Rammed Earth:
Adaptations to Urban Toronto.

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis.
This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Rammed earth is an ancient and imperishable *material-process*. Traditionally associated with rural construction and underdeveloped settings, the material has begun to enter the modern vernacular. While its use is not yet wide spread in the contemporary built environment, its benefits and positive applications to that setting are numerous. Rammed earth as a building material possesses ripe aesthetic qualities and hard geometric forms which frame the basis of the material's compatibility with the contemporary urban vernacular. As a building process, rammed earth has an exceptional opportunity for mechanization, allowing for its integration with the conventional modes of contemporary construction. Because of these advantages over other natural building strategies, rammed earth is poised as a viable building technique for the industrialized urban built environment. The desire for raw, unprocessed building materials should not be limited to the rural settings which hold most natural buildings. That need is present in all of global building culture, but especially in the developed built environments where resources for materials are consumed in their most concentrated abundance. Rammed earth satisfies the pressing demand for low impact materials, along with the goals of efficiency, longevity, and energy autonomy of architecture; the fundamental goals of sustainable architecture.

This thesis explores the contributions of rammed earth to the built environment of urban Toronto. The material can be adapted to suit the cold, wet climate and used as an effective exterior wall assembly. It can be used as an interior service and demising wall, providing an ideal sound and fire barrier to the typical semi-detached dwelling typology of Toronto's urban environment. It can also be employed within a trombe wall to capitalize on its solar thermal applications, for a climate with both severe winters and humid summers, in a setting where full solar exposure is unlikely. These three specific applications of this abundant, low-carbon material demonstrate its viability, desirability, and compatibility with the contemporary urban dwelling. Exploration of the benefits of this material, and its value within the urban environment, attempts to establish the advantages of this material-process compared to the conventional, contemporary wall assemblies which dominate Toronto's built fabric.

ACKNOWLEDGEMENTS

I have many thanks for the deluge of support and encouragement by which these fancies flowered.

It is often difficult in this high-tech world to pursue the low-tech objectives of a semi-Luddite. My anachronistic goals required certain anchors which I found slowly and surely, only through the support of my committee.

To Lloyd, thank you for teaching me how a railroad is never laid from end to end. It took me some time to learn that the track is best laid in pieces, a lesson that I have no doubt will serve me well in the future. And how exciting it is to connect all the tracks in the end.

To Terri and Anne, I will ever be grateful for your straightforward approach to showing me where my tracks were out of place. You helped me clear away the clutter, not too unlike moving mountains. I only wish such demolition had taken place sooner.

To David, the captive passenger on my train, whose patience found a depth unknown. The trip would have been lonely without you.

DEDICATION

To my rock,
who knew we would tie a greater knot after I first tied my loose ends.

And to my Parents,
who support, encourage, and chastise by effectively measured ratios.

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FOREWORD

"Ultimately, what [sustainable] *architectural design requires is neither an unconsidered rush to technophilia, nor a reversal to a romantic past that never existed. What is needed is inquiry through science and design of what is possible, dissemination of what is already known, and rediscovery of knowledge that is lost or forgotten. Only then can we address today's realities as well as tomorrow's hopes and aspirations, in what will continue to be a material world."*

Andrew Walker-Morison
A Material Difference
From: *Imagining Sustainability.*

"Creating a dwelling by hand and using natural materials from the immediate surroundings is a skill that has been practiced for thousands of years and one that goes back to prehistoric times. Now and in the future it will be necessary to revive this skill in order to enable the world's growing population to have access to sustainable housing and living conditions." [1]

Anna Herringer,
Simply Local.

INTRODUCTION:
WHAT IS RAMMED EARTH?

"The project permanently frees building with earth from the cliché of the troglodyte, the ecological naive, and raises it to a level of technical maturity and formal clarity that would have been unthinkable ten years ago."[2]

Otto Kapfinger,
on *Haus Rauch*.

Haus Rauch, Exterior
Schlins, Austria. 2011.
Martin Rauch with Roger Boltshauser

Fig 0.1

Rammed earth is both a building material and a building process. A *material-process*, wherein the process itself directly creates the material, on site and by hand. This process involves a mixture of raw soil, moisture, and additives, tamped into temporary formwork to an extremely hard-packed state. Through this process, free-standing, solid masonry walls are created. The walls are built in shallow layers called lifts, the loose material for each lift being compacted to roughly 50 percent of its volume within the formwork. The ramming process is repeated until a wall has reached the desired height. The formwork can be removed immediately, revealing the monolithic wall. Finished against the inside face of the formwork, the material is beautiful in its natural state. Rammed earth typically needs no cladding, finishes, plasters, or paints. The material is a portrait of its process, where the labour of each lift is communicated by the face of a rammed earth wall.

Much of the contemporary interest in rammed earth as a viable wall system stems from its characterization as a sustainable material. Rammed earth as a material has a range of applications which contribute to this sustainable reputation. It utilizes bulk resources readily available in nearly any location, has a significantly diminished life cycle impact, and is unparalleled in its solar thermal applications when compared to most conventional wall assemblies. The ability of rammed earth to function in virtually any climate zone, apply passive performance, and outlive most conventionally constructed buildings all demonstrate its sustainable characteristics. Sustainable architecture aims to tread lightly on the earth and to make a positive contribution to the built environment. A rammed earth building, despite its great mass, is able to tread lightly on the earth. A rammed earth building, despite being made of a low grade, un-engineered material, can and will last for generations. It is enduring.

Fig 0.2

Adobe City. Shibam, Yemen.
Named *"Manhattan of the Desert,"* Shibam is a contemporary urban environment created entirely of adobe. Much of the city was built between the 14th and 17th Centuries, and today is a cluster of around 500 towerhouses, up to 10 storeys tall. Their centuries of continuous use and adaptability demonstrate the enduring service life of adobe dwellings.

Fig 0.3

Rammed earth has its roots in adobe building. Nearly every text on earth building will open in reference to the adobe walls of Jericho, dated to 8300BC, which demonstrate the timeless application of earth as a building material. The next most common adobe reference is the Great wall of China, an example of 2000 year old earth walls which survive to the present day. In fact, most of China's great wall was originally constructed of rammed earth, and later clad with stone to appear as a masonry wall. [3] Both of these historical examples demonstrate earth as a viable, logical building material where local, bulk resources are demanded in great abundance. Other notable adobe examples are residential dwelling communities including Taos Pueblo in New Mexico, Arizona, and the high-rise, high-density, towerhouses of Shibam, Yemen. These less ancient, but no less historic examples demonstrate rural to urban earth buildings with centuries of useful service life. These are the examples which establish the desirability, durability, utility, and appeal of earth construction.

The rich history of adobe building has evolved with human culture along four distinct trajectories: mud bricks, wattle and daub, cob, and rammed earth. Because of the established appeal and sustainable attributes of earthen construction, all four of these building technologies have experienced some form of revival in recent decades. Adobe bricks are again becoming a dominate contemporary building technique in the South-Western United States. The term adobe now often refers to an architectural style which is tied to the modular construction technique. Wattle and daub has a variety of contemporary incarnations from light earth in Germany and New Zealand, to straw bale construction across North America. Cob as a contemporary building technology falls into a category of building solutions which revive basic passive thermal strategies. However, each of these earth building processes have significant limitations on potential for mechanization, climate viability, and urban applications.

Precedents of contemporary rammed earth construction originate from François Cointeraux: father of *pisé de terre*. His use of rammed earth for fireproof buildings in the Hautes-Alpes French landscape earned him the 1878 Accademia di Amiens award. His model of incombustible building was considered advantageous for use all across the European countryside. [4] Indeed, today, many of the modern precedents of this material are situated in that idyllic landscape. Most notable is Haus Rauch constructed in 2010 in Schlins, Austria, home of the master ceramicist Martin Rauch. His contemporary rammed earth dwelling is almost entirely fabricated of the loam excavated on site. Other contemporary examples of the material which are not situated in the rural countryside are to be found in a desert landscape of Australia, New Mexico, or even Osoyoos British Columbia. The Nk'Mip Desert Cultural Centre is the flagship building for contemporary rammed earth in North America. Its 80 meter wall of distinctive coloured lifts is the face of the modern material. Even closer to home in Castleton, Ontario's very first rammed earth house sits newly constructed in a deciduous forest setting. Rammed earth is being used today for almost any building typology imaginable, whether studios, factories, shops or places of worship. Yet the precedents of contemporary rammed earth are most often isolated structures, situated in rural or suburban locations.

Haus Rauch.

The house is a testament to high-design with low-tech material solutions. This house resolutely establishes that raw earth buildings can hold their own within our industrialized built fabric. Haus Rauch provides the prevailing precedent for those who seek to practice this particular vernacular method within the contemporary building culture.

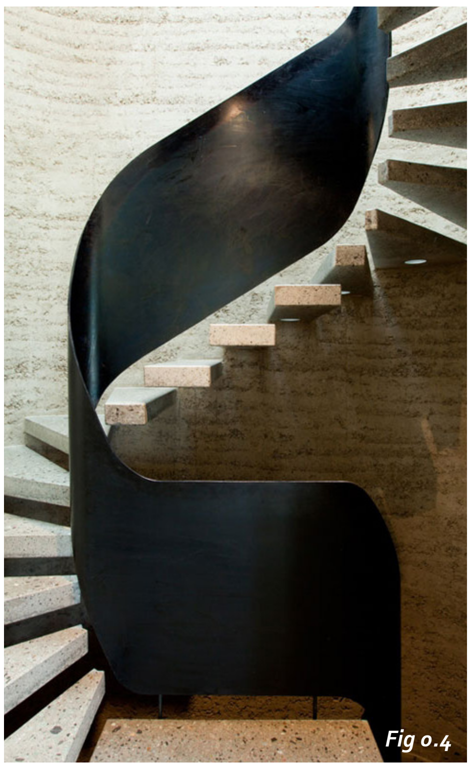


Fig 0.4

Fig 0.5

The desire for raw, unprocessed building materials should not be limited to the same rural settings which hold most adobe buildings. That need is present in all of global building culture, but especially the developed and developing built environments where resources for materials are consumed in their most concentrated abundance. The contemporary revival of rammed earth has generated a low-tech material solution which is aided by the high-tech conventions of industrialized building culture. This version of rammed earth involves precise chemistry for stabilization, and steel reinforcing for comprehensive strength. The contemporary rammed earth process is aided by mechanical mixing, motorized lifting and pneumatic tamping. The process and the material not only fit into many existing building conventions, but are also enhanced by those developed modes of building. This makes rammed earth unique among the other adobe building forms; it offers a greater opportunity for mechanization. Another major advantage over the other adobe methods is its adaptability to climate. Particularly with its contemporary capacities for conventional insulation methods, rammed earth can be tailored to perform well in any of the earth's climate zones. Finally, its potential applications within urban environments exceeds any other adobe building form. The urban setting, characterized by narrow rectangular properties and adjacent rectilinear forms, operates on an informal cooperation in which most adobe buildings simply cannot participate. Rammed earth is a much slimmer, straighter form of adobe. Its high strength, durability, and orthogonal nature allow it to happily participate in the industrialized urban vernacular.

Yet rammed earth has its limitations as well. It is very labour-intensive, limited to low-rise applications, and requires significantly more space than conventional wall assemblies. Earth construction faces other general challenges in contemporary, industrialized construction due to its lack of coverage in our codes and standards. Architects and engineers have little experience dealing with earth buildings and are uncomfortable predicting how they will perform. Home owners have little exposure to earth buildings and hold the perception that they are not modern or durable. Many are skeptical of inhabiting environments created of earth. But the contemporary version of rammed earth has the ability to correct these perceptions and foster a confidence in low-tech earth through high-tech building practices.

Fig o.6


Fig o.7

Nk'Mip Desert Cultural Centre*, *Exterior
Osoyoos, British Columbia. 2006.
HBBH Architects with S.I.R.E. Wall

The aboriginal cultural facility is set on conservation land in the Okanagen valley. The visual presence of the building is dominated by the high contrast rammed earth wall, the largest rammed earth wall in North America. And first commercial building of this modern version of the material worldwide, according to SIREwall.

Cook-Cavalier Residence*, *Exterior
Castleton, Ontario. 2012.
Terrell Wong Architects with Aerecura

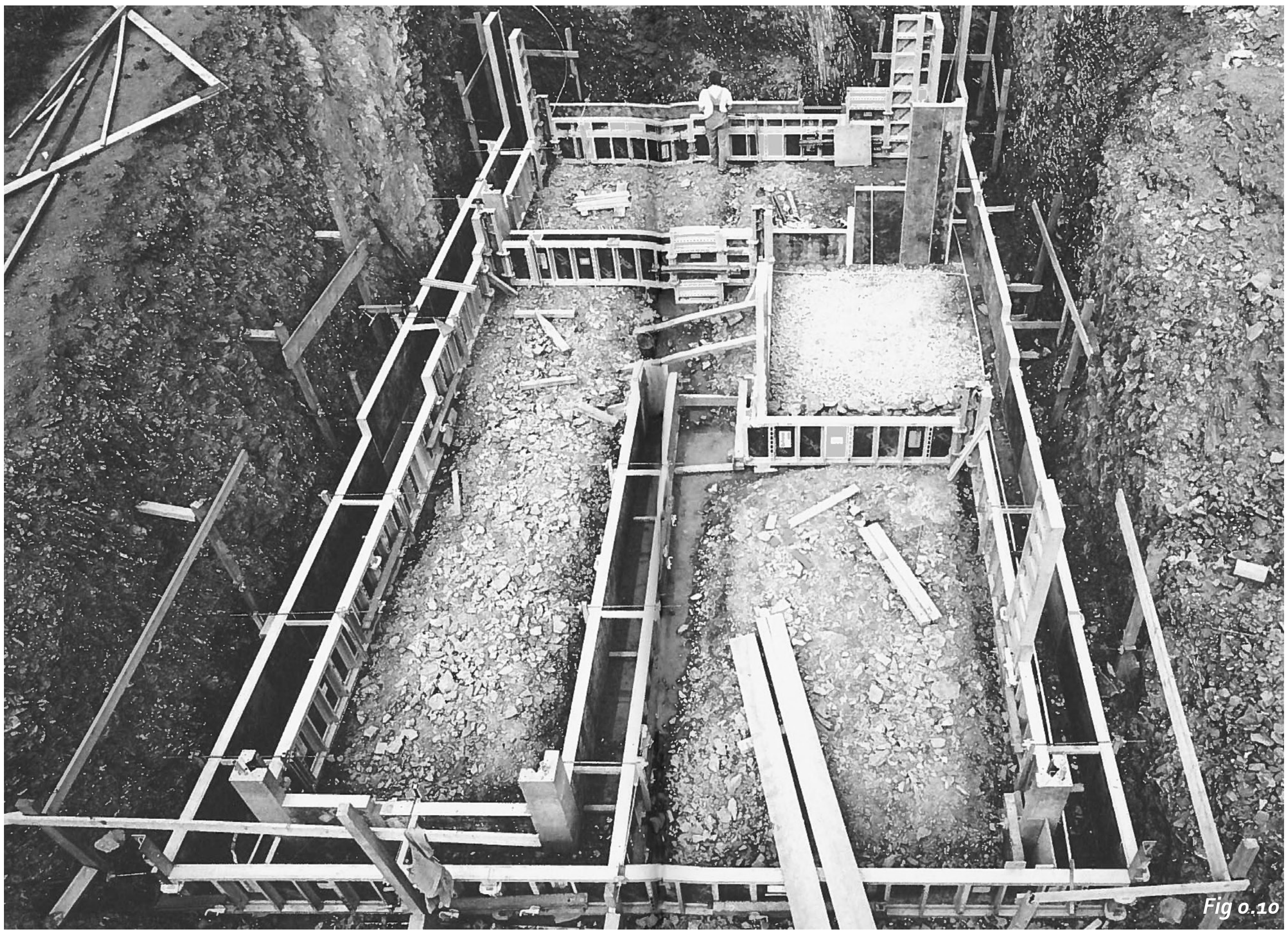
This private residence meets the demanding passive house standard. With no furnace or air conditioner, the house consumes less than 120 kilowatt hours/square meter annually. Advantageous south orientation and clerestory windows, along with R50 SIP insulation panels and high performance glazing allow this dwelling to achieve passiv haus certification.

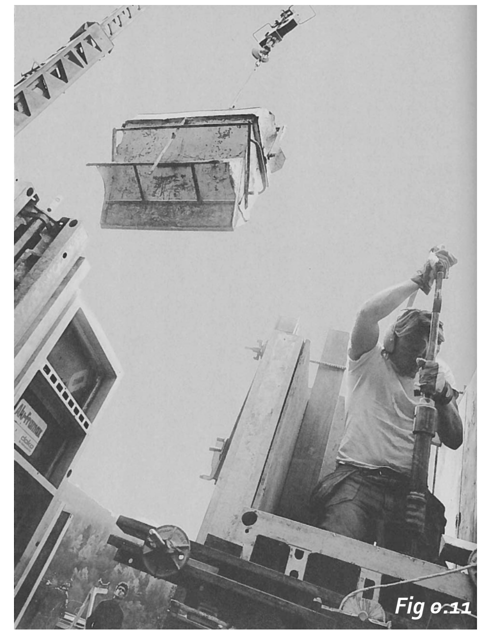
Rammed earth building is a wise construction investment. When properly executed, a rammed earth building will outperform and outlive a conventional wood frame assembly. In climates with aggressive freeze-thaw cycles (which can damage mortar and joints), rammed earth buildings can even outperform and outlive stone or masonry. [6] Properly orientated and fenestrated, a rammed earth building will gain free heat in winter. If properly shaded and ventilated, it will promote cool indoor environments in the summer. It will regulate humidity, dampen electro-magnetic fields, and maintain impeccable indoor air quality. Rammed earth is only one of a number of natural building strategies which are able to accomplish such things, but it stands out as superior in its ability to be absorbed into the built fabric of contemporary urban environments. Natural building strategies are a necessary tool for diminishing the resource intensity and environmental degradation of contemporary building practices. Natural building materials which fit within an urban setting are an urgent priority. Finding strategies which employ these natural materials to their particular advantages within specific climates is a prerogative of environmentally sensitive architecture.

This thesis proposes rammed earth has a contribution to make within the existing residential built environment of urban Toronto. The material can be adapted with insulation to suit the cold, wet conditions and used as an effective north-facing exterior wall. For a climate with both severe winters and humid summers, and a restrictive setting where full solar exposure is unlikely, the material can be used in conjunction with glazing as a south-facing trombe wall, to capitalize on solar thermal applications. It can also be used as an interior demising wall, providing an impeccable sound and fire barrier while effectively separating dwellings in the typical semi-detached residential typology of Toronto. These three specific applications of this abundant, low-carbon material demonstrate its viability within the existing Toronto housing stock. Exploring the benefits of this material and its value to the contemporary, urban built environment may prove its superiority not only over the other adobe building forms, but even over many of our conventional, contemporary wall assemblies.

"This wall has proven itself in terms of structural and formal properties, building physics and ease of construction." [5]

Martin Rauch,
on *Haus Rauch.*





***Haus Rauch*, Construction**

[Left] Formwork established in the excavation pit where 85% of the building materials were harvested. Excavated material was sieved and used in constructing the walls, floors, roof, bricks, pavers, tiles, and even the kitchen sink. [Above] The mechanized construction process for Haus Rauch shows industrial construction methods in action, aiding the creation of this low-tech natural material.

“Developing a design from only two materials (e.g. earth and bamboo) means fully committing to the character of the materials and giving them one’s entire focus. What results from this is an identity that - so long as the project is based on a concept that adds to the building culture - refers uniquely to the place and the builder, and that, ideally, can be considered architecture.” [1]

Anna Herringer,
Simply Local.

SECTION ONE: HOW IS IT MADE?

Rammed Earth Building Workshop.
Ottawa, Ontario. 2012.

Fig 1.1

The process of building with earth is significantly divergent to most conventional building methods. While rammed earth specifically is undoubtedly enhanced by contemporary modes of building, it still diverges from the basic conventions of industrialized residential construction. Rammed earth happens to be both a material - structural, monolithic, finished; and also a process of building - a method, technology, or technique. It merges these two, often distinct, aspects of building construction. The practice of building with rammed earth demands more than specifying and installing it as *a product:* the category to which most contemporary building materials belong. Products comprise the majority of conventional building components. These products are manufactured globally, shipped to a building site, and literally *assembled*, to form conventional *wall assemblies*. These products are often sourced from wide geographic locations, may contain any number of undisclosed toxins, are likely to have very high measures of embodied energy from extraction, manufacture, and transport, along with significant end-of-life environmental impacts.

Rammed earth is not manufactured or assembled in the method of conventional wall assemblies. It is not a product which can be purchased, but instead is a material to be created: in-situ, by hand, and tailored to each individual project. This distinct building process occurs in three phases: ***Soil Selection, Testing**, **and Construction***. The first two phases are unique to earth building and generally do not form part of the conventional residential building process. The latter phase is also fairly unique compared to typical conventions, but borrows from aspects of conventional construction, and employs tools and methods which are highly recognizable within standard residential building practices. All three of these stages of the rammed earth building process allow a high level of control on quality, aesthetic, and design potential, but are also a labour intensive process which requires a great deal of scrutiny and assessment to ensure the success of a rammed earth building project.

SOIL SELECTION → ***TESTING*** → ***CONSTRUCTION***

Soil selection involves assessment of the raw material for possible use in building. Contemporary applications of rammed earth building will usually source the base material from a local quarry, in which case the available options must be compared.

Once a soil is deemed suitable for construction, a series of testing phases are performed to ensure the success of the building project. The testing phase will establish the parameters of construction for both aesthetic and performance qualities.

The construction process involves creation of the material on-site and by hand. Doing so demands efficient project sequencing and diligent labour. Despite the effort and time, the process is both intuitive and repetitive.

1.1 SOIL SELECTION

Soil is the chief component of any earth building system, and appropriate soil selection is essential for the success of an earth building. In a rammed earth wall, soil will compose between ninety and one hundred percent of the wall by volume. This bulk material may be naturally occurring on site, or may be an engineered mix obtained from a local quarry. In contemporary applications, the soil for rammed earth is generally obtained from a quarry, allowing a higher level of control on the soil characteristics and minimizing much of the testing required to assess a material which is excavated on site. Regardless of where the soil is obtained, it will have unique characteristics which determine if it is suitable for building.

The primary assessment will be the composition of the soil. Soil is a broad term which encompasses any varying ratio of the five main soil classification groups: clay, silt, sand, gravel, and organic matter. These groups are designated by particle size, each with different contributions to the soil's performance as a building material. The soil for rammed earth building is likely to be classified as an inorganic, coursed-grained soil with fines. Building soils must not contain any organic content. If organic matter is present in soils used for building walls, those walls will be structurally compromised and susceptible to decay or damage. The other four major classifications of soil are inorganic subsoils and should all be present in a soil used for building.

	Definition	*Characteristics **	*Contribution*	*Particle Size*	*Ratio **	*Comments*
CLAY	• Inorganic • Fine-grained soil	• High Dry Strength • Medium Plasticity	• Binding Element • Stabilizer	< 0.002mm	5% - 20% †	• Specific clay type must be identified for viability in earth building.
SILT	• Inorganic • Fine-grained soil	• Low Dry Strength • Low Plasticity	• Binding Element	0.002mm - 0.75mm	> 10%	• Must be verified as inorganic soil. Organic matter can be mistaken for silt without proper testing.
SAND	• Inorganic • Coarse-grained soil	• High Cohesion	• Weathering resistance • Cohesion	0.75mm - 4.75mm	30% - 50%	• Sand must be the majority by volume to contribute to a uniform finished aesthetic.
GRAVEL	• Inorganic • Coarse-grained soil	• High Strength	• The structural matrix	> 4.75mm (Ideally < 19mm)	30% - 40%	• Gravel provides the skeleton for the structural building element.

