh/m ² /yr						
Elle, as built	2	15	5	197	10	229
Lungo, as built	4	24	6	227	12	273
1B						
Elle, as built	237	1,835	651	24,759	1,266	28,748
Elle, glass	1,158	1,835	938	35,564	1,266	40,761
Elle, solid	138	1,835	572	21,755	1,266	25,566
1C						
Lungo, as built	274	1,835	466	17,683	909	21,167
Lungo, glass	1,117	1,835	701	26,593	909	31,155
Lungo, solid	182	1,835	402	15,283	909	18,611
2A *kWh/m ² /yr						
area = 0.5	5	37	18	672	14	746
area = 1.0	2	19	7	266	11	305
area = 2.0	1	10	3	125	9	148
2B						
volume = 0.5	158	1,835	369	13,991	1,038	17,391
volume = 1.0	185	1,835	665	25,301	1,038	29,024
volume = 2.0	276	1,835	1,480	56,233	1,038	60,862
2C						
south	185	1,835	665	25,301	1,038	29,024
east	208	1,835	683	25,919	1,038	29,683
west	223	1,835	692	26,224	1,038	30,012
north	141	1,835	709	26,906	1,038	30,629

REVIT

MODEL	COOLING (KWH/YR)	EQUIPMENT (KWH/YR)	FANS (KWH/YR)	HEATING (KWH/YR)	LIGHTS (KWH/YR)	TOTAL
1A *kWh/m ² /yr						
Elle, as built	19	35	3	94	35	186
Lungo, as built	32	35	6	233	35	341
1B						
Elle, as built	347	4,083	2,181	10,800	4,083	21,494
Elle, glass	12,903	5,203	2,117	37,936	5,203	63,362
Elle, solid	1,414	4,083	228	8,931	4,083	18,739
1C						
Lungo, as built	1,250	1,378	247	9,081	1,378	13,334
Lungo, glass	8,503	1,542	1,669	31,081	1,542	44,337
Lungo, solid	558	1,378	153	8,964	1,378	12,431
2A *kWh/m ² /yr						
area = 0.5	82	51	18	360	39	550
area = 1.0	28	35	5	91	35	194
area = 2.0	17	36	2	27	36	118
2B						
volume = 0.5	1,636	3,161	203	3,872	3,161	12,033
volume = 1.0	2,497	3,161	411	8,089	3,161	17,319
volume = 2.0	4,036	3,161	847	16,972	3,161	28,177
2C						
south	2,497	3,161	411	8,089	3,161	17,319
east	2,414	3,161	444	10,017	3,161	19,197
west	2,583	3,161	517	9,953	3,161	19,375
north	1,597	3,161	287	11,497	3,161	19,703

table C1: BEOpt and Revit comparative results

figure C1: Iteration 1B, BEopt results

figure C2: Iteration 1B, Revit results

figure C3: Iteration 1C, BEopt results

figure C4: Iteration 1C, Revit results

figure C5: Iteration 2A, BEopt results

figure C6: Iteration 2A, Revit results

figure C7: Iteration 2B, BEopt results

figure C8: Iteration 2B, Revit results

figure C9: Iteration 2C, BEopt results

figure C10: Iteration 2C, Revit results

APPENDIX D: Quantitative Analysis Results

figure D1: "Wood siding wall at floor" detail used for the case studies' envelope [The Canadian Wood Council, *Wood Frame Envelopes: Best Practice Guide Building Technology* (Canada Mortgage and Housing Corporation, 1999), 7-14.]

	EQUIPMENT	HEAT PUMP	INSULATION (EX)	INSULATION (IN)	LIGHTS	WINDOWS
base	10.76 W/m ²	none	none	none	10.76 W/m ²	x2 glaze
equipment	3.88 W/m ²	none	none	none	10.76 W/m ²	x2 glaze
heat pump	10.76 W/m ²	yes	none	none	10.76 W/m ²	x2 glaze
insulation (exterior)	10.76 W/m ²	none	38 mm extra	none	10.76 W/m ²	x2 glaze
insulation (interior)	10.76 W/m ²	none	none	38 mm extra	10.76 W/m ²	x2 glaze
lights	10.76 W/m ²	none	none	none	5.38 W/m ²	x2 glaze
windows	10.76 W/m ²	none	none	none	10.76 W/m ²	x3 glaze, low-e
all (furnace)	3.88 W/m ²	none	none	38 mm extra	5.38 W/m ²	x3 glaze, low-e
all (heat pump)	3.88 W/m ²	yes	none	38 mm extra	5.38 W/m ²	x3 glaze, low-e

constant settings:

air changes per hour (ACH) = 0.3 (very airtight)