Table 1.1
The Four Major Classifications of Soil For Building.

* These characteristics and ratios are specific to the ideal soil for rammed earth building. Desirable characteristics and ratio vary with other earth building techniques.

† Clay content of a soil for rammed earth building will be determined by the choice of stabilization. If no chemical stabilization is used, clay is the stabilizing element and must be present > 10%. If a chemical stabilizer is used [e.g. cement] clay should be present < 10%.

Clay is the cornerstone of earth building. It is perhaps the most important factor of soil selection. For rammed earth applications, clay should be professionally tested for its specific properties. It must be dimensionally-stable, non-expansive clay, known as kaolinite. A non-expansive clay is useful as a binding and stabilizing element, making it ideal for building. Other classifications of clay include montmorillonites and illites, which are expansive clays, characterized by their ability to swell and retain water, making them problematic for building. If an expansive clay is naturally occurring in a soil which must be used for building, chemical forces such as lime or bitumen can be used to neutralize the swelling properties of these clays, but will also have the effect of neutralizing their binding properties.

It should be noted that clay is traditionally the stabilizing component of rammed earth building. In contemporary applications rammed earth is often stabilized with chemical forces which all together negate the need for clay in a building soil. Chemical stabilization can be any mixture of insoluble binders such as cement, fly-ash, trass, lime, or gypsum. These stabilizers induce a chemical reaction between the particles of the soil while the walls cure. They act in the place of clay to enhance the strength of the earth structure. Earth walls may be chemically stabilized for many reasons: stabilization can limit water absorption, stabilize volume, increase strength and durability, and provide a framework for structural evaluation. The need for stabilization will vary from project to project, depending on location, climate, and experience of those undertaking the work. The decision is generally subject to professional knowledge and experience. For the most part, stabilization is cautioned, and should only be employed where the strength and durability requirements of the project cannot be demonstrated with raw soil alone. Chemical stabilization will significantly increase both the end-of-life impact and embodied energy of the material.

Stabilization is the method by which contemporary rammed earth achieves compliance with regulatory bodies. While hundreds of historical precedents of unstabilized rammed earth exist, they cannot provide the technical data necessary to use in evaluating or predicting the performance of contemporary earth structures. It is for the first time possible to apply rational structural design methods to earth building techniques, but this rationale is only possible though familiarity with the performance of stabilizing compounds. Canada has no standards in effect regarding the construction of rammed earth, and so the material is generally held to other codes or alternative guidelines. It is most often compared to concrete, and so is held to the well established performance requirements of concrete masonry. *The New Mexico Abode and Rammed Earth Building Code* is the most comprehensive earth building code in North-America. It recommends a minimum 300psi strength for load-bearing rammed earth walls. [2] Studies in North Dakota have shown that stabilizing additives of 5% Portland cement content and 5% lignite (Class C) fly ash will contribute to a rammed earth wall with 462 psi. [3] In Australia, testing has demonstrated that 10% Portland cement content of a slim 12" wide wall can produce a compressive strength above 1,000 psi. [4] These high compressive strengths bring stabilized rammed earth into comparative range with standard 15MPa concrete. [5]

For now, stabilization must be accepted as a necessary tool in garnering trust within rammed earth building in the contemporary, industrialized building culture. As this trust grows, the amount of available data and experience will also grow, and eventually provide a framework for regulatory bodies to evaluate rammed earth as a unique and independent material. From contemporary stabilized rammed earth, a possible future unfolds for the material where the necessary guidance for building unstabilized rammed earth is established, trustworthy, and easy to execute. Until that time, stabilization serves to both propel and impede the material. While it diminishes the ideological 'cradle-to-cradle' [6] potential of the material, it provides a route for rammed earth to eventually achieve that ideology in the industrialized setting.

1.2 TESTING

The decision to stabilize a rammed earth building project will eliminate much of the testing required to assess a soil used in building. This is why stabilization is currently such an attractive solution to rammed earth building. The testing required to assess a suitable base material is a tedious and intensive process. Stabilization eliminates much of this tedium by providing the structural stability of the wall, and relying less on comprehension of the minute variabilities of soil. Yet regardless of stabilization, a suitable soil must be tested and assessed along factors which will contribute to the final aesthetic, strength, utility, and durability of the rammed earth. Testing will occur in the following three phases: ***Soil Property Testing, Construction Mix Testing,*** and ***Quality Control Testing.***

SOIL PROPERTY TESTING → **CONSTRUCTION MIX TESTING** → **QUALITY CONTROL TESTING**

Property testing provides the detailed characteristics of a selected soil, establishes its suitability for building, and will help to predict the performance characteristics of that soil.

Construction mix testing will establish the desired ratio of the soil to moisture and admixtures, for use in construction. Creation of samples for analysis is a core component of mix testing.

Quality control testing is usually professionally performed to discover any possible complications which may arise due to a particular soil or construction mix.

SOIL PROPERTY TESTING

Soil property testing should take place long before the building process is scheduled to begin. Soil will be analyzed using various field tests and laboratory tests to determine the very specific characteristics of a soil. This first phase of testing makes use of simple visual analysis, as well as detailed laboratory analysis. Many factors of the soil must be determined to predict the behaviour of the soil in building. If the clay content of a soil exceeds 30 percent, walls built of that soil will be prone to shrinkage and cracking. If the sand or gravel components have too many large aggregates, compaction will likely be uneven and the finished walls will not be uniform. If there is a high salt content in the soil, the walls will be susceptible to efflorescence [*fig 1.7 "Quality Control Testing" opposite*]. Soils with harmful contaminates like arsenic, which might be found in soil excavated near industrial locations, must not be considered. Such is the abundance of soil characteristics which must be determined to find an appropriate material for building.

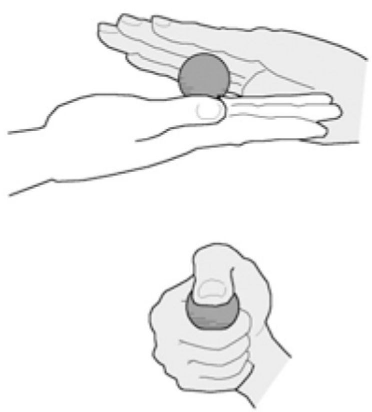


Fig 1.8

Fig 1.9

Dry Ball Test.
From ASTM 2392M
Design of Earthen wall Building Systems.
Wet soil is rolled into a small ball and left to dry completely. Once dried, the ball should maintain shape and integrity when under the light pressure applied between the thumb and fingers of one hand.

Ribbon Test.
From ASTM 2392M
Design of Earthen wall Building Systems.
Wet soil is worked into an extruded shape about the size of a finger. When hung as illustrated, the soil will demonstrate high plasticity. This characteristic is necessary for many of the adobe building forms, but the soil for rammed earth should not pass this test as high plasticity is not desirable.

Table 1.2
The Major Characteristics of Soil For Building

Soil Characteristic		*Testing*
Particle Type Distribution	• The composition or ratio of differing particle types within a soil. • Determines viability of a soil for building, [its likeliness to satisfy the other necessary soil characteristics below]. **In Rammed Earth:** • Must include clay, silt, sand, and gravel, but must not contain any organic material. • The ideal ratio of type distribution is suggested in Table 1.1.1 • Will *not* be classified as a "Clean" soil e.g. clean gravels, or clean sands.	*Field Assessment:* • The Shake Test. *Lab Assessment:* • Detailed Particulate Identification analysis of a soil.
Particle Size Distribution	• The composition or ratio of differing particle sizes within a soil. • Determines texture and structural integrity of the soil, its characteristics as a building matrix. • Distribution of the particle sizes should be varied within the limits of each particle type. **In Rammed Earth:** • Large stones may be used in rammed earth for specific aesthetic effect, but work best when they have a rough texture. Ideally a soil with no grain larger than 20mm should be used. • The largest particles must be limited to about half of the gravel ratio by volume. • Will *not* be classified as a "Well Graded" soil e.g. well-graded gravels, or well-graded sands	*Field Assessment:* • Visual inspection / Sieving. [See Fig. 1.5] *Lab Assessment:* • Detailed Particle Size Distribution Analysis [PSDA] of a soil.
Compactibility	• A soil's potential to reduce its porosity and increase its density. • Determines a material's capacity for water resistance and compressive strength. • Grain size and grain type distribution will proportionally determine compactibility. **In Rammed Earth:** • Soil compactibility should be very high for rammed earth material. • Too much gravel and too many large stones will decrease compactibility potential.	*Field Assessment:* • The Wet-Ball Test. [See Fig. 1.14-1.18] *Lab Assessment*: • Porosity Testing • Particle Surface Area Analysis

Soil Characteristic		***Testing***
Plasticity	• A soil's ability to deform, without cracking or disintegrating, • Determines a material's ability to breathe with changes in humidity or temperature. • Fine grains [silts and clays] contribute to plasticity. **In Rammed Earth:** • Medium-low plasticity is required to provide adequate sensitivity to changes in environmental conditions. • PI must be < 20 (Liquid limit < 45) • High Plasticity is to be avoided in rammed earth but is necessary for other adobe building types	*Field Assessment:* • The Ribbon Test. [See Fig. 1.9] *Lab Assessment:* • Plasticity Index Assessment *(will measure a clay's expansiveness.)*
Cohesion	• A soil's potential for sheer strength. • Determines how well the grains and particles will bond together. • Medium grains [sands and stones] contribute to cohesion. **In Rammed Earth:** • Cohesion is a factor of grain size and type distribution, compactibility, and plasticity all together. • Rammed earth needs	*Field Assessment:* • The Dry-Ball Test. [See Fig. 1.8]
Soluble Salt Content	• A soil's salinity measures the common inorganic solutes present in that soil. [Solutes such as: calcium, sodium, chloride, sulfate, bicarbonate, potassium, etc.] • Determines the long term aesthetic weathering of earth structures. • **In Rammed Earth:** • Soils with very low conductivity are desirable to avoid efflorescence. • Salt content must be < 2 % by mass • If the soil has too high a soluble salt content, carbonates will leech out leaving surface deposits and contributing to spalling.	*Lab Assessment:* • Electrical Conductivity Determination. [See Fig. 1.7 for example of efflorescence]

CONSTRUCTION MIX TESTING

Rammed Earth Building Workshop.

Fig. 1.10-1.13 [Right]
Two different soils, both suitable for rammed earth building, will generate very different finishes in built form. Both suitable soils were made into samples during the mix testing phase of the workshop. The upper material, with a more balanced gain size distribution, was selected for the build due to the more desirable finish.

Fig. 1.14-1.18 [Opposite]
The "Wet-Ball Test" is preformed by hand to assess the correct moisture content of the construction mix. The mixture should hold the shape of compaction with little pressure applied.

An experienced earth builder will have cultivated a sense of what a proper building soil is like. They will likely be able to assess a soil by hand testing combined with prior knowledge. Beyond knowing just soil characteristics, an experienced rammed earth builder would also understand how these soil qualities will behave in a rammed earth application, how they will become the aesthetic and structural characteristics of a building. Yet even the most experienced rammed earth builder will not proceed with a build until extensive mix testing is performed. While construction mix testing will be performed throughout the entire building process, the parameters of the construction mix should be established with samples done at least a month before construction begins. This stage of testing involves experimenting with admixtures, tinting, or stabilization. These experiments provide for immediate visual assessment of material, as well as later structural assessments which will be performed. This phase of testing allows one to fine tune the desired aesthetic and architectural qualities. It also helps to provide working experience with the materials, prior to beginning construction. These tests will give a sense of the right moisture content needed for a soil, the aesthetic effect of any admixtures like oxides or stabilizers, or the final texture to be anticipated by using a particular soil.

Mixing is a vulnerable area of the rammed earth construction process. It demands a trained eye to assess a perfect mix. This mixture will be prepared on site in sizable batches for the full process of building rammed earth walls, but during testing will be made in small batches in a bucket to fill pre-made form boxes. The mixture will involve ratios of roughly 90-97% of the selected soil, 3-10% of any stabilization if being used, perhaps 1% oxide powders if tinting is considered, and water added as required. Moisture content is the main vulnerability of the rammed earth process. Too little moisture will make a crumbly and weak mix, and will not provide for proper binding in the compaction process. Too much moisture will make a sticky mix, prone to shrink or crack, leading to water penetration and speeding decay. It is estimated that around 13% of

the dry mix weight is the correct amount of moisture to add to the mixture, [7] but the moisture content is not necessarily measured. It is added continuously during mixing until the mixture reaches the right consistency, and enough water is added to hydrate and activate all the stabilizing particles. The wet-ball test is the single most important test for finding the right construction mix. A wet clod of the mix is compressed by hand and dropped to the ground from waist height. The ball should break into several coherent clumps, it should neither shatter or splatter, which would indicate too little or too much moisture respectively.

QUALITY CONTROL TESTING

The final phase of testing is done to determine how the chosen construction mix will perform under normal stresses. The successful samples which were made for mix testing, will be quality control tested after they have had about a month to cure and stabilize. Some of these tests are simple enough to perform manually, like erosion testing with a garden hose or pressure washer, leeching tests with sun and water, or break tests with applied forces. If the structure is to be held up to contemporary code requirements the samples will also require structural material testing. Typical strength testing is preformed at 28-days, as established with concrete curing time. Rammed earth possesses a longer curing cycle where 56-day testing is ideal. 28-day testing will likely reveal only 60-70 percent of the rammed earth's material strength.[8] Other lab tests will determine properties such as wet and dry comprehensive strength, percent absorption, modulus of rupture, etc. These results will demonstrate to code officials that the earthen materials can be in compliance with prevailing standards. It is crucial in our developed building culture to provide the technical data needed to evaluate what is safe and reliable in earth building systems, and provide a base of knowledge which will further the ease of earth construction in the future.

1.3 CONSTRUCTION

Once the soil has been assessed and selected, an appropriate mixture has been determined, and the structural qualities of that mix are known and accepted, the building process may begin. This process is likely to vary drastically depending on location, climate, builder, or design. In general, concrete foundations will be laid, formwork will be constructed, and material will be stockpiled. It is important to establish detailed construction sequencing of forms and walls for rammed earth building. The low moisture content of the material provides quick curing, allowing forms to be removed and re-set the same day a wall is completed. Using these forms optimally will mean tailoring the building design to aid the construction sequence. Walls built to the same lengths, or established on a simple module will allow forms to operate efficiently without much customization between dismantling and resetting the forms. Well placed openings, of identical or modular sizing, will further minimize customization of the formwork for each wall or segment. Service conduits and electrical boxes must all be established prior to construction. Unlike a conventional wall assembly, these design factors cannot be decided later as construction progresses. A well designed project will lead to an efficient and organized building process.

THE SITE

The site is an integral part of the building process for rammed earth. It is not only the location of the build, but the location of the material manufacturing. There must be a well draining location to stockpile the soil. The stockpile, or total amount of soil required should have a volume equal to 150% the volume of the walls. This additional 50% loose material will account for the compaction process which reduces the volume of the soil by about half in forming the walls. It is essential that this soil stockpile be kept sheltered from rain, which would introduce an excess of moisture to the material. A generous space on the site is also needed for the mixing area. If a front loader is being used, this space must be adequately connected to the building site. If manual labour is used to transport the material, proximity will facilitate that intense labour. Ideally a level concrete pad, 25-40m^2 will be used for mixing.

THE FORMWORK

The formwork, although temporary, is essential to the success of rammed earth and must be well made, strong, stiff, stable, plumb, and level. It must be made of durable materials to withstand repeated placement, yet lightweight enough to be movable. Formwork is the main variability of this building process, subject to builder experience and aesthetic preference. Formwork may be wood or steel, and can be created in a variety of ways, with no specific method being better than the rest. Slip forms are common, especially for tall walls, but stationary forms work well too. As the inside face of the formwork will generate the exposing face of the rammed earth, its finish and joining must be considered. Paper-faced plywood will leave a smooth and rarified surface, textured wood, or slatted forms will affect the surface differently. The potential to recycle the formwork material should also be considered. Sheets of plywood or OBS used in forming can often be suitable for roof sheathing or other applications after the rammed earth is completed. 4 foot x 8 foot common building sheets, 5/8" thick, will be suitable facing materials for the formwork, stiffened with a system of whalers and jacks.

Rammed Earth Building Workshop.
Fig. 1.19-1.21
Erected formwork for an 8' wall, shown with an open face, which will be enclosed as the wall rises in height.

THE BUILD

The remainder of the building process is the creation of the material, formed in placed. While traditional, fully manual methods are still viable, this process can be much enhanced by applications of industrialized building practices. Front loading tractors can mix and move large amounts of soil relatively quickly, rototillers also aid mixing. Hoisting buckets can transfer the material efficiently, pneumatic and vibrating tampers speed compaction and increase reliability. With these conventions and a dedicated work crew, a sizable rammed earth wall can easily be completed in a work-day. Mixing and ramming are the main elements of the cyclical working process, and will be ongoing throughout the entire build. Batch sizes will be determined by the size of the working wall, and the design intension. If tinting variations are required between lifts, each batch will be fresh made for each lift. If the wall is small and no variations are required, a batch can be mixed once and provide for several lifts. This sizing might take a bit of experimentation to understand the working speed of the crew relative to the drying time of the soil and the specific weather conditions. There are four steps which establish the rammed earth build process: ***Measuring, Mixing, Loading,*** and ***Ramming.***

Rammed Earth Building Workshop.
Fig. 1.22
Compacting a lift into the formwork, using a pneumatic tamper.

STEP ONE:
MEASURING

The mix will be measured out on the predetermined ratio established in construction mix testing. In practice, this ratio is likely to be established on an unusual unit of measure, being whatever object is to be used for transport or mixing of the soil. For example, if a front loader is being used, the unit of measure will be based on the volume of its bucket, if wheelbarrows are used, that wheelbarrow would be the unit of measure. The quantity of the other admixtures will be determined from the ratio and the chosen unit of measure for the soil.

Tips

- Measure the materials out in a sequence, so they become layered on the mix pad. e.g. one unit of soil, one unit of stabilizer, one unit of oxide, and repeat. this will aid the mixing process as the materials will already be distributed among each other before the mixing begins.

STEP TWO:
MIXING

The soil and admixtures will be thoroughly mixed together before being mixed with water. Mixing will be accomplished with the bucket of the front loader, crew members with shovels, and a continuous, low-flow spray of water. While the soil is likely to be thoroughly mixed in terms of its composition and differing particle sizes, additives will need to be thoroughly dispersed. Especially with chemical stabilizers or tinting pigments, these particles must be evenly distributed within the soil to operate properly. Each and every mix should be tested for moisture content using the ball drop test.

Tips

- Mechanized mixing alone cannot be relied upon for entirely thorough mixing. Manual mixing by crew members with shovels is necessary for the material which falls to the edges of the mix pad. As a front loader mixes the main pile of the material, the edges of the pile should be continuously collected and reinserted into the mix. Similar to baking, when mixing ingredients with an electric mixer, the sides and bottom of the bowl must be scraped with a spatula.
- Water can be added with a simple garden hose, but it is very important to have a nozzle which is able to disperse the water in a wide spray. A single stream or jet of water will saturate specific areas of the mix and will be difficult to work through. A light mist over a wide area is the best way to introduce the moisture in an even and controlled way.
- Add water slowly throughout the mixing process, water cannot be removed if too much is added. Too much moisture can ruin a batch, especially with chemical stabilization, as it cannot be dried out. Once a certain saturation is reached, crew members should continuously test the mix for moisture content until the right mix is achieved.

STEP THREE: LOADING

Transporting the mix to the formwork and transferring the material inside must be a quick and seamless task. Similar to measuring, the lift sizes are likely to be determined by the established unit of measure [the front loader bucket or wheelbarrow]. The loose material will be placed in the forms manually with shovels, or dropped from a loading bucket. The material should be spread fairly evenly across the length of the wall, within the formwork.

Tips

- Attention must be paid to how the material is set into the forms. It should also be placed in ways that limit large aggregates collecting at the faces of the wall. If the mix is thrown from a shovel freely into the center of the formwork, large stones will roll down, collecting at the faces, near the base of each lift. Mix thrown from a shovel against both faces of the formwork will produce a convex pile where large stones will roll into the centre of the wall.

STEP FOUR: RAMMING

Physical compaction allows rammed earth walls to reach their extreme density and strength. The ramming process is very intuitive, loose material is first lightly compacted by foot, then the surface is passed over several times with either a mechanical or manual tamping device. Mechanical ramming is said to allow the material to reach much better compaction ratios than manual power. A hand-held, pneumatic vibrating tamper is used, with a head ideally 2"-6" dia. to will fit into all corners of the formwork. A mechanical rammer will provide upwards of 1200 blows per minute, and should have a blow length of 4 - 8".

Tips

- Pneumatic tampers should have steel heads. Rubber heads will scuff the inside face of the forms and leave marks on the finished walls.
- The hard blow of the tamper is likely to disrupt loose material at the surface as it compacts the material below the surface. This loose material should be of no concern, as these will just become compacted at the bottom of the following lift. However, a final pass with a hand tamper at the top edge of each lift will result in the cleanest possible lift joints.
- A cold joint occurs between lifts constructed on separate working days. If a wall is partially completed, and left to cure overnight before the next layer is added, this will create a highly visible joint between those lifts. This cold joint can be used purposefully and aesthetically, or it can be minimized by ensuring there is no loose material left in the forms before the new lift is added.

Rammed Earth Building Workshop.

[Fig. 1.27-1.30 Opposite]
The climactic moment when the formwork was removed after completion of the first wall of the build.

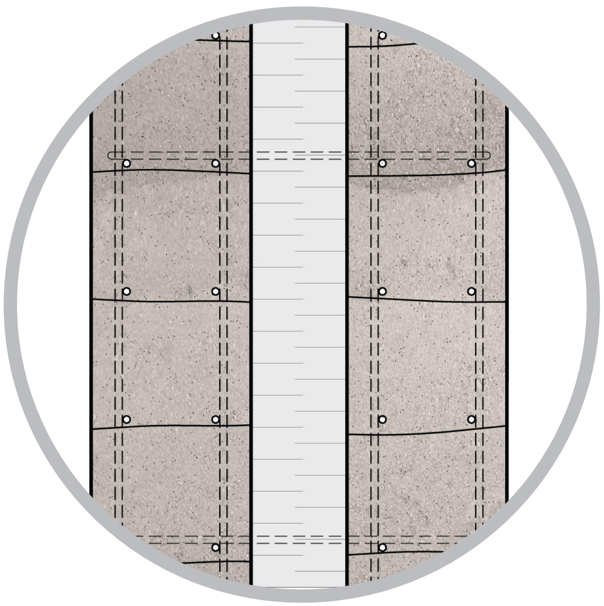
[Fig. 1.31 Left]
The chamfered corner of the monolithic wall. Chamfers, while not entirely necessary for stabilized rammed earth, help the material maintain structural integrity. Chamfered corners are an iconic symbol of rammed earth.

"Replacing a conventional American wall assembly, consisting of wood studs, fiberglass insulation, Sheetrock, plaster, paint, plywood, Tyvek, lathe, and stucco, every 50 or 70 years is not sustainable building. A solid earth wall, even built with high-tech components of trucked-in screened soil, 10 percent Portland cement, and diesel-powered equipment, offers a superior return on investment over stick-frame. It provides not only energy savings for the owner in five to seven years, but, with a functional life between 500 and 1000 years, a rammed earth wall can dramatically enhance global environmental health by saving natural resources that would otherwise have been used for replacement construction." [1]

David Easton,
Rammed Earth.

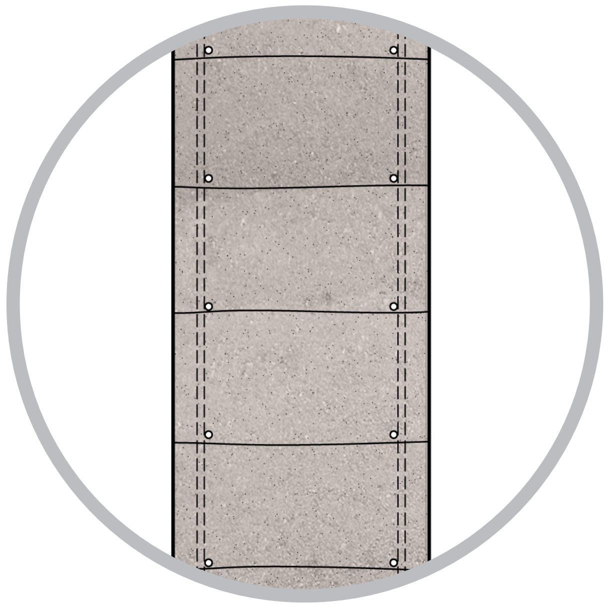
SECTION TWO: APPLICATIONS.

APPLICATION A



NORTH-FACING EXTERIOR WALL

APPLICATION B



INTERIOR DEMISING WALL

APPLICATION C

SOUTH-FACING TROMBE WALL

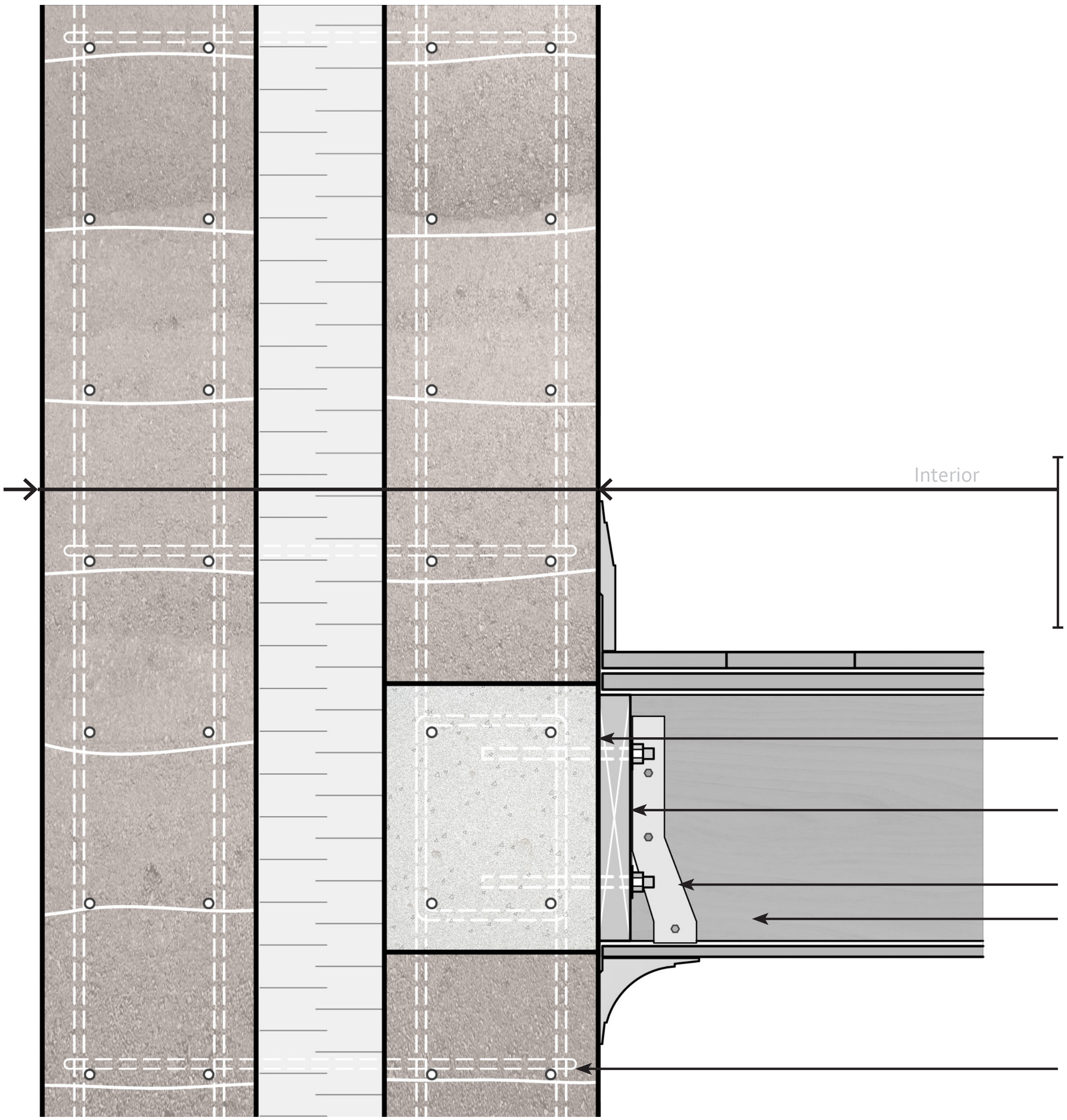
The Three Proposed Applications of Rammed Earth for the Urban Environment.

While most natural building strategies are stigmatized with the perception that they are incompatible with the urban environment, rammed earth is a natural building technique with the ability to transcend this stigma. Using Toronto as a specific urban setting, there are several distinct applications of the material which prove to be ideally suited to the urban environment. Being adapted to the specific climatic conditions and sociological dwelling conditions of Toronto, these applications are unique to Toronto, and may not necessarily be viable elsewhere. They serve as an example of the versatility of rammed earth and suggest the myriad possibilities of its application. Each of the three applications proposed utilizes some of the specific advantages of rammed earth. The first application, as a north-facing exterior wall, involves adapting the material with insulation to suit the climate, and demonstrates its advantages as a low maintenance, durable barrier. The second application, as an interior demising wall between dwelling units, demonstrates its advantages for sound dampening, fire resistance, and service distribution due to its absorption of electromagnetic fields. The third application, as a south-facing trombe wall, proposes a design language where rammed earth is paired with glazing to capitalize on its solar thermal advantages within the urban setting. A setting where full solar exposure is unlikely. The first two applications of rammed earth are herein compared to other wall types typically used in these same conditions. This comparison takes place along fundamental performance criteria established for each of these given wall types. The comparison is both quantitative and qualitative, and attempts to demonstrate rammed earth's feasibility and viability in each of the proposed applications. The third application is one with no existing precedent in the architectural language of Toronto. This application attempts to demonstrate the benefits of this material which cannot be achieved with the standard conventions of residential construction in urban Toronto.

APPLICATION A

NORTH-FACING EXTERIOR WALL [A-i]

The contemporary, cold climate, rammed earth wall enclosure involves two wythes of solid earth masonry, tied together through an insulated cavity. The insulation is ideally placed to regulate the slow transmission of heat between the thermal storage walls. The earth is stabilized with blended cement (i.e. clinker is replaced with pozzolans such as fly ash) to significantly reduce the carbon footprint. The stabilization provides compressive strength, while the steel reinforcement provides the tensile strength. The monolithic wall serves as the structure, the air and moisture barrier, as well as both the interior and exterior finishes. The density provides for a long service life, and because there are no other exposed materials or finishes there is absolutely no maintenance required. The walls are hygroscopic (moisture buffering) but they are not sensitive to moisture decay.



	Polymer Solvent Waterproof Sealant
9″	***Rammed Earth Wall [R3.5] w***
10M	***Steel Reinforcing***
6″	***Eco-sourced Rigid Insulation Panels [R24]***
9″	***Rammed Earth Wall [R3.5] w***
10M	***Steel Reinforcing***
	Linseed Oil Coating

Concrete bond beam, cast in place & reinforced
Formed into Rammed earth at floor plate bearing height.

2″ x 12″ Wood Ledger
Hung w pairs of 1/2″ø expansion anchors @ 32″ o.c.

Joist Hangers

2″x12″ Floor Joists @ 16″ o.c.

10M Tie Bars @ +/-24″ o.c. (Varies with lift height)

Scale 1 1/2″ = 1′-0″

2.1 NORTH-FACING EXTERIOR WALL

The most straight-forward application of rammed earth is as an exterior wall. The contemporary rammed earth exterior wall has many permutations; it may be insulated, it may be reinforced, it may have windows or doors, it may be clad or plastered, or it may be none of these things. The methods of applying rammed earth as an exterior wall are numerous, and the details of that application are subject to the factors and conditions affecting each individual project. For rammed earth to function as an exterior wall in urban Toronto, it must meet or exceed the established performance criteria given for any exterior wall in that location. Many of the necessary performance criteria for an exterior wall are well established in regulatory codes, standard practices, and even just practical conventions.

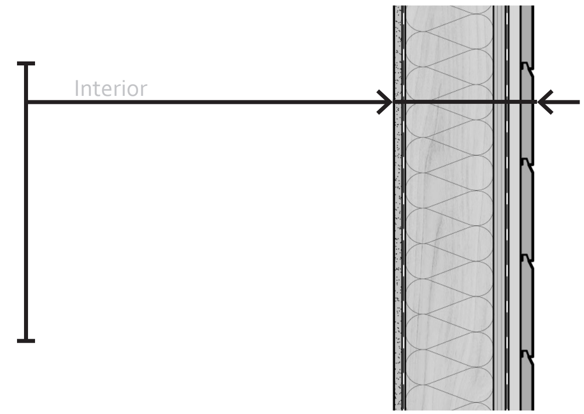
An exterior wall, in a cold climate, simply must provide thermal resistance. This criteria is set out by *The Ontario Building Code*, which mandates above-grade, residential walls of new construction to provide a minimum resistance value of 24 [R24]. [2] Other regulated criteria include air and moisture impermeability, by which the code requires demonstrable air and vapour barriers. [3] By standard practices, an exterior wall should be load-bearing, it should also be economical to construct in terms of both materials and labour. By practical conventions, an exterior wall should not be too bulky, and it should be both low maintenance and aesthetically pleasing. Many additional criteria could be applied to assess an exterior wall on environmental concerns, such as embodied energy, end-of-life impact, VOCs, etc. In practice these criteria are not all given equal weight, some of these criteria are given no bearing in the selection of an exterior wall assembly. While environmental criteria is well established in theory, it is not necessarily placed in practice. While durable, low maintenance walls are necessary for building with long-term goals, this criteria is often overshadowed in practice by short-term objectives. It is necessary here to evaluate walls on their long-term performance and impacts in order to compare the walls with a more balanced, holistic approach. All together, these criteria are the factors by which we ought to assess, select, design and construct our exterior walls. When evaluated altogether, they establish the ways we should measure overall performance of an exterior wall, allowing *that* performance to dictate where and when we employ such walls.

In Toronto, there are only a handful of typical exterior wall typologies which are active and common in use. Most notable is the double wythe brick bearing wall, the prevailing typology of Toronto's ageing, yet enduring, housing stock. These double brick facades are our legacy of the Victorian era colonization of the city. Today, these brick facades are often fitted with interior furr walls to provide insulation, weatherproofing, and resist heat flow. The second typical Toronto exterior wall is light wood frame construction. 'Stick framing' is the standard new wall assembly, insulated, sheathed, and clad at the exterior. This is the most common wall assembly for contemporary dwellings or additions and commands the vast majority of new residential low-rise construction. Slightly less popular, but worthy of inclusion, is a concrete masonry wall assembly with an exterior cementitious stucco cladding. All three of these wall types involve complicated layering assemblies, off-gassing materials or finishes, compromises in terms of permeability, and varying amounts of required maintenance, upkeep, and replacement. The rammed earth wall, by comparison to these other typologies, has significant advantages on many of the established criteria. The rammed earth wall is undoubtedly bulkier and more labour intensive to build than the others. It is comparable in thermal resistance and load-bearing capacity. But it far exceeds the other walls in its low material cost, zero maintenance requirements, total impermeability, and, arguably, finished aesthetic. Beyond this the rammed earth has capacities to regulate both changes in temperature and humidity. A rammed earth wall, because of its mass, provides an ideal inertia against temperature swings. Known as the *Thermal Flywheel Effect*, rammed earth walls are able to absorb or release heat energy as needed during the cycle of diurnal temperature changes. Similarly, rammed earth walls are hygroscopic, meaning they can absorb and release humidity in the same way, and along with humidity, odours too are absorbed and regulated. Both of these effects contribute to energy conservation of a building. Finally, a rammed earth wall is entirely pest resistant. No rodents, insects, or termites are able to penetrate this exterior wall. These advantages are specific to the rammed earth wall alone, such actions cannot be performed by conventional wall assemblies. These performance factors provide additional comfort to the interior environment, and as such are major advantages for the application of rammed earth as an exterior wall.

WALL SECTION [A-ii]:
EXTERIOR WOOD FRAME

New residential wall construction in Toronto is dominated by light framing or "stick frame" construction. This wall assembly employs conventional dimension lumber for structure, and is enclosed with sheathing and some lightweight cladding material at the exterior, and finished at the interior with conventional painted drywall. The framing cavity is filled with fiberglass batt insulation to meet the resistance requirements of the Ontario Building code for new walls [R24]. Because stick framing is permeable by nature, attention must be paid to placing air and vapor barriers as independent layers of the assembly. The complexity and frangibility of these layers require high maintenance to ensure a long and useful service life.

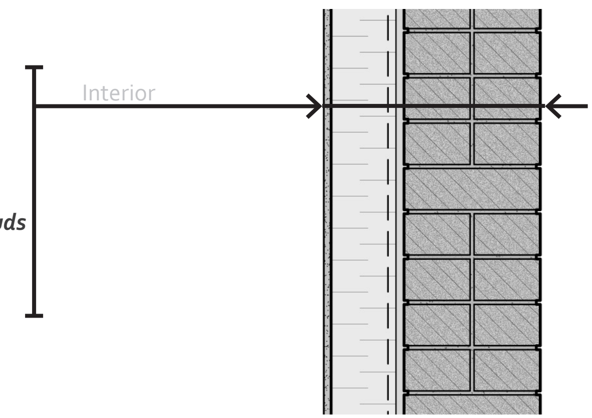
1"x6"	*Fibercement Cladding*
1"x3"	*Vertical Furring strips 12" o.c.*
	Weatherproof Membrane
	Sheathing
2"x6"	*Framing wall w*
	Fiberglass Batt Insulation [R24]
6mm	*Polyethylene Vapour Barrier*
	Gypsum Board
	Paint



WALL SECTION [A-iii]:
EXTERIOR DOUBLE WYTHE BRICK MASONRY

This is the typical condition of a recently renovated Toronto residential enclosure. If well maintained, the existing brick masonry will be a reliable load-bearing wall for generations. A Toronto home in existing condition will typically only have an interior plaster on lathe finish. When renovating, an insulated furr wall is commonly installed at the interior of the existing brick shell to meet the resistance requirements of the Ontario Building code for existing walls [R19]. Because these walls are often old, they cannot be relied upon for moisture impermeability, so some vapour protection is required to impede moisture entering the assembly from both the interior and exterior. It is an imperfect solution to insulating brick walls, but a common reality of Toronto dwellings.

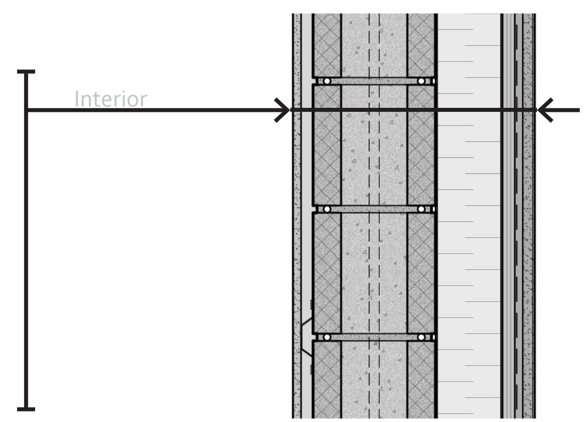
	2 Wythe Brick Masonry Wall w
	Bituminous Dampproof coating
1/2"	*Airspace*
2"x4"	*Furr Wall w*
	Expanded Polystyrene Insulation [R19]
	Ship lapped continuous behind wood studs
6mm	*Polyethylene Vapour Barrier*
	Gypsum Board
	Paint



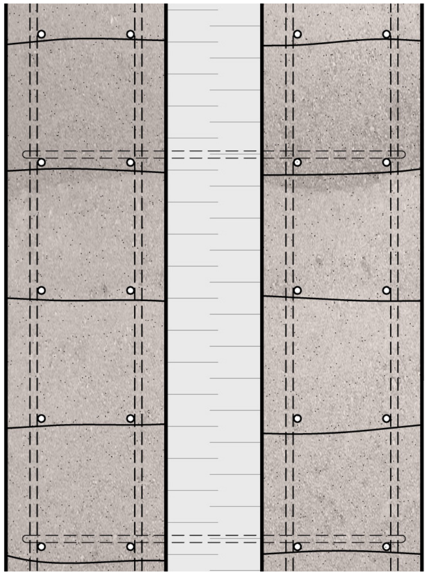
WALL SECTION [A-iv]:
EXTERIOR STUCCO ON CONCRETE MASONRY

Stucco can be employed in numerous ways as a cladding or rainscreen at the exterior of many conventional wall assemblies. The most enduring use is as a cementitious cladding for concrete masonry construction. This fairly successful wall assembly can be adapted and customized easily. The Concrete Masonry Units (CMU) provide the load bearing structure, as well as the air and moisture block. The addition of insulation is necessary to meet resistance requirements, but may be appropriately placed at the exterior of the structural assembly. If well constructed, the exterior stucco face can provide a fairly low-maintenance cladding, but is often subject to weathering, cracking, decay, or pest invasions.

	Finish Coat or Paint
5/8"	*Cementitious Stucco Plaster*
	Wire Mesh furring lathe
30lb	*Felt Vapour Barrier*
	Sheathing
18ga	*Z-Channel Furring strips w*
	Expanded Polystyrene Insulation [R24]
8"	*Concrete Masonry Wall w*
15M	*Steel Reinforcing*
	Steel Furring Channels
	Gypsum Board
	Paint



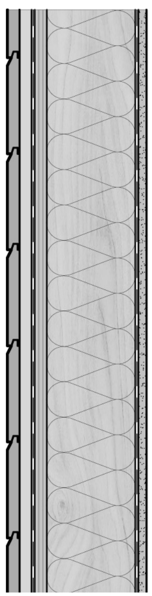
Scale 1" = 1'-0"



Bearing Structure	**STABILIZED EARTH**
Assembly Depth	**+/- 24” [60cm]**
Resistance Value	**+/- R31**

Air Permeability	☁
Moisture Permeability	💧
Labour Time	🕒 🕒 🕒 🕒 🕒
Material Cost	$
Maintenance	🔨
Embodied Energy	🏭 🏭

WALL SECTION [A-i]
The advantages of this wall are its very low material costs, its impervious nature, and extremely low maintenance requirements. A rammed earth wall, properly built, can last well beyond a century. The disadvantages of this wall are its very generous assembly depth, which is not favourable in the urban environment, along with high labour costs. Yet these drawbacks are easily overcome by the other advantages when thinking long-term about the built environment. The embodied energy will depend on the stabilization content (both the selected stabilizer and the ratio at which it is used) and the selection of insulation. Cement clinker and common expanded polystyrene will significantly increase the embodied energy of this assembly.



Bearing Structure	**FRAMED LUMBER**
Assembly Depth	**+/- 8.5” [22cm]**
Resistance Value	**+/- R24**

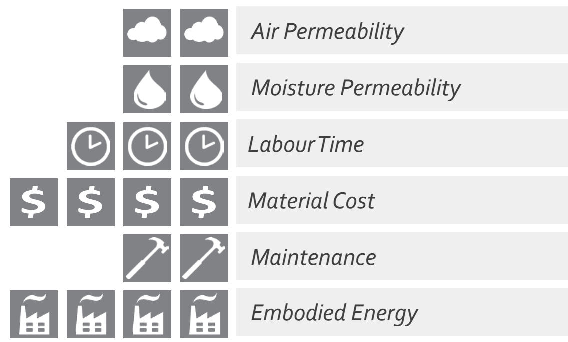
Air Permeability	☁ ☁ ☁ ☁
Moisture Permeability	💧 💧 💧 💧
Labour Time	🕒 🕒
Material Cost	$ $
Maintenance	🔨 🔨 🔨 🔨 🔨
Embodied Energy	🏭 🏭

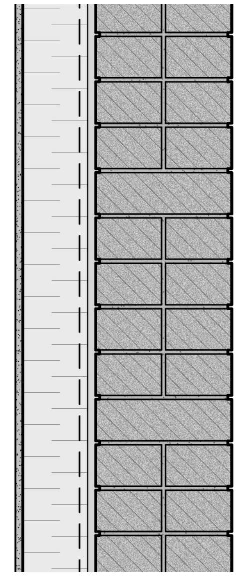
WALL SECTION [A-ii]
The advantages of this wall assembly are it’s low cost of both materials and labour. Its secondary advantages are its slender depth and capacity for customization in regards to insulation depth and exterior cladding aesthetics. The disadvantages are the permeability. While it is certainly possible to build this wall assembly air and moisture resistant, the potential for permeability is very high due to the layered nature of the assembly. Additionally this wall is disadvantaged for its high maintenance requirement. Gypsum board requires finish painting which will likely occur every few years. Cladding likewise will need painting or replacement several times during the lifespan of the wall. The embodied energy of the wall is subject to specific project details, depending upon the insulation and cladding selected.

WALL SECTION [A-iii]
The advantages of this wall are the high bearing capacity, low maintenance, and low permeability. The disadvantage is clearly the low insulation value, and its problematic location at the interior of the assembly. While the initial costs of labour and materials is somewhat high, the reliability of brick masonry is often worth the cost. Interior gypsum board will require refinishing every so often, but bricks and mortar will require re-pointing no more than once a generation, making the maintenance of this assembly ideal for the tough freeze-thaw climate of Toronto. The embodied energy of kiln-fired bricks is high, as well as the rigid insulation required for the furr wall, and the bit-tar coating used as an air barrier.

BRICK MASONRY

BRICK MASONRY	*Bearing Structure*
+/- 13” [33cm]	*Assembly Depth*
+/- R19	*Resistance Value*

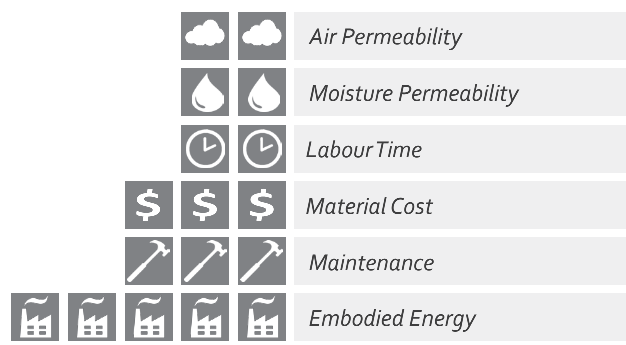


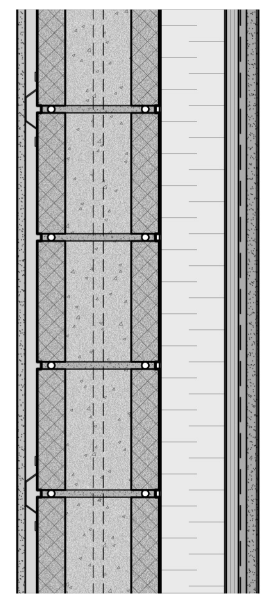


WALL SECTION [A-iv]
The advantages of this wall are its high bearing capacity, speed of construction, and low costs for labour and materials. The embodied energy of this assembly is very high due to the cement clinker blocks, the cement filled hollow cells, the cementitious exterior finishing, as well as the steel reinforcing and steel or aluminium accessories required for assembly (the furring strips and wire furring lathe). The maintenance requirements will depend on the competence of construction and minute environmental conditions such as pests or concentrated weathering. The potential for decay of the rainscreen will lead to high maintenance requirements.