HVAC = Residential 14 SEER/0.9 AFUE split/package gas < 5.5 ton

table D1: settings for upgrade models

ELLE (1 WAYS LANE, L-shape)														
area (m²) 115.51 area per person = 38.5 m² (3 ppl)														
variable	HEATING (kW/h/m²)	HEATING (kW/h/m²)	COOLING (kW/h/m²)	COOLING (kW/h/m²)	LIGHTS (kW/h/m²)	LIGHTS (kW/h/m²)	NT. EQUIP. (kW/h/m²)	NT. EQUIP. (kW/h/m²)	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	OVERALL RANK
all (heat pump)	1.733	1.733	1.350	1.350	1.486	1.486	1.072	1.072	15	25	15	25	492	6.633
HVAC	1.733	1.733	1.350	1.350	1.486	1.486	1.072	1.072	15	25	15	25	492	7.939
all (A/C)	15.239	15.239	2.975	2.975	1.486	1.486	1.072	1.072	13	19	13	19	-30	18.895
equipment	15.239	15.239	2.975	2.975	1.486	1.486	1.072	1.072	13	19	13	19	-30	19.895
lights	15.861	15.861	1.986	1.986	1.486	1.486	1.486	1.486	13	7	13	7	-2	20.030
base	15.833	15.833	2.031	2.031	750	750	1.497	1.497	13	6	13	7	-2	20.055
insulation (exterior)	14.831	14.831	2.394	2.394	1.486	1.486	1.497	1.497	11	x	13	7	x	20.166
insulation (interior)	15.833	15.833	2.394	2.394	1.486	1.486	1.497	1.497	11	x	13	7	x	20.166
insulation (exterior)	12.642	12.642	1.567	1.567	2.969	2.969	2.969	2.969	26	15	26	15	-22	20.261

LUNGO (608 SHAFTESBURY AVENUE, rectangle)														
area (m²) 38.99 area per person = 13.0 m² (3 ppl)														
variable	HEATING (kW/h/m²)	HEATING (kW/h/m²)	COOLING (kW/h/m²)	COOLING (kW/h/m²)	LIGHTS (kW/h/m²)	LIGHTS (kW/h/m²)	NT. EQUIP. (kW/h/m²)	NT. EQUIP. (kW/h/m²)	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	% OF TOTAL DIFFERENCE	OVERALL RANK
all (heat pump)	1.754	1.754	1.383	1.383	759	759	1.308	1.308	17	17	17	17	0	7.619
HVAC	1.754	1.754	1.383	1.383	759	759	1.308	1.308	17	17	17	17	0	7.619
all (A/C)	15.794	15.794	2.050	2.050	1.308	1.308	1.308	1.308	11	-9	15	3	-56	18.908
equipment	15.794	15.794	2.050	2.050	1.308	1.308	1.308	1.308	11	-9	15	3	-56	19.908
insulation (exterior)	14.899	14.899	2.239	2.239	1.308	1.308	1.308	1.308	11	-1	15	3	-56	19.908
equipment	14.899	14.899	2.239	2.239	1.308	1.308	1.308	1.308	11	-1	15	3	-56	19.908
lights	16.125	16.125	2.106	2.106	1.308	1.308	1.308	1.308	10	-6	15	3	-55	20.272
base	15.333	15.333	2.250	2.250	1.308	1.308	1.308	1.308	11	x	15	3	-55	20.272
insulation (exterior)	15.333	15.333	2.250	2.250	1.308	1.308	1.308	1.308	11	x	15	3	-55	20.272

table D2: detailed quantitative analysis results

figure D2: Elle, sections showing envelope upgrades

figure D3: Lungo, sections showing envelope upgrades

APPENDIX E: Qualitative Analysis Results

figure E1: Elle bedroom/studio, three window variations results, 1:200

figure E2: Elle master bedroom, three window variations results, 1:200

figure E3: Elle family room, three window variations results, 1:200

figure E4: Elle kitchen, three window variations results, 1:200

figure E5: Elle living/dining room, three window variations results, 1:200

figure E6: Lungo bedroom, three window variations results, 1:200

figure E7: Lungo master bedroom, three window variations results, 1:200

figure E8: Lungo living room, three window variations results, 1:200

figure E9: Lungo kitchen/dining, three window variations results, 1:200

ELLE (1 WAYS LANE)