CONCRETE MASONRY

CONCRETE MASONRY	*Bearing Structure*
+/- 16” [40cm]	*Assembly Depth*
+/- R24	*Resistance Value*

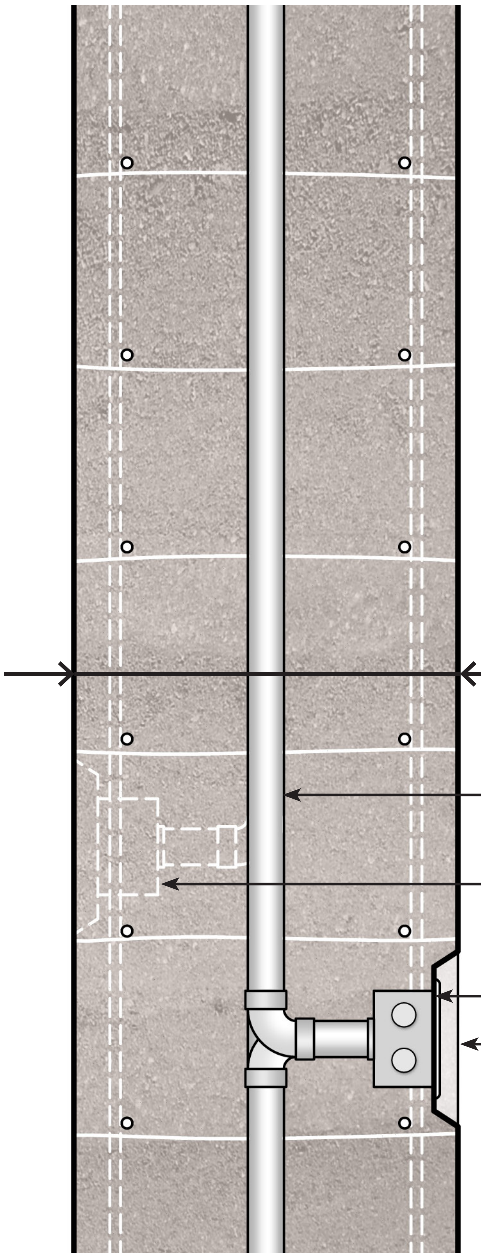




APPLICATION B

INTERIOR DEMISING WALL [B-i]

Mass is the simplest method of providing a sound barrier. The mass of a wall directly correlates to its resistance to acoustical transmission. The proposed rammed earth wall, with its high mass and high density provides an ideal sound barrier. Rammed earth contributes a tranquil ambiance to living spaces by eliminating reverberation and absorbing sound. A 14″ wythe of solid rammed earth will provide an STC rating over 60, the point at which no audible sounds will travel through that wall. This same mass also performs as an effective fire barrier. Rammed earth is non-combustible construction, stabilized and properly constructed, will provide over 4 hour FRR, the highest rating required by code for any purpose. Rammed earth fire ratings have been established by Standards Australia, AS 1530.4-2005 which has rated the material for use in high risk fire zones.



Scale 1 1/2″ = 1′-0″

2.2 INTERIOR DEMISING WALL

The application of rammed earth as an interior demising wall is somewhat unique. Rammed earth is usually applied as an exterior wall in rural or suburban settings to capitalize on its value as a thermal barrier, an air barrier, and a moisture barrier. But rammed earth functions as an effective barrier for other environmental concerns unique to the urban environment. The high density characterization of the urban environment demands effective barriers for both sound and fire. Such a barrier is erected between dwellings as an interior demising wall. These walls, called party walls by code, are architectural elements which divide separately owned living spaces. Rammed earth applied as a demising wall provides a powerful barrier between dwellings. Like exterior walls above, party walls have established performance criteria based on the code, standard practices, and practical conventions.

A party wall has two fundamental criteria as established by code: fire resistance and sound transmission. Per *The Ontario Building Code,* a party wall must be constructed as a firewall. [4] A firewall for residential occupancy must be made of non-combustible construction with a fire resistance rating not less than 2 hours. [5] Despite being attached by a party wall, distinct dwelling units are indeed entirely separate households. A party wall must provide adequate sound control to ensure that attached dwellings offer the necessary privacy and distinction each dwelling deserves. This is why the OBC also sets criteria on sound control though minimums on sound transmission class ratings. [6] Per OBC, dwelling units must be separated by construction providing an STC rating not less than 50. [7] Controlling the spread of fire is the major life-safety issue in terms of party walls, while controlling the transmission of sound contributes to quality-of-life within attached dwellings. Both of these concerns are somewhat exclusive to the urban setting where the threat of fire spreading or noise pollution are increased relative to population density.

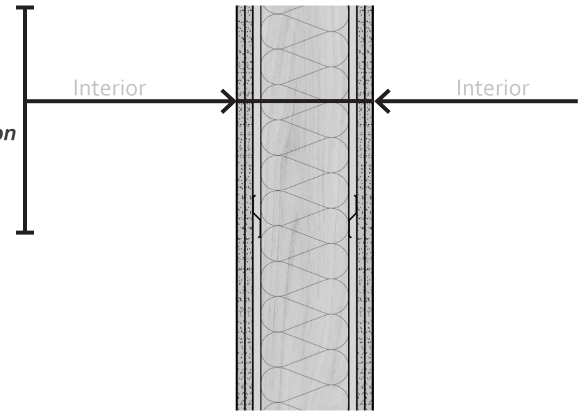
The same standard practices for an exterior wall are often applied to a demising wall as well. One should be load-bearing, economical to construct, low maintenance, and aesthetically pleasing. The other environmental criteria should be applied as well, such as embodied energy, and specifically VOCs, because the construction choice of such an interior party wall will off-gas in two directions, affecting the indoor air quality of not only one dwelling but two. These are the established and necessary performance criteria of a demising wall. Although only two of the criteria are regulated, all should be deemed relevant in assessment, selection, and design of our interior demising walls.

In Toronto, there are again only a handful of common demising wall typologies in standard practice. Double wythe brick is again most notable as the prevailing construction style of Toronto's housing stock. Concrete masonry is another common, viable choice of demising wall, as well as typical wood-frame construction, which can be assembled into a party wall with the addition of Type X gypsum board, sound insulation, and resilient channels. Wood framing requires much additional support to make it a viable party wall, all of this support comes in the form of highly manufactured products. The embodied energy and overall toxicity required to make a wood frame wall into a functional party wall ought to preclude its use in this application. Masonry is the most logical choice for demising walls because masonry is ideal for non-combustible construction with a high resistance to fire. Yet these walls too, have many of the same drawbacks in terms of complicated layering assemblies, off-gassing finishes, and required maintenance. A rammed earth demising wall, by comparison to these other common wall typologies outperforms on all of the established criteria. Because of its mass and density, it far exceeds the fire and sound resistance capacities offered by even the masonry demising walls. Because of its natural construction and lack of finishing, it precludes contamination of the indoor air. Because of its hygroscopic and moisture buffering qualities described previously, it will work to balance the interior environments of both dwellings to which it is attached. None of these performance qualities can be matched through the use of conventional wall assemblies. Additionally, although not yet scientifically corroborated, rammed earth is believed to have the effect of weakening or absorbing high frequency radiation.[8] A rammed earth home often suffers a lack of cellular reception and weak transmission of wireless frequencies. Although not demonstrably proven, it seems certain that the density of a rammed earth wall is a barrier to electromagnetic fields. This makes rammed earth an ideal service-wall, for use in distributing those services which create EMFs. Concerns over the potential harms of EMFs is relatively recent, the study of these harms is in its infancy. As our dwellings and cities become increasingly laden with wires, cables and transmitted frequencies, the role of architecture in shielding us from such effects will become a pivotal issue. Materials with that capacity should find a secure future in our building culture. Again, these performance factors provide additional comfort to the interior environment, and as such are major advantages for the application of rammed earth as an interior demising wall.

WALL SECTION [B-ii]:
INTERIOR WOOD FRAME DEMISING WALL

Recent construction relies so heavily on light wood framing, that assemblies have been designed to employ wood as a demising wall. This wall is most frequently used in new townhouse-style developments, commonly around 4 storeys high. To create a firewall with wood framing requires calculated use of additional materials, usually Type X Gypsum wall board. The framing cavity is filled with sound insulation and the gypsum is hung from resilient channels for increased sound control. The wall is both complex and simple, it uses simple construction techniques with highly manufactured components. Each part of this assembly must be specifically fire rated, a complex and calculated use of materials for building. This wall provides 2 hour FRR and an STC rating of 51.

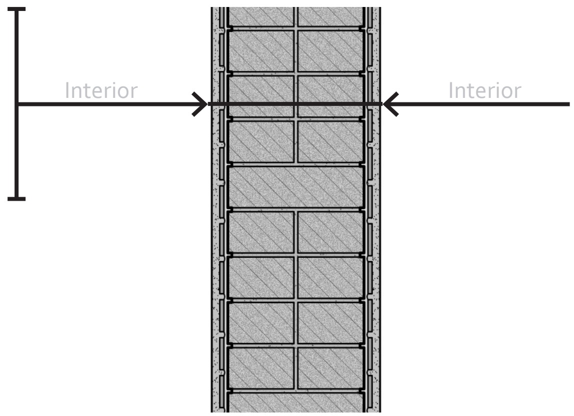
	Paint
2x 5/8″	***Type X Gypsum Board***
	Resilient Channels
2″x6″	***Framing wall w***
	Fiberglass Batt Sound Insulation
	Resilient Channels
2x 5/8″	***Type X Gypsum Board***
	Paint



WALL SECTION [B-iii]:
INTERIOR BRICK MASONRY DEMISING WALL

This is the typical demising wall of Toronto's semi-detached residential dwellings. The original condition of these Toronto homes is a double wythe masonry party wall, finished with plaster on lath at both interior surfaces. Brick masonry serves as an ideal fire and sound barrier, and unlike the wood frame wall, which provides its fire resistance at its finished surfaces, the finishes on a masonry fire wall are not necessary for the wall to perform as required, but are most often installed anyway. Even a single wythe of common Toronto clay brick is able to provide the 2 hour rating required, the common double wythe brick wall far exceeds that required fire protection. This wall provides a 4 hour FRR and an STC rating of 53.

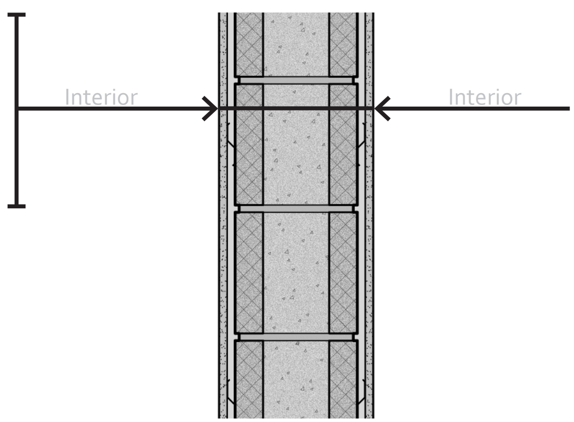
	Paint
	Plaster
1/4″	***Lath***
	2 Wythe Brick Masonry Wall
1/4″	***Lath***
	Plaster
	Paint



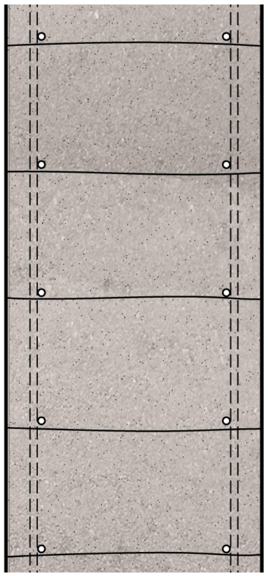
WALL SECTION [B-iv]:
INTERIOR CONCRETE MASONRY DEMISING WALL

Concrete block masonry also provides an ideal demising wall in terms of fire control, but is not itself ideal for sound control. A nominal 8″ hollow cell CMU, has a solid thickness of around 4″, providing a 2 hour fire rating, but only a 46 STC, insufficient to meet code requirements. The hollow cells of a CMU can be filled with mortar to increase both fire and sound resistance, but this is rarely done in practice due to the significant additional expense. For the required sound proofing, the interior finished wall is hung on resilient channels which generally increase the STC rating by 12. This wall provides a 2 hour FRR and an STC rating of 58.

	Paint
	Gypsum Board
	Resilient Channels
8″	***Concrete Masonry***
	Resilient Channels
	Gypsum Board
	Paint

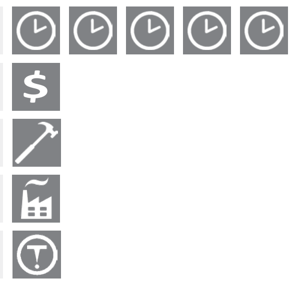


Scale 1″ = 1′-0″

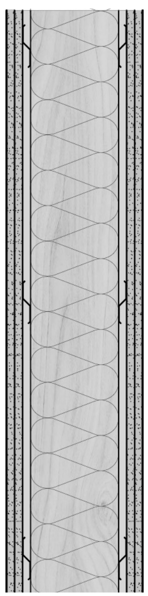


Bearing Structure	**STABILIZED EARTH**
Assembly Depth	**+/- 14" [35.5cm]**
Fire Resistance Rating	**> 4 HOUR**
Sound Transmission Class	**> 66**

Labour Time
Material Cost
Maintenance
Embodied Energy
Off-Gassing

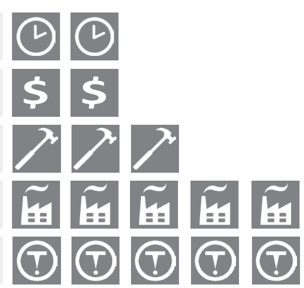


WALL SECTION [B-i]
The advantages of this wall are its extremely low material costs, low toxicity, low maintenance requirements, and low embodied energy. These advantages, combined with its superior performance on fire and sound resistance, demonstrate that this wall is ideally suited to the application of an interior demising wall. Its only drawbacks are again its generous assembly depth and high labour costs, yet disadvantages are far more comparable to the other typical walls in this application. This is a very pure use of rammed earth, where no additional materials are required, in the application of an interior demising wall, rammed earth is functioning at its highest.



Bearing Structure	**FRAMED LUMBER**
Assembly Depth	**+/- 8.5" [22cm]**
Fire Resistance Rating	**2 HOUR**
Sound Transmission Class	**< 51**

Labour Time
Material Cost
Maintenance
Embodied Energy
Off-Gassing

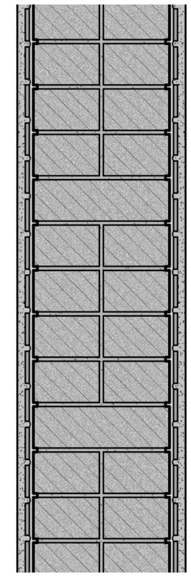


WALL SECTION [B-ii]
The advantages of this wall assembly are it's slender depth and low costs of materials and labour. The disadvantages are its insubstantial mass, which contributes to poor sound and fire resistance. Because of this disadvantage, fiberglass batt sound insulation is required, as are resilient channels and double layers of finished gypsum wall board. All of these additional, highly manufactured materials carry heavy embodied energy as well as high levels of toxicity. This wall assembly is not naturally suited to the application of a demising wall. Despite it's low cost, the environmental costs of this wall are high, and assessed together should exclude this wall from application as a demising wall.

WALL SECTION [B-iii]
This wall is fairly balanced in terms of all its criteria, advantageous or disadvantageous, the assembly seems well suited to the application of a demising wall. Like the rammed earth, it needs no finishes or additional materials to meet the demanded performance criteria of this application. The brick masonry wall itself is sufficient for fire and sound performance, and is accomplished with reasonable construction costs and maintenance. Unfortunately, in common practice this wall is always plastered or finished with gypsum board and paint, unnecessary elements which contribute to the overall maintenance and toxicity of this wall assembly.

BRICK MASONRY	*Bearing Structure*
+/- 10.5" [26.7cm]	*Assembly Depth*
4 HOUR	*Fire Resistance Rating*
53	*Sound Transmission Class*

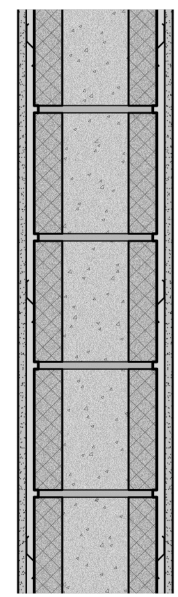
Labour Time
Material Cost
Maintenance
Embodied Energy
Off-Gassing



WALL SECTION [B-iv]
The advantages of this wall are its lower material and labour costs for masonry construction. Although CMU is not solid masonry like rammed earth or brick, it is masonry with sufficient mass and density to perform as a fire and sound barrier without the need for too many additional, manufactured materials. While a painted finish will still contribute to toxicity, and the steel resilient channels will contribute to the embodied energy, the wall assembly is not arduous, and well suited to the application of an interior demising wall.

CONCRETE MASONRY	*Bearing Structure*
+/- 9.5" [24cm]	*Assembly Depth*
2 HOUR	*Fire Resistance Rating*
58	*Sound Transmission Class*

Labour Time
Material Cost
Maintenance
Embodied Energy
Off-Gassing



APPLICATION C
SOUTH-FACING TROMBE WALL

Extensive Green Roof Assembly

Roof Overhang Designed for Summer Shading

Recessed Roll Screen, Reflective Solar Shading

High Wall Warm Air Output Louvres
Prefinished steel casing with operable venting panels set into Rammed Earth wall at 36" o.c.

Anodized Aluminum Casement Windows
Low-E , Krypton Filled, Tri-Glazing

14" Interior Rammed Earth Wall w
10M Steel Reinforcing
Linseed Oil Finish on both Interior Faces

Heavy Night Insulating Drapery (Interior, Out of View)

Sun space

Habitable Dwelling Space Beyond

Deciduous planting for Seasonal Shading

Low Wall Cool Air Intake Louvres
Prefinished steel casing with operable venting panels set into Rammed Earth wall at 36" o.c.
Finished flush with Baseboard

Usable Basement Area

CMU Foundation Wall w Interior Insulated Furr Wall

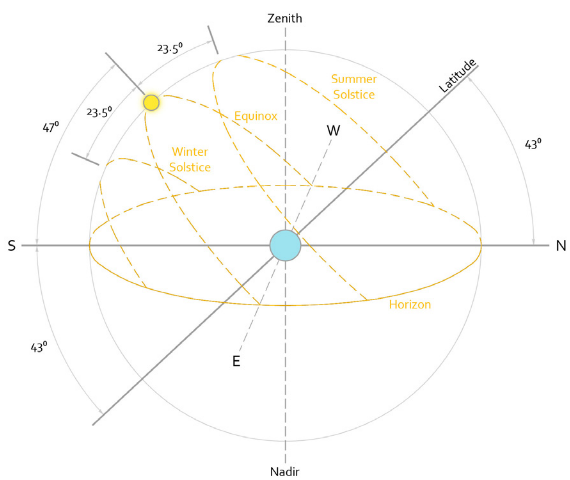
Reinforced Concrete Footing w Upstand for Rammed Earth Wall

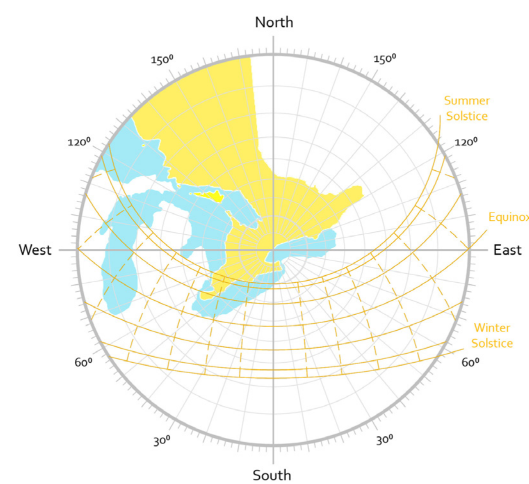
NTS

2.3 SOUTH-FACING TROMBE WALL

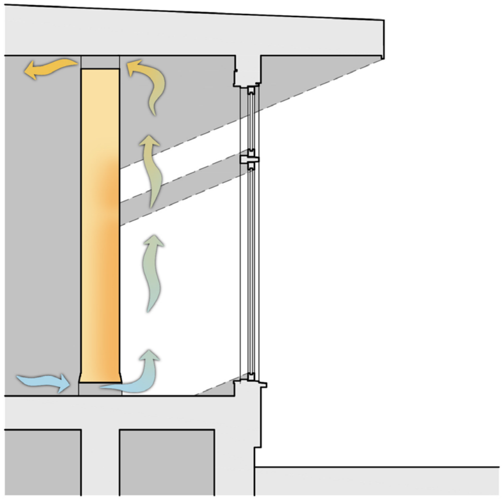
The application of rammed earth in a trombe wall is both intuitive and unconventional. Rammed earth is conventionally employed as thermal mass in exterior walls for passive solar heating and cooling. Thermal mass is a critical element of passive solar heating, and rammed earth is almost synonymous with thermal mass. Because of both its high density and high heat capacity, the large, dense material volume of a rammed earth wall is able to retain and transmit the heat energy it receives over a long period of time, *the thermal flywheel effect*. Rammed earth is traditionally applied in practice for this specific thermal storage advantage. These traditional applications are frequently in rural or suburban buildings, where they can be designed and constructed with advantageous orientation. Building orientation is critical for passive design strategies to ensure a building is designed and sited to receive as much free solar heat energy as possible, directly from the sun. In the urban setting, it is rarely possible to orient a building properly for full solar exposure. This is because of the density of the urban condition, where neighbouring buildings are often immediately adjacent and block much of the available solar energy. A trombe wall is a system which employs controlled direct gain in conjunction with thermal mass, to capitalize on the amount of solar energy that is available in a given location. Although rammed earth is not often applied in this way, it is a strategy suited to exploit the passive thermal potential of rammed earth within the urban environment.

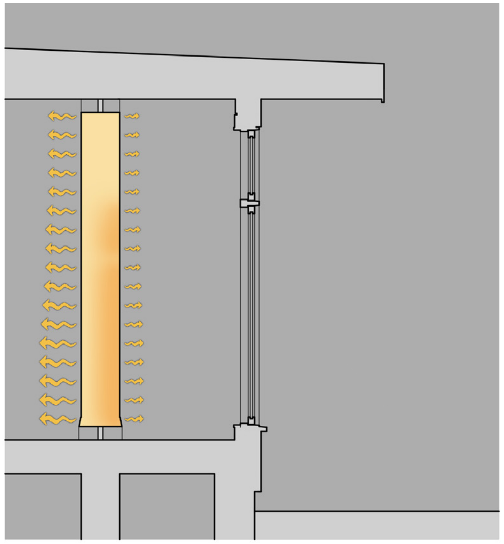
While direct gain is the quickest and simplest way to introduce external heat into a building, it is thermal storage which is able to hold that thermal energy for viable use in regulating the interior environment. In the trombe wall application, the solar gains of heat energy are transmitted through a large glazing wall where they accumulate in a sun Space. The sun Space is a controlled and contained area, annexed off the main living space of the dwelling. As heat energy accumulates in this zone, it is absorbed by the rammed earth wall behind it, and stored for use after dark, to be transmitted into the adjacent living spaces. The sun Space is designed for use as passive solar heating in the winter months. The low winter sun in transmitted through the glazing, which is selected to reflect as little sun as possible and transmit the greatest amount of energy possible. Once inside the sun Space, the heat energy will do one of two things: if it falls directly onto the earth wall, it will be directly absorbed; if it does not fall on the wall, it will heat the air within the space, such ambient heat will also be absorbed by the earth wall. When operating properly, this space will continue to build and store heat throughout the day, making it much warmer than the adjacent living spaces. Then, just as water always flows from higher to lower by the law of gravity, so too the heat will flow from higher to lower temperatures by the laws of thermodynamics. Once the sun has set, and the temperatures decrease, the heat energy stored from the operational trombe wall will be slowly released to heat the adjacent living spaces.

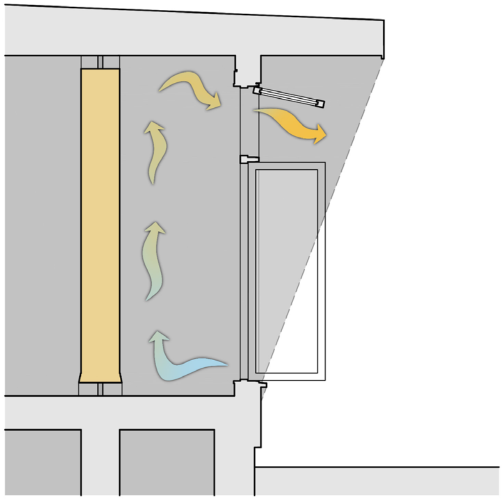


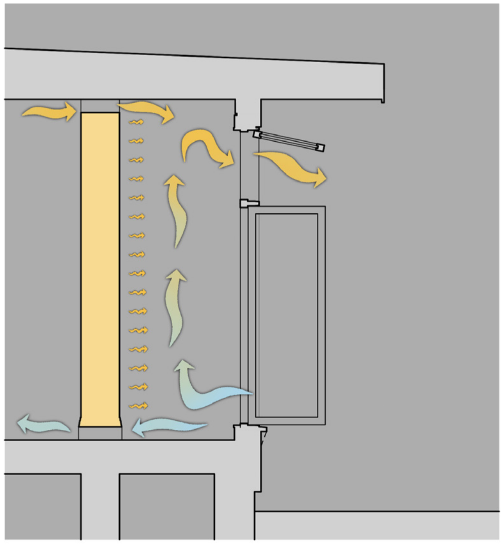


[Fig. 2.13] Solar Path for 43° North
[Fig. 2.14] Solar Chart for 43° North
It is vital for the design of passive architecture to understand solar geometry. These simple diagrams attempt to illustrate the interaction between the sun and the earth, and how that interaction is a dynamic relationship, one which changes seasonally. Solar geometry was used to calculate the roof overhang of the trombe wall for peak winter heating as well as peak summer shading. Solar geometry is also used to calculate shading of nearby structures.









Trombe Wall Functions

Winter-Day [Fig. 2.15 Far Left]
On a winter day the sun space will heat up from direct solar gain, storing that heat in the rammed earth wall. The sun space should be closed off the main house all day to allow the solar gains to build. The venting panels could be open or closed. If open, heated air will circulate into the adjacent living space. If closed, the heated air should continue to build within the trombe wall.

Winter-Night [Fig. 2.16 Left]
On a winter night the rammed earth wall will release its stored heat energy into the adjacent living space. Once the sun has set, the night insulation drapery (not shown) should be drawn closed to guard against heat loss though the glazing, and ensure the heat flows through the storage wall in the intended direction.

Summer-Day [Fig. 2.17 Far Left]
On a summer day the facade of the trombe wall is shaded and windows left open for ventilation so heat will not accumulate in the sun space. The roof overhang is designed to shade the glazing wall from the peak summer sun, but a reflective solar shade (not shown) can be pulled down to deflect additional solar energy. If the trombe wall is properly shaded and ventilated, it will not contribute to any additional heating.

Summer-Night [Fig. 2.18 Left]
On a summer night the rammed earth wall should draw heat out of the living spaces into the ventilated sun space. The venting panels can be used to draw additional heated air out of the adjacent living spaces. The earth wall will transmit any stored heat to whichever space is cooler. Provided the adjacent living space is not air conditioned, the ventilated sun space should be cooler and thus will draw the heat out of the living space.

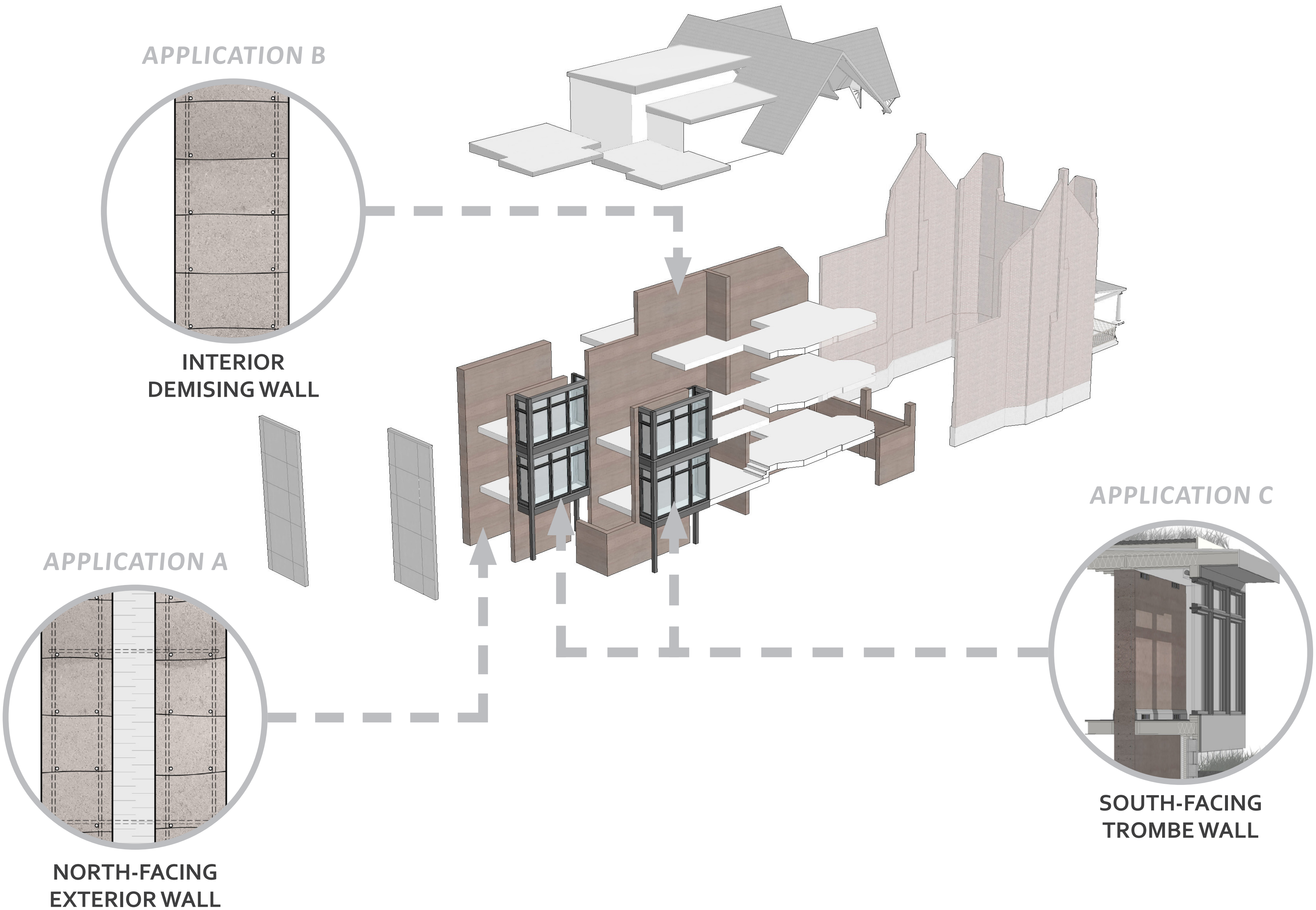
During the summer months, ideally this system will work in reverse, drawing heat out of the living spaces into the shaded and ventilated sun Space, providing a passive cooling effect. The glazing wall provides a critical component in controlling the phase shift of the building envelope. The intermediate space created by the glazing wall decreases the extremity of diurnal temperature swings, which are severe in the climate of Toronto. The sun Space significantly reduces the temperature amplitude ratio to which the building envelope is exposed, the envelope in this case being the interior layer of the trombe wall - the rammed earth. Essentially the space between the glazing and the rammed earth performs somewhat like insulation, as it contributes to the building's resistance of heat transfer, however insulation is generally limited in its performance; it can only resist the transfer of heat, it cannot aid it, or permit it when advantageous. The trombe wall is a highly active building component, comprised of various operable features which allow it to interact with both the interior and exterior environmental conditions. The trombe wall is not only active, but interactive, and depends upon user engagement to function optimally. On winter nights, heavy drapery must be drawn to act as a sort of night insulation, and each winter morning those same drapes must be opened so the space receives sun. In summer, windows must be opened and a reflective solar shade drawn. Although the roof overhang is designed to shade the glazing from most intense hours of summer sun, the shade will be relied upon to reflect the sun at different hours or seasons. Even these actions should be fine tuned for the specific conditions of each day. An overcast winter day might warrant the drapery drawn closed. In the spring and autumn months specifically, solar conditions should be evaluated for the trombe wall to be used appropriately. All these actions are required of the building users and demonstrate the common adage: *'passive buildings need active users.'*

This application of rammed earth suggests a design language where this material is intrinsically linked to glazing for use in the urban environment. These materials used in conjunction cement the feasibility of rammed earth to be applied in this setting. While rammed earth performs passive thermal functions naturally, without the use of a sun Space, in the urban condition the glazing wall is necessary to enhance its ability to be used productively. While the advantages of rammed earth as an exterior wall or a demising wall are certain, they are not necessarily sufficient to make rammed earth a compelling option for use in the urban environment. Neither the north-facing exterior wall or the interior demising wall use the rammed earth to its most primary advantage: passive thermal functions. The application of rammed earth in a south-facing trombe wall suggests how we can use the material to that advantage within the urban environment. Passive solar strategies which operate within the urban setting are difficult to implement in practice. In Toronto, there are no existing typologies of this nature by which to make a comparison. Yet passive design strategies are a very necessary tool for reducing the energy consumption of buildings. Climatically robust architecture demands passive architecture. While this strategy alone is insufficient for an urban dwelling to reach the passiv haus standard, it is a proposal for passive adaptation, a critical step on the path to ecologically benign architecture for our cities.

"It is necessary to cultivate a sense for beauty, for the artistic. 'Necessary' because our culture tends to suppress this sense, and 'cultivate' because everyone has it latent within them. It used to be so strong that pre-industrial common people could not make a spoon, a cart, a boat, even a house look ugly. To do so would have been like a crime against themselves." [1]

Christopher Day,
Places of the Soul.

SECTION THREE: DESIGN PROPOSAL.


APPLICATION B
INTERIOR
DEMISING WALL
APPLICATION A
NORTH-FACING
EXTERIOR WALL
APPLICATION C
SOUTH-FACING
TROMBE WALL

The design project which follows aims to illustrate how the three proposed applications of rammed earth might function in practice. The design closely resembles that which might be considered a typical residential project in urban Toronto. It proposes a renovation and addition to an existing semi-detached brick dwelling, a common undertaking with regards to residential architecture and construction within almost any of the city's downtown neighbourhoods. Although no two projects are ever identical, much of Toronto's housing stock and land division is. Toronto has very distinctive long and narrow houses, set on similarly long and narrow properties. Owners planning to grow their dwellings have little choice but to expand to the rear of their structure and/or upwards into dormers of the classic Toronto gable roof. Such a typical project, one so often repeated across the city, is ideal for demonstrating implementation of rammed earth applications. The north-facing exterior wall is a fitting application for the common rear extension. The south-facing trombe wall is fitting for the opposite face of that same rear addition, with implied cooperation of the adjacent dwelling. Implementation of the interior demising wall is somewhat unconventional for a renovation project and also relies heavily on that same implied cooperation, as it is a single architectural element jointly owned. Beyond the three applications developed in this thesis, there are some additional applications for which rammed earth is well suited. These include retaining walls for a basement walkout and cold storage room excavated below the typical Toronto porch, along with an interior feature and service wall, used for an interior staircase. Demonstrating these applications as viable solutions to such conventional design challenges establishes the compatibility of this material with the contemporary urban residential vernacular.

THE DWELLING TYPOLOGY

Toronto's houses are generally marked by conservatism: a reluctant to embrace the avant-garde. A Toronto house is not likely to be pretentious or extravagant. It is bound to be tried, tested and true in terms of its form, style, and construction. Toronto's abundance of existing housing stock is a product of the late Victorian era, yet tends to err on the reserved side of typical Victorian eclecticism. Even as the turn of the century brought a progressive attitude to the architectural development of Toronto's commercial buildings, its houses remained staunchly reserved and traditional. With an array of revival detailing, Gothic, Romanesque, Georgian, or Queen Anne, Toronto's houses belong to no architectural movement specifically but have a character all their own. The most notable design influence on Toronto's residential architecture is perhaps the Arts and Crafts movement, wherein honest bricks and honest forms dominate. Arts and crafts architecture was a response to the shoddiness of industrial enabled mass-production. The principles of arts and crafts architecture suggest that one material must never be used to imitate another, essential construction should not be disguised or hidden, and decorative elements must be a direct product of craft or construction (as opposed to decoration which reflects themes of religion or art). These principles were the same ones to be popularized by John Ruskin, and influenced the Arts and Crafts guilds of Britain in the 1880s. It was Eden Smith who brought these ideals to Toronto. His residential design work established the Toronto vernacular though which the bay-and-gable was cemented as the quintessential Toronto Dwelling.

The classic Toronto *"Bay-and-Gable"* semi-detached house is the focus dwelling typology of this design proposal. Toronto is home to thousands of these dwellings, all nearly identical but including several distinct permutations of the which exist across the city. These symmetrical houses tend to occupy entire spans of the North-South Avenues of Toronto's urban core. These long, narrow dwellings were well suited to the long, narrow lots divided for low and middle income family housing in late 19th Century Toronto. They were always constructed with a double wythe brick shell. Brick houses are the most distinguishing trait of Toronto's architectural legacy. This solid construction technique is a firmly entrenched tradition of residential architecture in Ontario. Today, these brick skeletons offer the contemporary home owner a remarkable point of departure for contemporary work. Provided the brick is well maintained, a Toronto house will rarely be torn down but renovated from the interior. A steep gable roof is the second most entrenched tradition of Ontario's architecture. The soaring peak of a gable roof has two practical conventions which led to its wide spread adoption: first, it makes attic space usable, half storeys and dormer rooms are a charming characteristic of Toronto homes; second, and most practical, the steep gable roof easily sheds snow, a necessary climatic design consideration. Although the roof has a shorter life span than the brick shell, its form is enduring and is rarely altered. Below the gable roof, a bay window provides the name-sake of this

Fig 3.2


Fig 3.3


Fig 3.4

Bay and Gable Toronto Houses.
[Left] ***Brunswick Avenue in the Annex.***
The Bay and Gable houses marching symmetrically along the streetscape.
[Above] 94-100 Oak Street. Aug. 22, 1949.
From the Toronto City Archives.
The same dwelling typology at the East end of the city, near Corktown.
[Top] Augusta Avenue in Kensington Market.
A row of Bay and Gables have been brightly painted and transformed into a retail strip much loved by the community.

dwelling typology. The bay window generally runs vertically from the foundations up the full front facade of the house. The bay is the dominant feature, often maintaining more than half of the width of the house, and is given a cross-gable intersection with the main roof. The bay offers significant advantages for day lighting, an amount of privacy for the entrance door, and cooperates well with the front porch which completes each bay-and-gable dwelling. These three architectural elements are practical conventions which form the bay-and-gable dwelling. The bay-and-gable is thoroughly reliable as a dwelling typology for the urban condition. The style is so pervasive in Toronto that it is perhaps the sole attribute of Toronto's residential architectural character.

SLATE ROOF RESTORATION

The muted colours and patterns of an original condition slate roof finish are a charming characteristic of a classic Toronto roof. Restoring the slate roof finish is preferred to the conventional installation of asphalt shingles, especially considering the heritage status of the house's street face.

HERITAGE STATUS

This row of bay and Gable dwellings along Brunswick Avenue is given Heritage status by the City of Toronto. The heritage status is applied to the front facade of the houses, meaning it cannot be substantially altered. Any additions or renovations must preserve the existing streetscape and not be visible from any vantage point on the street.

PORCH EXCAVATION AND MASONRY PIERS

The only alterations proposed to the protected front facade of the dwelling is for a new cold storage room, excavated below the rebuilt front porch. The existing brick masonry piers will be rebuilt with rammed earth. This proposal will require approval by Toronto's Heritage Preservation Services. While maintaining the original presence of the house, this minor alteration will allude to the drastic alterations at the rear which make this house unique among its neighbours. Employing rammed earth for use as retaining walls requires great detail regarding drainage and waterproofing. The walls will be ideal for a raw and rough subterranean space, well suited to an un-insulated cold storage room.

SITE PLAN

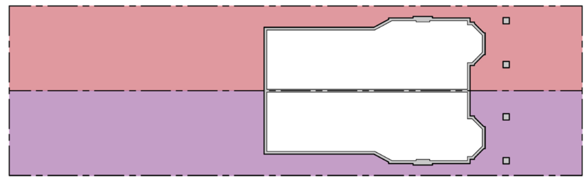
THE NEIGHBOURHOOD

The Annex is the neighbourhood chosen for this design proposal, a historical residential pocket ideally located adjacent to the downtown core boasting a sizable collection of bay-and-gable dwellings. Home to families, students, artists, and even the occasional celebrity, the Annex is a vibrant and varied community. Jane Jacobs lived at 69 Albany Avenue from the late 1960's until her passing in 2006. Her influence over the '*Stop Spadina'* movement is a notable moment in Toronto's history. The Stop Spadina movement established a collaborative effort which still palpitates through the Annex to this day. It is characterized as a grass-roots neighborhood, with a strong vein of environmentalism, a product of Jacobs' influence and the camaraderie of the residents maintained for decades. Like other notable neighbourhoods of the city such as Cabbage Town, The Danforth, or High-Park, where once was a setting for middle or low-income families, today is an affluent neighbourhood. But the affluence of the Annex, unlike these other areas, is not exclusive. There is a diversity present in the Annex which other similar Toronto neighbourhoods fail to offer. Partly this is because of the densification of the Annex in the 1960's by Uno Prii, which established the mid-rise vernacular of Walmer Road. The density provided by these mid-rises is a key component to the great charm and success of the neighbourhood. Additionally, proximity to the University of Toronto provides an influx of students to the neighbourhood, necessitating mixed-income and mixed-used offerings, the very ideals eschewed by Jane Jacobs herself.

TORONTO ZONING INFORMATION **[fig 3.7]**
Per Zoning By-Laws 438-86 & 569-2013

Zone:	**R2 Z1.0***	
Height:	12m	[39'-4"]
Max Building Depth:	17m	[55'-9"]
Side Yard Setback:	0.9m	[3'-0"]
Rear Yard Setback:	7.5m	[24'-7"]

* **R2** is the residential zone designation
Z1.0 is the maximum density allowed as-of-right for the designated property (eg GFA is limited to 1.0 x the lot area)



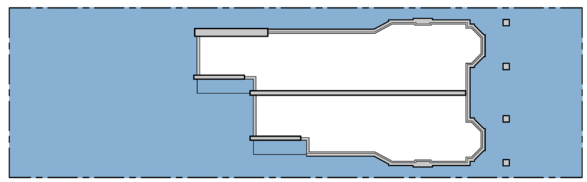
PROPERTY A

Lot Frontage:	21'-10"	Ground Floor Area:	967 sf
Lot Depth:	147'-6"	Second Floor Area:	967 sf
Lot Area :	3 220 sf	Third Floor Area:	542 sf
Density:	0.77	**Gross Floor Area:**	**2 476 sf**

PROPERTY B

Lot Frontage:	21'-10"	Ground Floor Area:	967 sf
Lot Depth:	147'-6"	Second Floor Area:	967 sf
Lot Area :	3 220 sf	Third Floor Area:	505 sf
Density:	0.76	**Gross Floor Area:**	**2 439 sf**

EXISTING PROPERTY A
EXISTING PROPERTY B
PROPOSED PROPERTY A+B



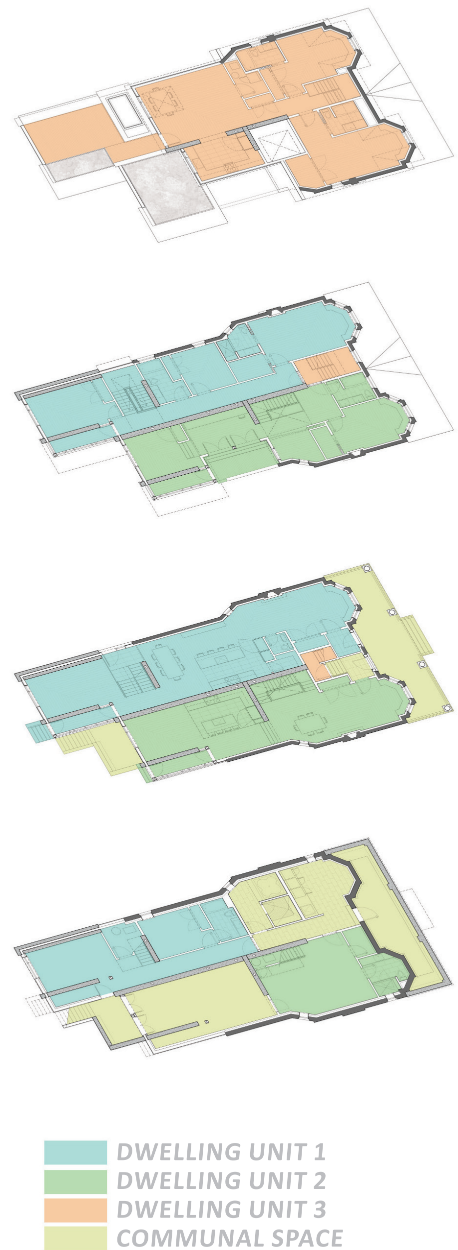
PROPERTY A+B

Lot Frontage:	43'-8"	Ground Floor Area:	2 116 sf
Lot Depth:	147'-6"	Second Floor Area:	2 116 sf
Lot Area :	6 440 sf	Third Floor Area:	1 350 sf
Density:	0.86	**Gross Floor Area:**	**5 582 sf**

THE DESIGN GOALS

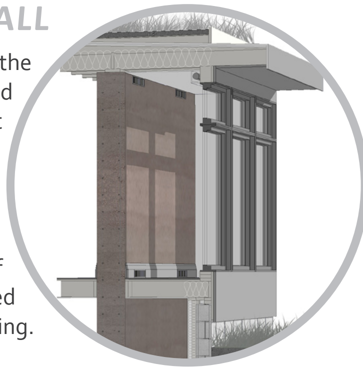
Although this design could be instigated with almost any bay-and-gable in the city, a pair of dwellings on Brunswick Avenue in the Annex has been selected to anchor the proposal. The atmosphere of the Annex is ideal for such a proposal, and Brunswick Avenue, with its mature trees, idyllic parkettes, and historic landmarks, is specifically appealing. The heritage status of the facades on Brunswick Avenue add an extra challenge and a mandate to preserve the bay-and-gable which is aligned with the design goals of the proposal. The proposal hinges on collaboration, an attitude well suited to the Annex. The design incorporates both halves of the semi-detached dwelling into a single project. This amalgamation is an atypical condition for renovations, but the cooperation is a key component to the success of this design proposal. The collaboration of two legally distinct properties provides each with increased solar advantages. The bay-and-gable dwellings of Toronto are utterly symmetrical, a symmetry oriented to the streetscape. The emphasis of the design creates a new axis of symmetry which responds to solar possibilities. In the urban condition, cooperation of distinct properties provides the only opportunity for passive design, as proper orientation and full solar exposure is impossible within the typical, narrow, East-West orientation of properties. Brunswick Avenue, like so many of its neighbouring Avenues, is a long North-South axis to which the building is oriented. The solar axis is oriented East-West, and so the design attempts to reorient the building in a way that is more advantageous for both of the dwellings.