ROOM	VARIABLE	HEATING (kWh/Yr)	COOLING (kWh/Yr)	LIGHTS (kWh/Yr)	INT. EQUIPMENT (kWh/Yr)	FANS (kWh/Yr)	TOTAL (kWh/Yr)	% DIFF. FROM BASE	RANK	DAYLIGHT AUTONOMY
bedroom	existing	1,781	381	558	403	169	3,292	0	4	10.70
	full height	1,817	494	558	403	200	3,472	+5	5	20.76
	high ribbon	1,733	267	558	403	139	3,100	-6	1	1.50
	standard sill	1,744	317	558	403	150	3,172	-4	2	6.49
master	new	1,747	367	558	403	161	3,236	-2	3	7.99
	existing	1,564	342	217	156	161	2,440	0	2	18.23
	full height	1,517	661	217	156	228	2,779	+13	4	22.25
	high ribbon	1,636	253	217	156	142	2,404	-1	1	18.24
family	standard sill	1,564	342	217	156	161	2,440	0	2	18.38
	new	1,567	342	217	156	161	2,443	+1	3	18.28
	existing	1,467	169	503	361	139	2,639	0	1	16.19
	full height	1,517	200	503	361	150	2,731	+3	3	29.77
kitchen	high ribbon	1,747	47	503	361	94	2,752	+4	4	4.37
	standard sill	1,667	81	503	361	108	2,720	+3	2	11.23
	new	1,503	203	503	361	150	2,720	+3	2	26.41
	existing	1,044	56	78	56	39	1,273	0	3	8.75
living/dining	full height	803	147	78	56	69	1,153	-9	1	33.05
	high ribbon	1,047	53	78	56	39	1,273	0	3	4.81
	standard sill	986	75	78	56	47	1,242	-2	2	7.29
	new	1,050	50	78	56	39	1,273	0	3	3.57
house	existing	1,886	47	439	317	106	2,795	0	3	9.92
	full height	1,886	47	439	317	106	2,795	0	3	9.92
	high ribbon	1,826	28	439	317	97	2,707	-3	1	5.33
	standard sill	1,844	31	439	317	100	2,731	-2	2	7.27
house	new	1,886	47	439	317	106	2,795	0	3	9.92
	existing	1,753	569	1,486	1,072	1,783	6,663	0	1	9.74 / 12.17
new		1,831	733	1,486	1,072	1,917	7,039	+5	2	12.14 / 11.34

Table E1: Elle, individual rooms daylighting results

LUNGO (40R SHAFESBURY AVENUE)

ROOM	VARIABLE	HEATING (KWH/YR)	COOLING (KWH/YR)	LIGHTS (KWH/YR)	INT. EQUIPMENT (KWH/YR)	FANS (KWH/YR)	TOTAL (KWH/YR)	% DIFF. FROM BASE	RANK	DAYLIGHT AUTONOMY
bedroom	existing	1,133	175	94	67	67	83	1,552	0	3
	full height	1,003	289	94	67	67	117	1,570	+1	4
	high ribbon	1,131	150	94	67	67	78	1,520	-2	1
	standard sill	1,122	178	94	67	67	83	1,544	-1	2
master	new	883	408	156	131	131	122	1,700	+8	5
	existing	1,211	233	181	131	131	100	1,856	0	2
	full height	1,025	428	181	131	131	147	1,912	+3	4
	high ribbon	1,300	172	181	131	131	86	1,870	+1	3
living	standard sill	1,214	228	181	131	131	100	1,854	-1	1
	new	961	667	311	261	261	178	2,378	+22	5
	existing	1,514	400	167	119	119	175	2,375	0	2
	full height	1,511	625	167	119	119	217	2,639	+10	4
kitchen/dining	high ribbon	1,517	353	167	119	119	167	2,323	-2	1
	standard sill	1,514	400	167	119	119	175	2,375	0	2
	new	1,514	417	167	119	119	178	2,395	+1	3
	existing	1,600	364	272	197	197	175	2,608	0	4
house	full height	1,600	364	272	197	197	175	2,608	0	4
	high ribbon	1,567	256	272	197	197	150	2,442	-6	1
	standard sill	1,581	292	272	197	197	158	2,500	-4	2
	new	1,606	308	272	197	197	164	2,547	-2	3
house	existing	1,756	1,183	739	581	581	1,917	6,176	0	2
	new	1,767	1,158	736	581	581	1,922	6,164	-1	1

table E2: Lungo, individual rooms daylighting results

ELLE (1 WAYS LANE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
kitchen	3.50	3.20	11.20	8.75
living/dining	5.60	4.00	22.40	9.92
bedroom/studio	9.20	5.30	48.76	10.70
family room	4.50	5.90	26.55	16.19
master bedroom	4.50	5.90	26.55	18.23
average				12.76

LUNGO (40R SHAFTESBURY AVENUE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
bedroom	3.00	2.40	7.20	13.13
master bedroom	3.00	3.90	11.70	13.32
kitchen/dining	3.10	4.50	13.95	14.72
living	3.10	3.90	12.09	14.89
average				14.02

table E3: Elle and Lungo, daylighting results before

ELLE (1 WAYS LANE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
kitchen	3.50	3.20	11.20	3.57
bedroom/studio	9.20	5.30	48.76	7.99
living/dining	5.60	4.00	22.40	9.92
master bedroom	4.50	5.90	26.55	18.28
family room	4.50	5.90	26.55	26.41
average				13.23

LUNGO (40R SHAFTESBURY AVENUE)

ROOM	WIDTH (M)	HEIGHT (M)	AREA (M ²)	MEAN DAYLIGHT AUTONOMY (%)
kitchen/dining	3.10	4.50	13.95	10.07
bedroom	3.00	2.40	7.20	11.86
living	3.10	3.90	12.09	16.09
master bedroom	3.00	3.90	11.70	17.88
average				13.98

table E4: Elle and Lungo, daylighting results after

ELLE (1 WAYS LANE, L-shape)

WINDOW	LOCATION	NEW LOCATION	SILL HEIGHT (M)	WIDTH (M)	HEIGHT (M)
W1	kitchen, east	- none	1.71 "	1.50 "	0.50 "
W2	kitchen, east	- family, east	0.41 1.51	0.56 1.52	1.80 0.70
W3	family, north	- family, north	1.33 1.30	1.44 1.94	0.50 0.91
W4	family, west	- none	0.00 "	1.94 "	2.21 "
W5	family, west	- none	0.00 "	0.46 "	2.21 "
W6	living/dining, north	- none	0.00 "	0.96 "	2.21 "
W7	living/dining, north	- none	0.00 "	0.46 "	2.21 "
W8	bed, east	- none	0.91 0.51	1.17 "	1.30 1.50
W9	bed, east	- none	0.91 "	0.81 "	1.52 0.91
W10	bed, north	- none	0.33 0.41	0.87 "	1.50 1.60
W11	bed, north	- none	0.33 1.10	1.81 "	1.50 0.91
W12	master bed, east	- none	0.91 1.10	1.26 "	0.91 "
W13	master bed, north	- none	0.91 1.10	1.18 "	0.91 "
W14	master bed, west	- none	0.91 1.10	0.92 "	0.91 "
W15	master bed, west	- none	0.91 1.10	0.92 "	0.91 "

LUNGO (40R SHAFTESBURY AVENUE, rectangle)

WINDOW	LOCATION	NEW LOCATION	SILL HEIGHT (M)	WIDTH (M)	HEIGHT (M)
W1	living, south	- none	1.26 0.91	1.64 "	0.80 0.91
W2	living, east	- none	1.26 1.13	2.41 "	0.80 0.70
W3	kitchen, east	- kitchen, east	1.26 1.13	1.00 "	0.80 0.70
W4	kitchen, north	- none	0.00 "	1.08 "	2.06 "
W5	kitchen, north	- none	0.00 0.91	0.73 "	2.06 0.91
W6	master bed, south	- none	0.31 1.33	0.72 "	1.40 0.50
W7	master bed, east	- none	0.91 "	1.92 "	0.80 0.91
W8	upper hall, east	- none	0.91 1.33	1.01 "	0.80 0.50
W9	bed, east	- none	0.91 "	1.33 "	0.80 0.91
W10	bed, north	- none	0.31 0.91	0.44 "	1.40 0.91
W11	courtyard, west	- none	0.91 "	1.05 "	0.91 "
W12	courtyard, north	- none	0.00 0.91	0.71 "	2.43 0.91
W13	courtyard, south	- none	0.00 0.91	0.71 "	2.43 0.91
W14	skylight, north	- none	- "	0.73 "	3.81 (length) "
W15	skylight, south	- none	- "	0.73 "	3.92 (length) "