To achieve this collaboration, the distinct properties within the site are have been amalgamated. The resulting dwelling structure is far too large to house a single family. The proposal suggests the resulting structure might be best used as a multi-generational residence, to enhance the interconnectedness of the single dwelling. According to Statistics Canada, in Ontario the number of grandparents who live with their grandchildren has increased 45% in the decade between 2001 and 2011.[2] This demonstrates an overwhelming trend which affects the nature of dwelling units. It is possible for multiple families to share dwellings in a way that promotes both privacy and connection. An additional aspect of the multi-generational dwelling allows for adult children to remain in their parents' homes in a way which also promotes a similar privacy while maintaining connection. This design attempts to demonstrate a flexibility of dwelling which can accommodate the changes of a family household over time. *"Aging In Place"* is a long held planning, social, and economical ideal.[3] Particularly today, as the baby boomer generation passes the phase of retirement, while simultaneously the Millennials[4] seem reluctant to leave their parents' homes, the multi-generational dwelling is coming of age. These statistics were used to inform the architectural program of this residential design proposal. Yet this multi-generational residence is designed to remain flexible, with the ability to be used as combined or distinct and private dwelling units.



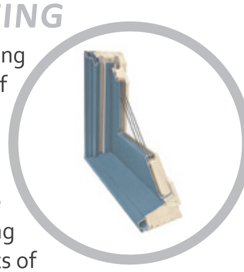
DWELLING UNIT BREAKDOWN **[fig 3.8]**
The multi-generational residence contains 3 distinct dwelling units. Dwelling unit 1 is the predominate residence, likely the owner-occupied unit. Containing 3 bedrooms, 3.5 baths and a possible basement in-law suite. Dwelling unit 2 is a substantial family residence containing 2.5 bedrooms and 2 baths, it is ideal for a young family with room to grow. Dwelling unit 3 is a possible rental suite, but remains connected on the second floor to both other dwellings. It is an ideal private residence for adult children of the families residing in of either dwelling 1 or 2.

SOUTH-FACING TROMBE WALL

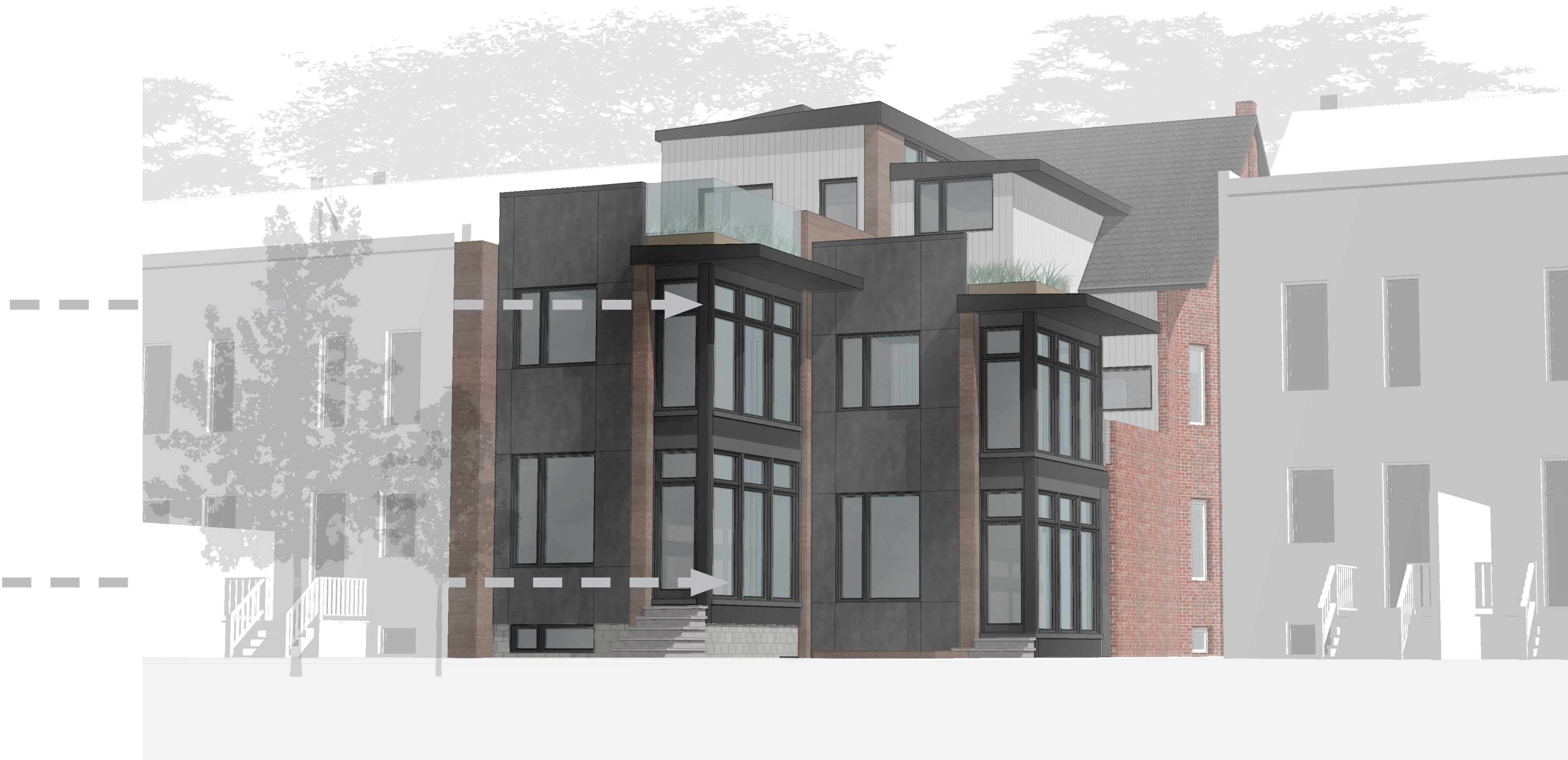


The pair of trombe walls proposed perform passive solar functions for each of the main dwellings. The 2 storey sun spaces are accessible at both the ground and second floors. On the ground floor of both dwellings, the sun space is adjacent to the main living space. On the second floor of both dwellings, the sun space is adjacent to a bedroom. This adjacency is deliberate. In the event of a prolonged black out, wherein active systems are unable to thermally regulate the interior environment, each dwelling maintains a living and sleeping space which is thermally regulated by passive means. The trombe walls drive the massing of the house and the orientation of the rear extension. Neither one could operated without the cooperation of the adjacent dwelling.

HIGH PERFORMANCE GLAZING

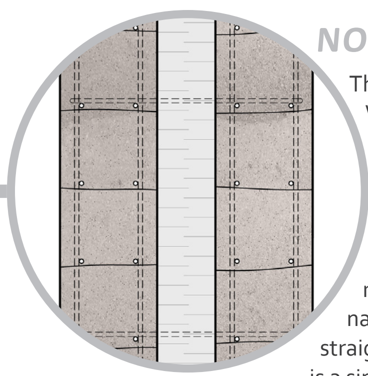


All glazing in the existing house will be replaced with high performance units. The glazing will be a significant investment which will contribute to the overall energy efficiency of the house. The typical glazing will be argon-filled double glazing with a tinted low-E 272 coating to reduce solar heat gain where it is not desirable. In the trombe wall configuration, the glazing must be selected for ultra high performance. In this location, krypton-filled tripane glazing, is used with a non-tinted low-E 179 coating to promote winter heat gain, as this glazing is properly shaded in the summer. All west facing glazing will be Low-E 366 as shading is not possible and this facade will receive high amounts of solar exposure in the summer times when heat gain is undesirable.



EXTENSIVE GREEN ROOF

The new roof areas over the rear extensions are proposed to be planted roofs where they are not a roof deck. The location of these roofs, in interaction with the third floor dormers makes steep gable roofs untenable. Low slope or flat roofs are often considered problematic in a wet, snowy climate and prone to water leakage. When well detailed they can preform nearly as well as a pitched and shingled roof. The other problematic aspect of a flat roof is the common bitumen membrane roofing used to finish it. This common dark finish for roof surfaces contributes to the urban heat island effect as well as heat loads for the interior spaces. A green roofing system (such as those produced by Soprema), will reduce heat absorption. Low maintenance native grasses and perennials are proposed.

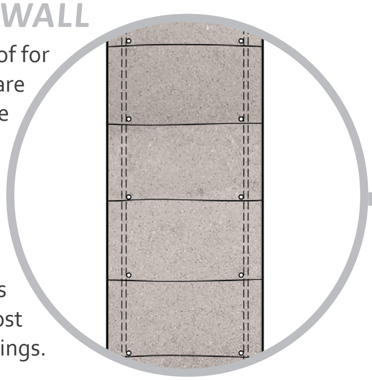


NORTH-FACING EXTERIOR WALL

The north-facing exterior wall is an ideal application for a rear extension. While this wall might also be used for east, west, or south-facing applications as well, within this proposal the application is restricted to the north facade. There is no solar thermal potential on a north-facing wall, yet the rammed earth still has an effect on regulating the interior environment. This wall will resist the transfer of heat, slowing heat loss from the shaded north side of the building. It's hygroscopic properties will regulate the humidity of the interior environment. Its low-maintenance natural finish contributes to healthy indoor air quality. This is the most straightforward application of rammed earth, and with no doors or windows, it is a simple and direct use of the material being easy to construct and maintain.

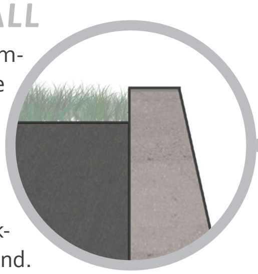
INTERIOR DEMISING WALL

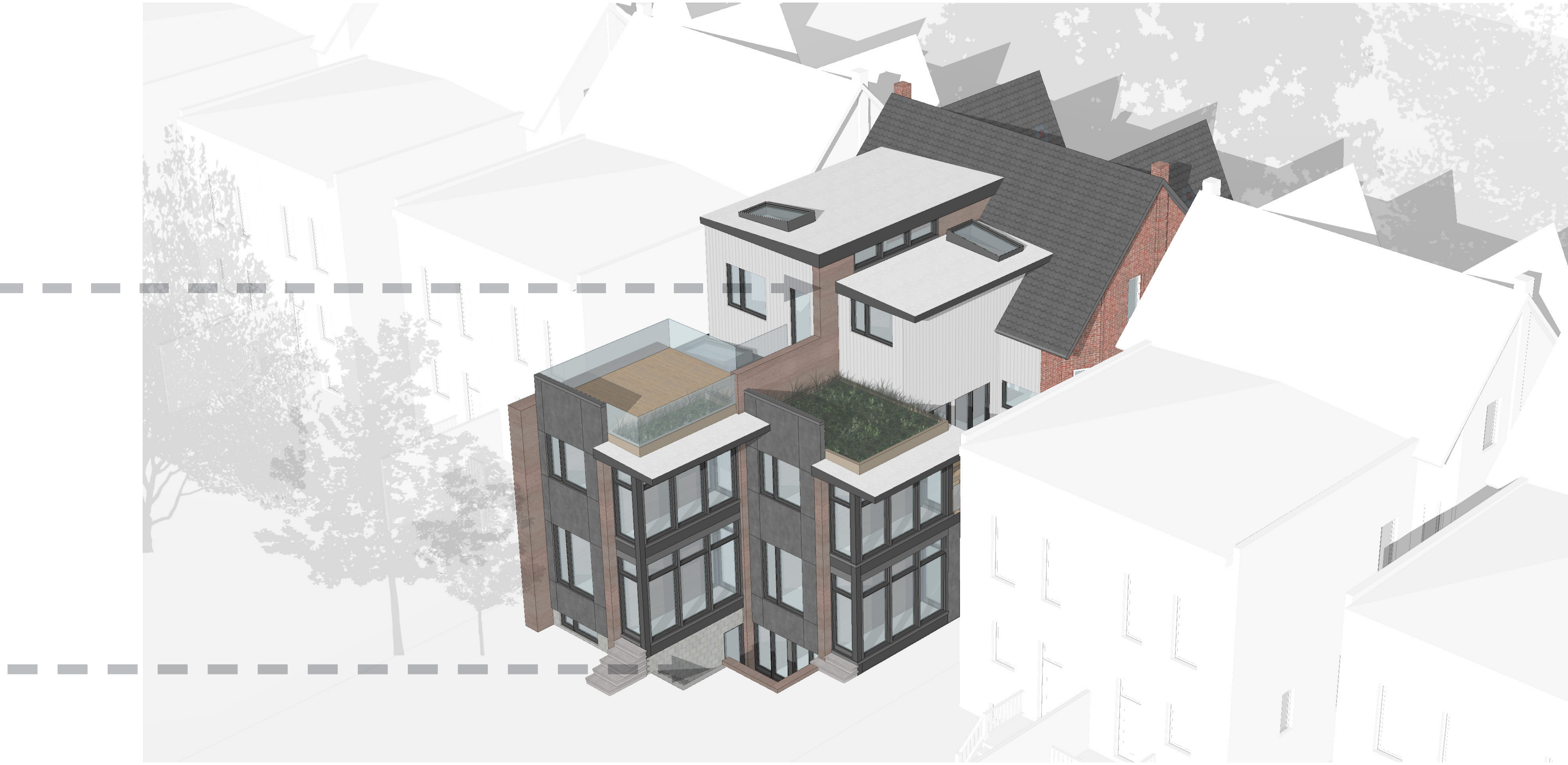
The interior demising wall runs continuous from the basement to roof for almost the entire length of the house. As the properties in this proposal are amalgamated, the demising wall is not required by code to act as a true party wall. While it still functions as a division between dwellings, it does not function as a division between properties and thus is not held to the same criteria. Replacing a party wall in a renovation project is a labour and resource intensive process as the wall is load bearing and supports all floor plates as well as the roof structure. Demolishing the existing wall is an invasive task best suitable only for the most extensive renovations projects. This particular application of rammed earth is perhaps most suitable for new construction of attached dwellings.



RETAINING WALL

Rammed earth is proposed for use as a retaining wall at the rear basement walkout of the communal recreation space. The retaining walls are shown as simple gravity walls, but might be anchored or placed on a cantilever footing. The structural detailing for rammed earth used as a retaining wall is relatively straightforward. The waterproofing of rammed earth for use as a retaining walls is far more complex. The back side of the wall, constantly exposed to moisture, should be given a bit-tar dampproof coating as well as a dimpleboard drainage membrane. Various weeping tiles should be used to ensure good drainage all around the wall, and the backfill against the face of the wall should be well draining gravels or sand.





BASEMENT PLAN

1. **Recreation Room (Communal)**
2. **Recreation Room (Private)**
3. **Boiler room/Utilities**
4. **Steam Room (Communal)**
5. **Laundry Facilities (Communal)**
6. **Cold Storage (Communal)**
7. **Storage (Private)**
8. **Bathroom**
9. **Bicycle Storage**
10. **Basement Walkout (Communal)**

The design proposal includes significant underpinning of the existing foundations for increased headroom at this level. The existing unfinished basement is only 6'-0" clear, the new finished basement varies in height but headroom is > 7'-6" clear. The basement plan is divided into private and communal spaces. The communal spaces of the basement are shared between dwellings 1 & 2 only. On the north side of the house the private space of dwelling 1 is left flexible. The private Recreation Room [2] could be configured into a kitchenette and this entire area of dwelling 1 might easily serve as an in-law suite. The private space on the south side is part of dwelling 2. This space is composed of typical basement program and provides the second bath for this dwelling unit. The open space of the communal Recreation Room [1] might be used as a workshop, a game room, a theatre space; whatever the occupants of dwellings 1 & 2 might agree upon. The shared Spa [4], Laundry [5], and Cold Storage [6] facilities are generous program spaces, allowable due to the shared floor area. Every entrance to communal spaces can be locked for the privacy of each dwelling. Each of the Utility Rooms [3] house a high-efficiency, on-demand gas boiler and hot water tank, feeding the HVAC of each dwelling separately. The floors are unfinished except where tile is indicated. The new hydronic concrete slab is polished and left exposed.

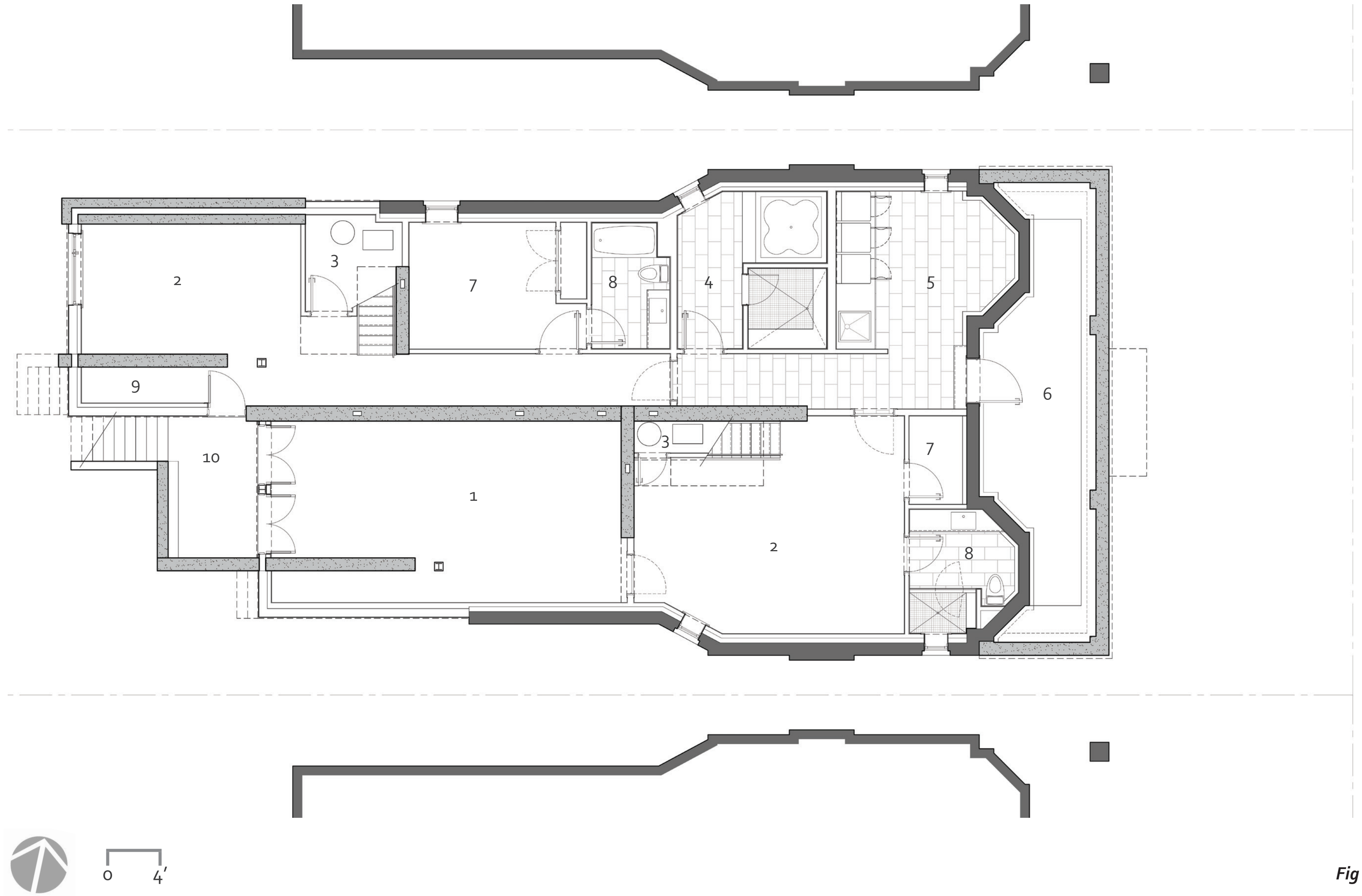


Fig 3.12

GROUND FLOOR PLAN

1. **Sun Space**
2. **Living Space**
3. **Dining Space**
4. **Kitchen**
5. **Hearth**
6. **Vestibule (Communal)**
7. **Pantry**
8. **Powder Room**
9. **Open Covered Porch (Communal)**
10. **Landscaped Open Space (Communal)**

The ground floor plan of each dwelling 1 & 2 is comprised mainly of open living, dining, and kitchen space. Each private stairwell is configured as a feature, and not a utility space. The stairwell leading up from the communal Vestibule [6] is the locking private entrance to the third floor dwelling 3. The built-in millwork will be crafted from sustainably harvested, solid-wood, to exclude any toxic glues, laminates, or particle boards. Likewise, the floor finish is sustainably harvested quarter sawn oak throughout, finished with zero VOC stain and varnish. Each of dwellings 1 & 2 are provided with a pair of Living Spaces [2]. These spaces book-end the house with thermal mediating devices. The front of the house is given a Hearth [5], these are left as solid fuel burning fire-places which can be used to actively heat the house. The rear of the house is given the Sunspaces [1] which can be used to passively heat the house. In-floor hydronic heating, fed by the on-demand boiler can also be relied upon to heat the open space in the coldest months of the Toronto winter. Each sun space provides the dwelling's direct access to the rear landscaped yard [10] which is shared by dwellings 1 & 2. The yard might hold a barbecue area, greenhouse, cultivated edible garden beds, a storage shed, and access to a rear garage.

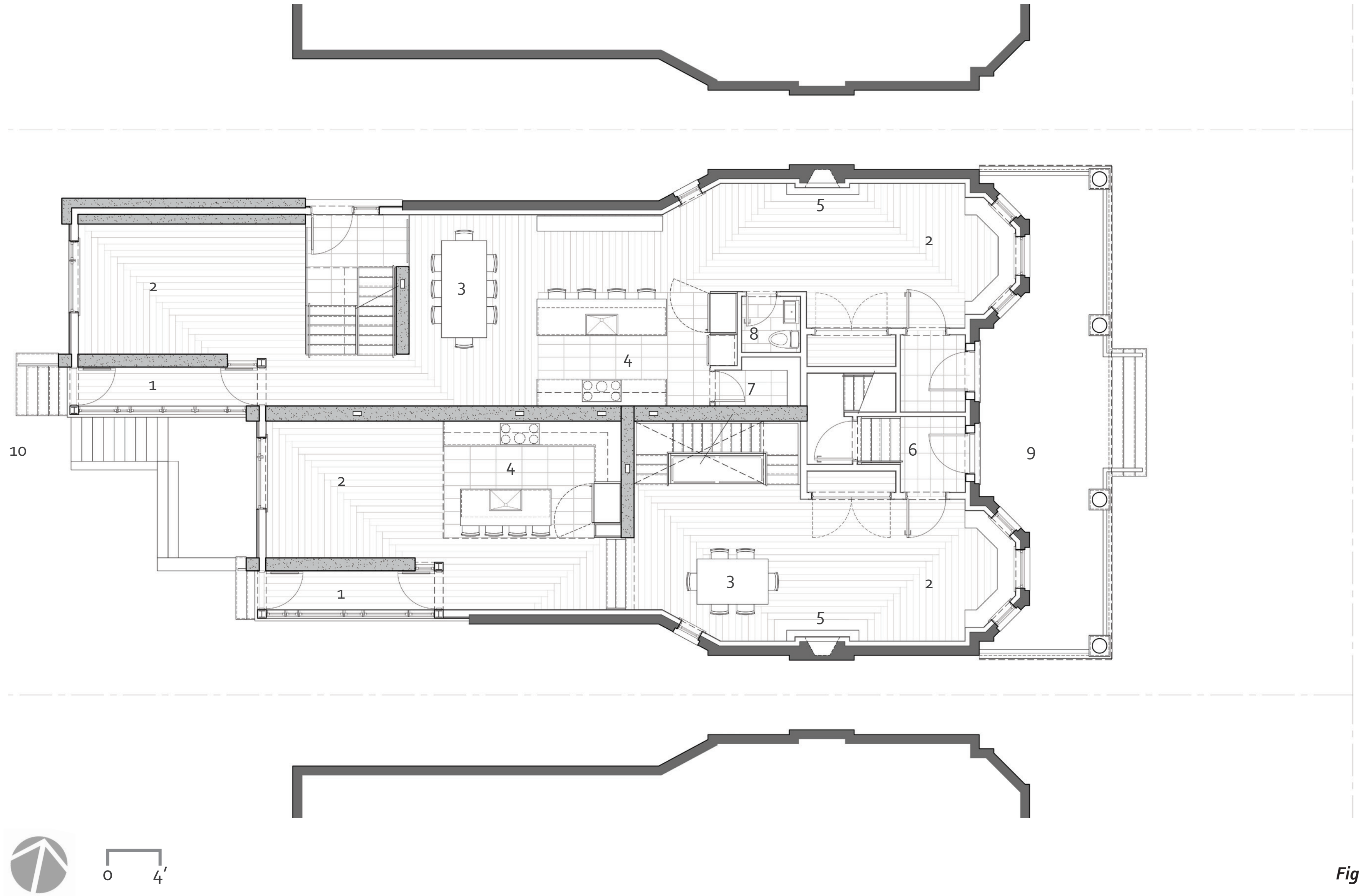


Fig 3.13

SECOND FLOOR PLAN

1. **Sun Space**
2. **Bedroom**
3. **Bathroom**
4. **Study**
5. **Nursery**
6. **Private Deck**
7. **Ensuite**
8. **Walk In Closet**
9. **Hearth**

The second floor plan of each dwelling 1 & 2 is comprised mainly of Bedroom Spaces [2], closets and Bathrooms [3]. The stairwell leading up from the vestibule at the ground floor below continues up to the third floor dwelling 3. Like the ground floor below, all built-in millwork will be crafted from sustainably harvested, solid-wood, to exclude any toxic glues, laminates, or particle boards. Likewise, the floor finish is sustainably harvested quarter sawn oak throughout, finished with zero VOC stain and varnish, except where tile is shown. Again, each of dwellings 1 & 2 are provided with a solid fuel burning Hearth [9] and a Sun space [1] which book-end the house with thermal control devices. In-floor hydronic heating, fed by the on-demand boiler can also be relied upon to heat the spaces during the coldest months of the Toronto winter. Dwelling 1, on the north side is larger, equipped with an additional bed-room and a full Master suite. Dwelling 2, on the should side, imagined for a young family, is less one bedroom, but left more flexible in terms of its second floor plan. The Nursery [5], Study [4], and Private Deck [6] are valuable spaces for adaptation as a young family grows. Each sun space is accessible though not vitally connected space. Ideally, on this floor, the sun space could be used as a pseudo-greenhouse space for year-round container gardening.

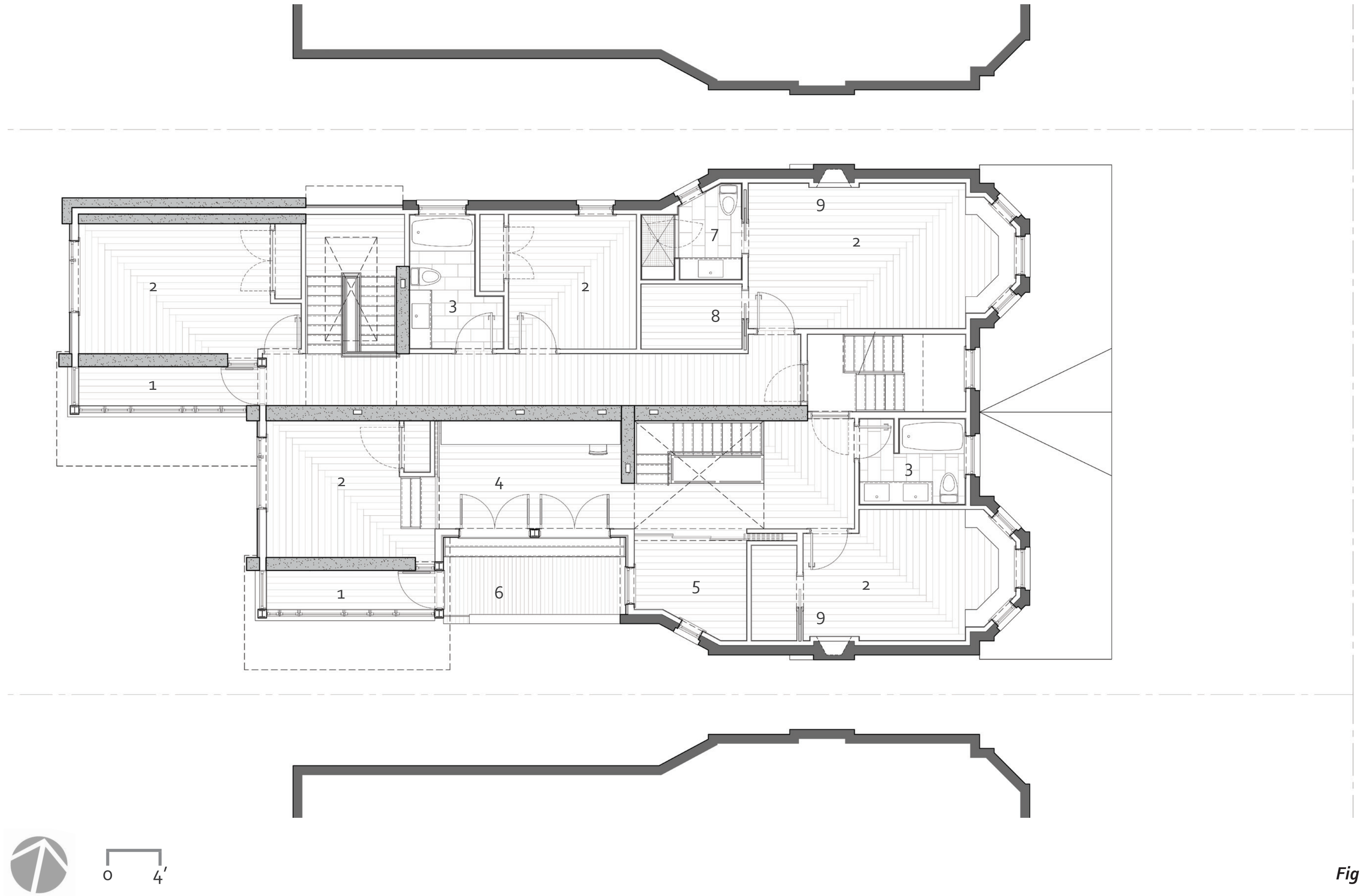


Fig 3.14

THIRD FLOOR PLAN

1. **Private Deck**
2. **Green Roof**
3. **Living Space**
4. **Kitchen**
5. **Bedroom**
6. **Ensuite**
7. **Light Well**
8. **Utility Closet**
9. **Skylight**

The entire third floor is given to Dwelling 3. This 2 bedroom dwelling unit is generous in comparison to much of Toronto's rental market. Each Bedroom [5] contains its own Ensuite [3] making the dwelling suitable for mature couples or young professionals. Although the dwelling is envisioned as an extension of either dwelling 1 or 2 below, to accommodate the growth or development of either family, it is designed such that it can be marketed as a high-end rental suite. The Private Deck [1] provides the dwelling with outdoor space, a coveted commodity in Toronto real-estate. Like the ground and second floors below, all millwork and finishes should be sustainably, and ideally locally, harvested, containing no toxins, or other chemicals. The Utility Closet [8] provides the dwelling with its own on-demand gas boiler and hot water heater, as well as a stacking washer dryer as this unit does not share the communal facilities in the basement. In-floor hydronic heating, fed by the boiler will also be relied upon to heat the dwelling as there is no demonstrable passive thermal control at this dwelling unit. However, the well insulated attic spaces and new dormer roofs can be relied upon to capture much of the ambient heat from the dwellings below, and this top floor should require minimal heating loads.

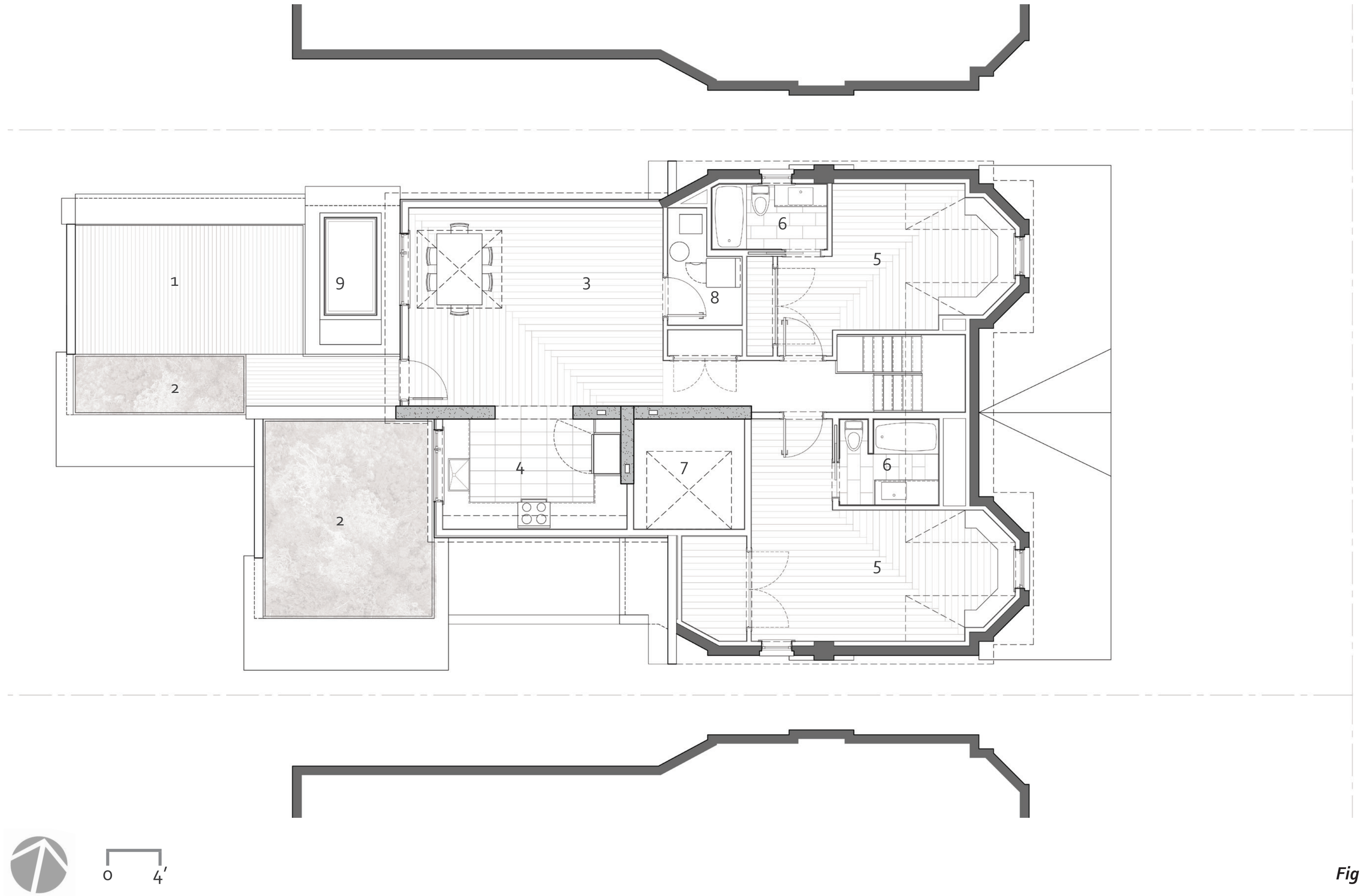


Fig 3.15

ROOF PLAN

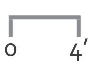
1. **Skylight**
2. **New Dormer Roof**
3. **Existing Gable Roof**
4. **Existing Cross-Gable Roof**
5. **Existing Brick Chimney**

Each of the 3 Skylights [1] provides diffuse daylighting to each of the 3 dwellings. The Skylight of dwelling 1 provides daylighting to the feature stairwell. The Skylight of dwelling 2 is set over a deep lightwell which penetrates all the way through the third floor to reach the dwelling at the second floor. This light well is ideally situated to bring a small amount of heat energy onto the interior rammed earth demising wall, whose heat transfer can be shared by all three dwellings. The New Dormer Roofs [2] are low-slope roofs and should be high albedo surfaces, finished with a reflective material. The existing gable [3]and cross gable roofs [4] will be refinished with the classic Toronto slate tile.

Fig 3.16

EAST ELEVATION

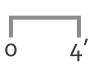
Fig 3.17



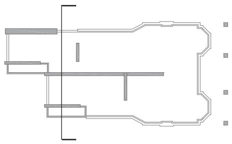
SOUTH ELEVATION
Fig 3.18

WEST ELEVATION

Fig 3.19



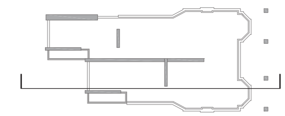
NORTH ELEVATION
Fig 3.20

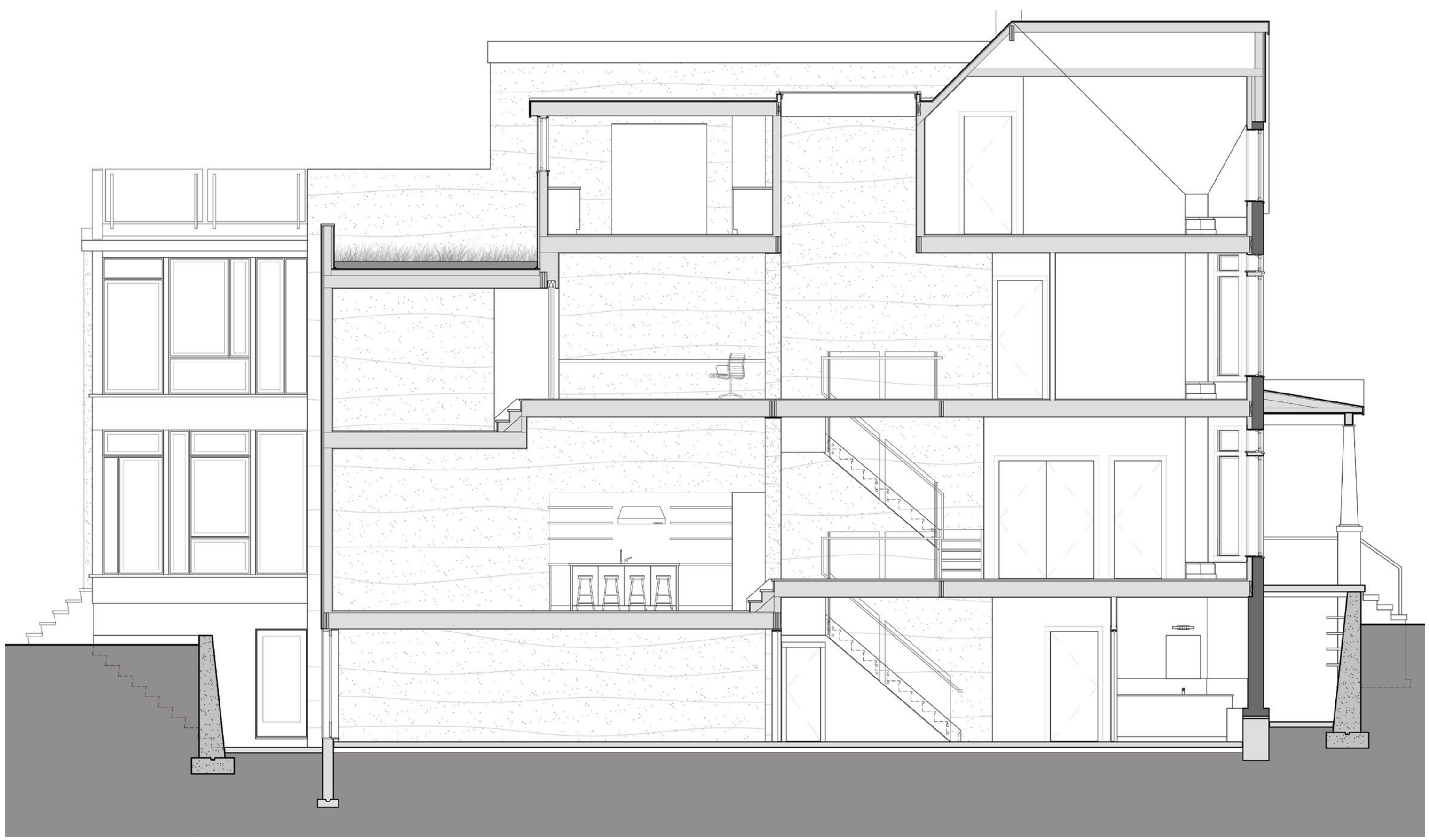


SECTION A

Fig 3.21

0 4′



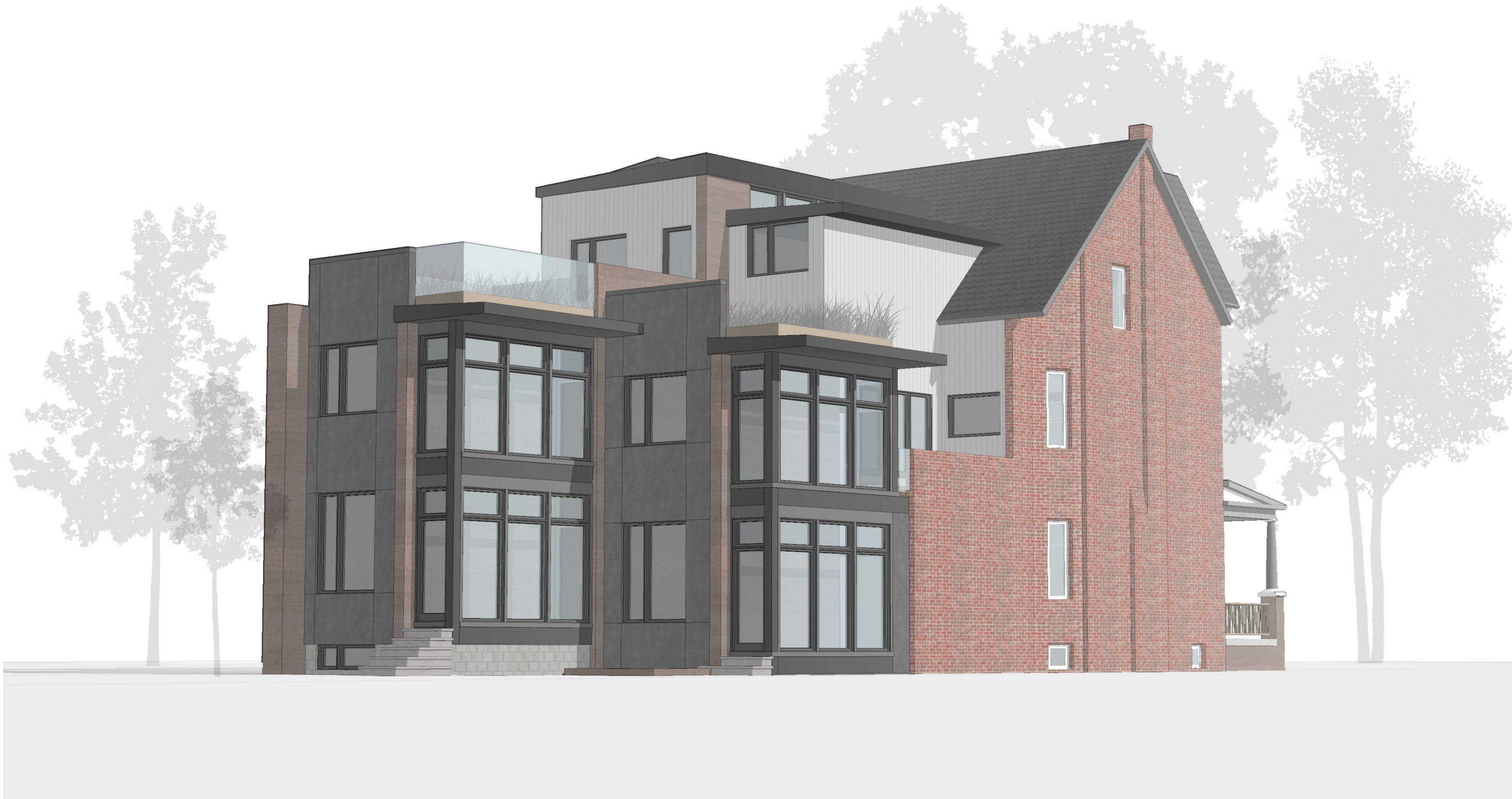


SECTION B
Fig 3.22

The design project proposed herein is no small undertaking. From the lowest foundation to the highest peak of the gable roof, the existing structure would undergo a dramatic transformation. The scope of work for this project pushes the boundaries of what might legitimately be considered a renovation. The very extensive scope can be attributed to three critical elements of the design which are unique to this project: the amalgamation of two distinct properties, the elaborate undertaking of replacing an existing load bearing party wall, and the considerable amount of foundation work involved in underpinning the entire structure. Although these structures are semi-detached, they have undergone nearly a century of service life as separate buildings. To bring them together as one cohesive structure is an excellent way to ensure the structure can maintain a service life of another century, yet each half is likely to be in a very distinct state of repair or disrepair after a life so long divided. Replacing an existing party wall such as this requires the removal of nearly the entire interior of the structure on both sides, all the way up to the gable roof. While it is theoretically possible that the existing floor plates and roof could be held in place temporarily with posts and bracing while the new wall is installed, this proposal demands gutting the entire structure. While the existing front half of the gable roof will remain, with only the ridge beam temporarily secured until the bearing can be replaced, the rest of the structure will be disassembled floor plate by floor plate, joist by joist. This is not necessarily a good use of labour or resources, even if the floor plates are to be reassembled from existing true 2”x12” joists. The existing double wythe masonry party wall is likely to be in decent condition. While the new rammed earth wall will provide increased fire and sound control along with aesthetic appeal, the decision to replace such an existing wall should be weighed carefully.