table E5:
window dimensions

APPENDIX F: Methodology

figure F1: massing 01 site plan, 1:300

figure F2: massing 02 site plan, 1:300

figure F3: massing 03 site plan, 1:300

figure F4: massing 04 site plan, 1:300

figure F5: massing 05 site plan, 1:300

figure F6: massing 06 site plan, 1:300

REVIT							
ITERATION	HEATING (kWh/Yr)	COOLING (kWh/Yr)	LIGHTS (kWh/Yr)	INT. EQUIPMENT (kWh/Yr)	FANS (kWh/Yr)	TOTAL (kWh/Yr)	
Massing 01	2,239	872	1,344	969	328	5,752	5
Massing 02	2,192	897	1,111	803	325	5,328	2
Massing 03	2,033	881	1,097	792	308	5,111	1
Massing 04	2,311	847	1,247	897	322	5,624	3
Massing 05	2,236	861	1,344	969	328	5,738	4
Massing 06	2,364	878	1,306	942	347	5,837	6

DIVA				
ITERATION	LEVEL 1 MEAN DA (%)	LEVEL 2 MEAN DA (%)	AVERAGE DA (%)	
Massing 01	30.95	47.04	39.00	3
Massing 02	34.42	46.86	40.64	2
Massing 03	33.87	49.70	41.79	1
Massing 04	23.39	46.96	35.18	4
Massing 05	27.07	38.53	32.80	6
Massing 06	26.54	41.53	34.04	5

table F1: massing, quantitative and qualitative results

REVIT							
ITERATION	HEATING (kWh/Yr)	COOLING (kWh/Yr)	LIGHTS (kWh/Yr)	INT. EQUIPMENT (kWh/Yr)	FANS (kWh/Yr)	TOTAL (kWh/Yr)	
Option 01	1,953	936	561	528	289	4,267	2
Option 02	1,925	553	792	711	233	4,214	1

DIVA				
ITERATION	LEVEL 1 MEAN DA (%)	LEVEL 2 MEAN DA (%)	AVERAGE DA (%)	
Option 01	9.59	6.60	8.10	2
Option 02	3.22	19.77	11.50	1

table F2: planning, quantitative and qualitative results

ROOM	VARIABLE	HEATING (kWh/Yr)	COOLING (kWh/Yr)	LIGHTS (kWh/Yr)	INT. EQUIPMENT (kWh/Yr)	FANS (kWh/Yr)	TOTAL (kWh/Yr)	RANK	DAYLIGHT AUTONOMY (%)
bedroom	full height	1,983	286	217	156	175	2,817	3	31.01
	high ribbon	2,153	164	217	156	136	2,826	4	4.86
	standard sill	2,081	200	217	156	147	2,801	2	20.30
	final	2,019	214	217	156	153	2,759	1	16.46
master	full height	1,661	731	250	214	225	3,081	4	19.07
	high ribbon	1,642	608	250	214	206	2,920	1	3.77
	standard sill	1,647	647	250	214	211	2,969	2	11.20
	final	1,642	697	250	214	219	3,022	3	13.69
kitchen	full height	2,447	292	264	192	225	3,420	2	38.61
	high ribbon	2,558	222	264	192	203	3,439	4	23.61
	standard sill	2,522	239	264	192	208	3,425	3	30.10
	final	2,483	244	264	192	214	3,397	1	27.71
living	full height	2,800	422	264	192	281	3,959	4	21.65
	high ribbon	2,811	336	264	192	264	3,867	1	9.15
	standard sill	2,808	361	264	192	269	3,894	2	20.57
	final	2,792	381	264	192	277	3,901	3	16.80
house	final, 2 storeys	2,756	1,694	375	342	525	5,692	1	19.26 / 16.09
	final, w bsmt	2,717	1,422	1,642	1,447	461	7,689	2	19.26 / 16.09

table F3: openings, quantitative and qualitative results by room

HOUSE	HEATING (kWh/Yr)	COOLING (kWh/Yr)	LIGHTS (kWh/Yr)	INT. EQUIPMENT (kWh/Yr)	FANS (kWh/Yr)	TOTAL (kWh/Yr)	RANK	LEVEL 1 MEAN DA (%)	LEVEL 2 MEAN DA (%)	AVERAGE DA (%)
new house	2,756	1,694	375	342	525	5,692	1	19.26	16.09	17.68
Elle	1,831	733	1,486	1,072	1,917	7,039	3	12.14	11.34	11.74
Lungo	1,767	1,158	736	581	1,922	6,164	2	9.75	28.82	19.29

table F4: quantitative and qualitative results by house