The basement underpinning and foundation work is another monumental task. Underpinning from the existing slab level to the new proposed level will remove roughly 8,500 cubic feet [240m^3] of raw subsoil. Excavation for the cold storage room below the existing front porch will remove an additional 2,400 cubic feet. [70m^3] of densely packed subsoil. And excavation for the rear addition and basement walkout will remove another 3,000 cubic feet. [85m^3]. Indeed, such work pushes far beyond the scope of a typical Toronto home renovation. Yet this total 14 thousand cubic feet [400m^3], while seemingly substantial for a residential renovation project, is utterly insignificant compared to the amount of earth excavated and removed almost daily by any number of active large scale construction projects in the city. Infrastructure projects like the new Metrolinx underpass at Strachan Avenue, or new commercial and high-density residential projects which break new ground almost ceaselessly, will move earth in that quantity on a daily basis. This earth is trucked away, perhaps for fill at other construction sites, perhaps temporarily set on a vacant lot, and sometimes sent directly to a landfill as waste material. While not all soil is suitable for building, *(as discussed in Section 1)*, and the possibility of contaminated soil on urban sites can be high, the fundamental aim of this project is to create the perception of earth as a material of intrinsic value to building. The total volume of all rammed earth walls in this design proposal is 5,500 cubic feet [155m^3] which requires about 8,250 cubic feet [235m^3] of loose material to construct. Allowing for even 40% of the excavated site material to be untenable for building (either organic topsoil or large stones and rocks) the remaining 60% of that earth sufficient to generate all of the earth walls in the proposal.

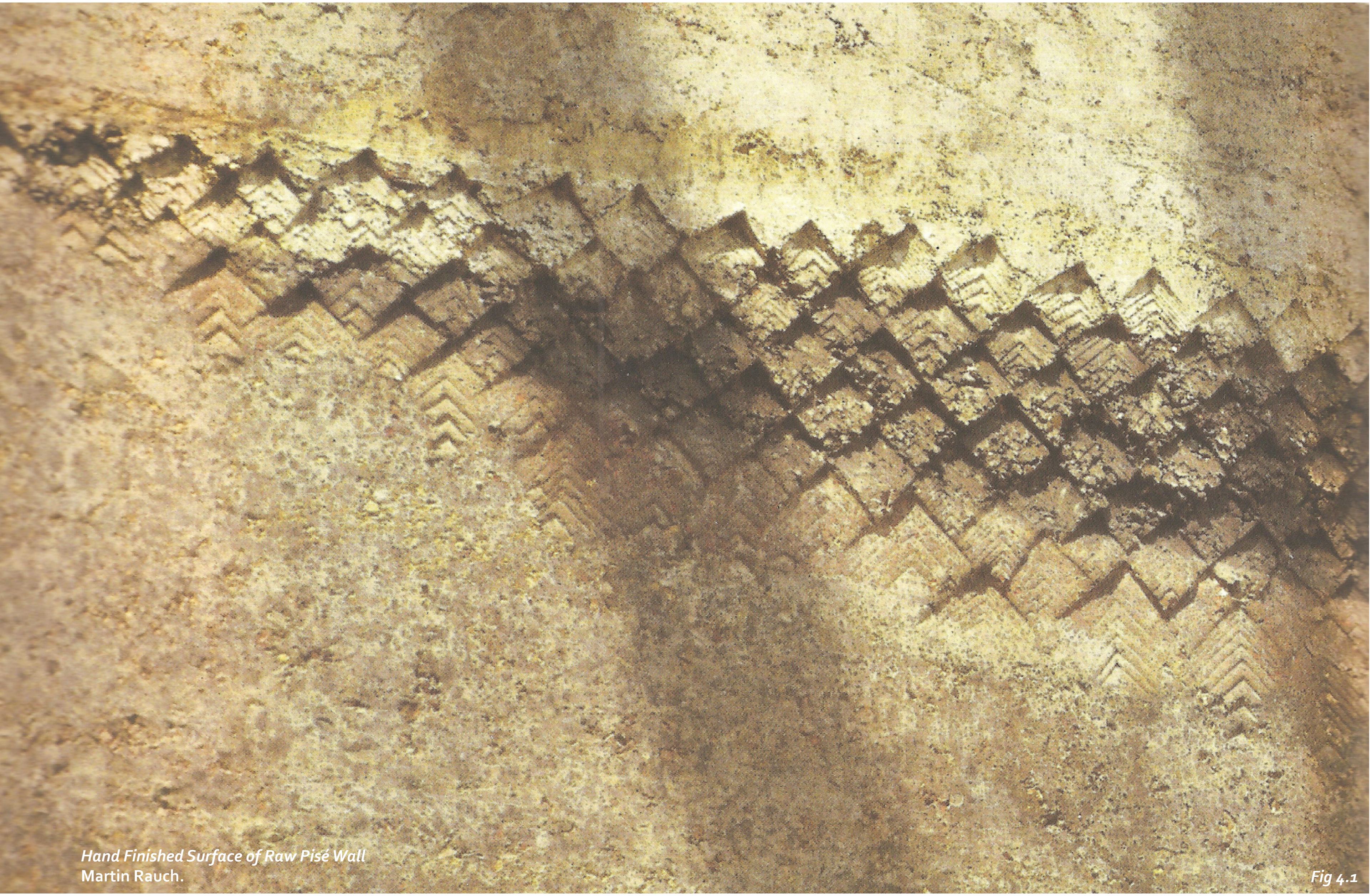
The architectural finish of a Toronto residential dwelling is already tied to the soil upon which it is built. These houses are identified by the bricks from which they are created. These bricks came from the rich glacial clay upon which the city was developed. The brightest red bricks came from the ancient bed of Lake Iroquois, in the far east of the city, where Leslieville sits today. Less saturated or lighter coloured Toronto bricks are likely to have originated from the Don Valley quarry and brickworks, some of the highest quality of bricks being produced in the world at the end of the 18th century. [5] It seems applicable to Toronto's architectural legacy to once again engender an identity between Toronto's rich and valuable soil and it's residential architectural identity. While the contemporary use of rammed earth seems reliant upon oxides and dyes to control the colour of rammed earth walls, this practice is unnecessary to the application of rammed earth. Using raw, site excavated material for the creation of new walls on that very site is an idealism in building construction. This practice has the ability to strengthen that architectural identity which Toronto has already established with brick. Rammed earth, augmenting brick, might affirm the connection between earth, materials, and buildings. To create an architecture out of the very earth upon which that architecture stands is sustainability incarnate. An idealism placed into practice.



“It’s natural to feel at home with ‘natural’ materials. Humanity has grown up with them; their source is life.[1] [. . .] *The issue of life-full or life-less is at the heart of architecture. Much construction is designed to protect buildings, not their inhabitants or living surroundings.”*[2]

Christopher Day,
Places of the Soul.

CONCLUSION:
WHY RAMMED EARTH?



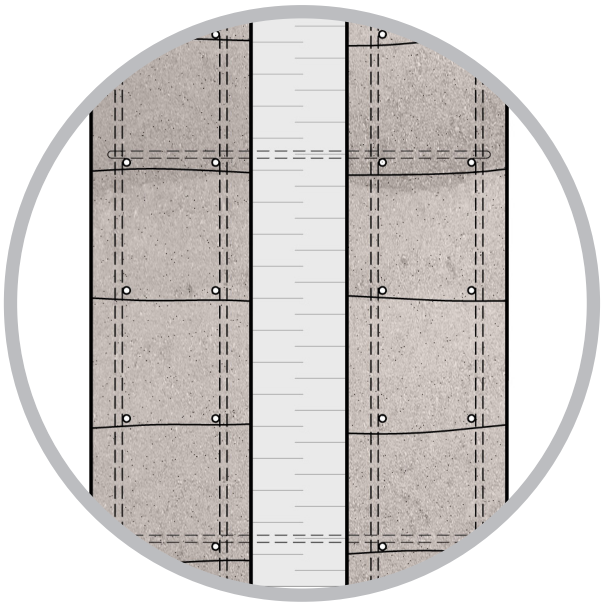
Hand Finished Surface of Raw Pisé Wall
Martin Rauch.

Fig 4.1

Why should we build with rammed earth? We should do so because rammed earth is a simple, elegant, and viable solution to many of our conventional design challenges. Rammed earth is able to gain free heat in the winter, and promote cool spaces in the summer. Rammed earth is an exceptional barrier, resistant to air, moisture, fire, sound, and pests. It is able to regulate humidity, dampen electromagnetic fields, and provide flawless indoor air quality. It is low maintenance and low embodied energy. It is an enduring material which will last for generations with a perpetually alluring finish for the full length of its useful service life. Beyond this, it is nearly a frictionless solution, one which can adapt itself to the prevailing norms and conventions of our building culture. With rammed earth, new norms might be created from existing norms, because it is a resolution found in practice, a solution developed by hand. Architect William McDonough states that *design is a signal of human intention*. Our intentions speak loudest through our most well established norms and conventions. When we evaluate the success of our walls only on their cost benefits, their compliance with regulatory codes, or the speed at which we might construct them, we betray the limit of our intentions. While such factors cannot be ignored within our context, they fail to offer a holistic framework for evaluating the performance of our walls.

Each of the proposed applications of rammed earth for the urban environment have their established advantages and appeal. The north-facing exterior wall has been shown to meet the basic performance criteria of an exterior wall. While it's width as an assembly and labour to construct are disadvantageous, it's zero maintenance requirement and impervious nature make it well suited for the functions of an exterior wall enclosure. But it is the additional performance capacities offered by a rammed earth wall, capacities which are not available though any of our conventional wall assemblies, which truly demonstrate the appeal of rammed earth as an exterior wall. Its hygroscopic properties which maintain an equilibrium interior humidity and temper odours, and its thermal inertia which shields the indoor environment from the drastic diurnal temperature fluctuations are the auxiliary wall functions which make this wall type so enticing. The application of rammed earth as an interior demising wall is perhaps the most appealing and successful application of rammed earth for the urban environment. There seem to be no disadvantages to this application. Successful resistance to fire and sound transmission are the established performance criteria of a demising wall, rammed earth outperforms conventional wall assemblies on both these counts. Again, rammed earth offers additional functions in this application which establish its unique appeal as such a wall type. Because of its natural construction and lack of finishing, it precludes contamination of the indoor environment, because of its mass and density, it absorbs and diminishes electromagnetic fields. These are the qualities which further establish the appeal of rammed earth for such an interior wall application. Finally, the trombe wall offers a method by which to use rammed earth for its quintessential strengths in an environment where it otherwise may not be possible to do so. The trombe wall is the application by which this historic vernacular building method is married to and enhanced by the conventions and potential of modern building technologies. This is the application which engages that conversation between past success and future possibility, between vernacular methods and architectural design.

APPLICATION A



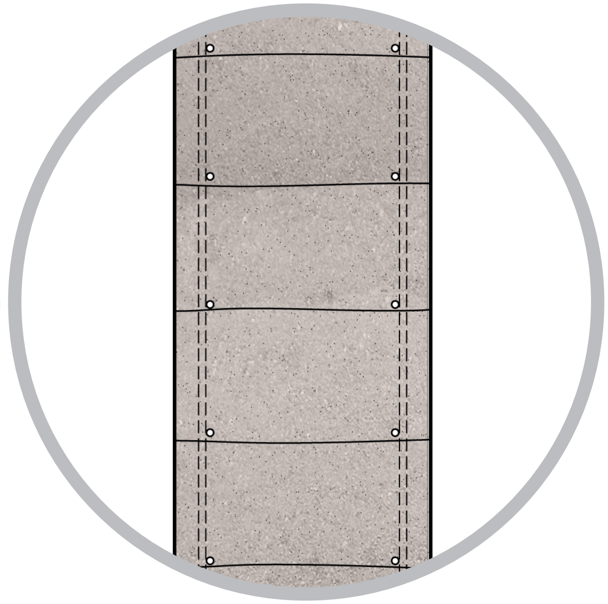
NORTH-FACING EXTERIOR WALL
UTILIZES DENSITY

ADVANTAGES
Complete impermeability
Zero maintenance
Hygroscopic properties
Thermal inertia
Long service life
Pest resistant

DISADVANTAGES
Labour intensive
Space expenditure
Height limitations

APPLICATIONS
New walls for almost any project.

APPLICATION B



INTERIOR DEMISING WALL
UTILIZES MASS

ADVANTAGES
Soundproof
Fireproof
Zero off-gassing
Hygroscopic properties
Thermal inertia
Long service life

DISADVANTAGES
Labour intensive
Space expenditure
Height limitations

APPLICATIONS
New party walls for townhouse developments. Noise barriers at roads, highways, boundaries between public/private spaces.

APPLICATION C

SOUTH-FACING TROMBE WALL
UTILIZES SOLAR THERMAL POTENTIAL

ADVANTAGES
Passive thermal heating
Passive thermal cooling
Decreased building heating loads
Decreased building cooling loads
User engagement

DISADVANTAGES
Major space expenditure
Only occasional opportunities for implementation

APPLICATIONS
New buildings or additions where southern exposure is viable, or passive design strategies are required.

The objectives of this investigation were to present an understanding of how this material might be introduced to the contemporary, industrialized urban environment, and to demonstrate some of the applications for which it is suited to that very environment. The demands of the urban environment as a whole are beyond the capacities of this material to address alone. Cities demand high-rise structures. Rammed earth will never be able to replace concrete as the predominate load bearing material of condos or large commercial buildings. Yet today, Terra Firma builders are constructing a 52’ [16m] tall load bearing wall for the new Briton Museum in Wyoming. Once complete, this will be the tallest earth wall in the world to have been subject to regulatory compliance and receive approval. [4] So while rammed earth does indeed have height restrictions which limit its use in the urban built environment, just as wood construction is limited by code to 5 storeys in Canada, the potential of the material continues to grow. Another major question which arises from proposing rammed earth in the urban environment relates to space: the generous amount of usable city space which is taken up for such a wall. While the exterior rammed earth wall can vary in its overall assembly width, it is generally 3 times wider than a conventional wood frame wall. In the urban environment, where space is truly at a premium, such use, or misuse, of space can be concerning. Yet if that conventional wood frame wall, although 3 times thinner, might be replaced more than 3 times during the life cycle of the larger earth wall, we ought to question if it is truly preferable to sacrifice material resources directly for space. Perhaps a rammed earth wall, made as it is, non-combustible and fire rated, might be given relaxations in zoning setbacks, allowed to project it’s extra width outside of a structure and closer to a property line. The most serious question which arises from proposing this material is resource availability. Should everyone begin to build with earth, are the resources truly available to accommodate that? The answer of course is no. Nor are there resources available for every single structure to be made entirely of wood, or of concrete, or of steel. We must balance our use of resources against their availability. That is why this proposal focuses on those applications of rammed earth which are suitable to augment some of our practices, some of our architectural elements, some of our consumption of other resources.

Earth has been used as a building material in every human culture from the dawn of civilization up until our own. Earth construction, while making use of a low-grade material, is already highly refined as a practice, having been continuously improved upon for millennia. This proposal is not novel in its suggestion that we continue that process to refine this craft. Earth is one of the only material resources left on our planet which has not yet been subject to extensive industrialization. As such, it remains a specialized practice, necessarily supple to the conditions of geography. Yet it is exactly because it has not been cultivated in the same way as other materials that our industrialized society stands to lose the craft. Because earth cannot be sold as a building product, it remains a nuanced building practice, such nuances are often seen in our culture as uncivilized, unnecessary, and difficult to implement. Yet earth is the most primary bulk resource at our disposal. Our industrial appetite for resources is insatiable. Despite efforts to reduce consumption, resources will never cease to be consumed. Fostering the productive consumption of this material within our own industrialized civilization is a straightforward sustainable solution with a visible material impact. What sustainability must accomplish through its material presence is a marriage of the past, such nuanced practices, with the future, standardized implementation of such practices. Rediscovery of material success from our past, reinterpretation of that success in light of present norms and conventions, and reintroduction of those material concepts as a proposed success for the future. This thesis offers a single perspective on that process of contemporizing past material success. It explores a traditional and successful vernacular building technology, and presents a range of methods by which such a vernacular might be brought into conversation with the modern industrialized vernacular which prevails in the urban condition today.

“The high architecture stream is inspired by cosmic ideas, the vernacular stream rooted in daily reality. One is learnt by prolonged esoteric study, the other by making, doing and building; by mud, dirt and wood shavings. Both are artistic but neither is complete or balanced without the other: they need to be brought into conversation.” [3]

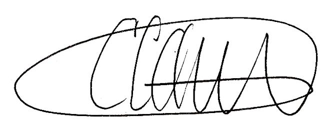
Christopher Day,
Places of the Soul.

AFTERWORD

The creation of this afterward was prompted by the provocative discussion which came from the defence of this thesis. The discussion was extensive, proposing lines of inquiry which warrant inclusion herein, and the following summarizes the most salient points.

I was drawn to this thesis by the sustainability promised in the material of rammed earth. An architectural material which can be created from raw resources harvested on a building site, involves no transportation, no industrial manufacture, and no extraneous complexities. Through the thesis, complexities crept in which brought the feasibility of the proposal into question. Because of the cost of urban real estate and the arduous method of construction for rammed earth, this material may not be altogether suited to the urban environment. Despite this, a client, a builder, or even a developer may very well be attracted to this timeless material and wish to pursue its use within that environment. Herein lies the value of this exploration. The three proposed applications of rammed earth may each be practical for limited utilization, but together, in a project such as was proposed, is a stretch of practicality. Yet the sustainability of this ageless adobe building processes cannot be disputed, and for that reason alone such a building process as rammed earth deserves attention and study. The timelessness of this material promises its use will extend far beyond our contemporary context. The forms by which it will endure are yet to be seen. To be truly compatible with the construction industry of today and that of tomorrow, a strategy of commercial possibilities will need to be developed for this material. Marketing the durability, versatility, and inherent spiritualism of the material is the key to developing its feasibility, to harnessing the sustainable potential of such a timeless building technology.

This thesis was an exploration of a material. The thesis *was* the material and the material the thesis. The difficulty of centering on such a topic for a thesis is in developing the concept you choose to surround the material in order to create a viable exploration. What I have learned from this experience is that such a concept is an architectural hypothesis which can be either proven or disproven without detracting from the validity of the exploration. In pure science, a disproven hypothesis remains a valid exploration, providing proof to the contrary. Having demonstrated rammed earth untenable for urban renovations, does not detract from the powerful potential I found, and continue to find, in this material. The proof of the thesis is not the proof I originally sought, but instead, proof of something altogether new, a valid potential to be found in the future explorations, the investigations which follow where this one left off.



NOTES

INTRODUCTION

1 Heringer, Anna. (2012). *Simply local*. In I*N DETAIL: Building Simply Two*, ed. Christian Schittich, 51. Architektur-Dokumentation GmbH & Co.

2 Kapfinger, Otto. (2012). *Terrestrial Building.* In *Rauch House: A model of advanced Clay Architecture.* ed. Rauch, Martin, and Boltshauser, Roger, 62. Birkhauser.

3 Minke, Gernot. (2006). *Building With Earth*. 12. Birkhauser.

4 Rael, Ronald. (2009). *Earth Architecture. 10.* Princeton Architectural Press.

5 Rauch, Martin. (2012). *Construction.* In *The Rauch House: A model of advanced Clay Architecture*. ed. Rauch, Martin, and Boltshauser, Roger. 116. Birkhauser.

6 Easton, David. (2000). *Rammed Earth*. In *Alternative Construction: Contemporary Natural Building Methods.* ed. Elizabeth, Lynne. and Adams, Cassandra. 153. John Wiley & Sons Inc.

SECTION ONE

1 Heringer, Anna. (2012). *Simply local*. In I*N DETAIL: Building Simply Two*, ed. Christian Schittich, 55. Architektur-Dokumentation GmbH & Co.

2 Calkins, Meg. (2009). *Materials for Sustainable Sites*. 147. John Wiley & Sons Inc.

3 Pflughoeft-Hassett et al. (2000). In *Materials for Sustainable Sites.* 165. John Wiley & Sons Inc.

4 Easton, David. (2000). *Rammed Earth*. In *Alternative Construction: Contemporary Natural Building Methods.* ed. Elizabeth, Lynne. and Adams, Cassandra. 165. John Wiley & Sons Inc.

5 Ontario, Building Code Act. O Reg.332/12. Part 9: Housing and Small Buildings. 2012: 9.3.1.1.(1): 15MPa is the compressive strength required by reference to CAN3-A438-M: Concrete Construction for Housing and small buildings.

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6 McDonough, William., and Braungart, Michael. (2002) *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point Press. Cradle to Cradle is a term registered to (MBDC) and was the central theme of architect William McDonough's 2002 manifesto, Cradle to Cradle: Remaking the way we make things. It refers to a holistic system of design and ideology towards creation that is efficient and entirely waste free. It contrasts the dominating cradle-to-grave modes of production wherein resources are used within a product and then discarded. Cradle-to-cradle design would see resources entering into closed loop cycles of use and service.

7 King, Bruce. (1996). *Buildings of Earth and Straw*. 58. Ecological Design Press.

8 King, Bruce. (1996). *Buildings of Earth and Straw*. 57. Ecological Design Press.

SECTION TWO

1 Easton, David. (2000). *Rammed Earth*. In *Alternative Construction: Contemporary Natural Building Methods.* ed. Elizabeth, Lynne. and Adams, Cassandra. 153. John Wiley & Sons Inc.

2 Ontario, Building Code Act. O Reg.332/12. Supplementary Standard SB12: Energy Efficiency for Housing. 2012: Table 2.1.1.2.A

3 Ontario, Building Code Act. O Reg.332/12. Part 5: Wind, Water and Vapour Protection. 2006: 5.4.1.1(1), 5.5.1.1(1)

4 Ontario, Building Code Act. O Reg.332/12. Part 9: Housing and Small Buildings. 2012: 9.10.11.1

5 Ontario, Building Code Act. O Reg.332/12. Part 3: Fire Protection, Occupant Safety and Accessibility. 2012: 3.1.10.2 (2)

6 Ontario, Building Code Act. O Reg.332/12. Part 9: Housing and Small Buildings. 2012: 9.11.1.1: STC ratings shall be determined in accordance with ASTM E413, as designated by ASTM E90 or ASTM E336

7 Ontario, Building Code Act. O Reg.332/12. Part 9: Housing and Small Buildings. 2012: 9.11.2.1 (1)

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8 Kamm, Thomas. (2011). *Energy.* In *Rauch House: A model of advanced Clay Architecture.* ed. Rauch, Martin Rauch, and Boltshauser, Roger. 152. Birkhauser.

1 Day, Christopher. (2004) *Places of the soul: Architecture and Design as a Healing Art.* (2) 30. Architectural Press of Elsevier.

2 Hague, Matthew. (2014). With changing demographics, the multigenerational house comes of age. *The Globe and Mail.* March 12. (accessed March 20, 2014).

3 Ageing in Place is a term defined by The Centre for Disease Control as: *"The ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level."* It suggests that individuals and communities benefit from long-term relationships with places, specifically individuals who prefer to remain in their home of choice as long as they are able, in so doing, they strengthen the communities in which they choose to remain.
http://www.cdc.gov/healthyplaces/terminology.htm (accessed May 25, 2014).

4 The Millenials are the cohort generation known as Gen Y. The majority of Millenials are currently in their 20's, having graduated with burdensome student debt, into an economy of recession, with a sluggish job market, with particularly high levels of youth unemployment. While characterization of the Millenials is extremely polarized, their economic prospects have undoubtedly forced many of them to return to their parent's dwell ings after completing their post-secondary educations. According to Pew Research, as of 2012, 1 of 3 Americans aged 18 to 31, live with their parents.
http://www.pewsocialtrends.org/2013/08/01/a-rising-share-of-young-adults-live-in-their-parents-home/ (accessed March 25, 2014).

5 The bricks produced by the don valley brickworks were considered of the highest quality. In 1893 the bricks from the Don Valley Brick Works won the highest award at the World's Fair in Chicago.
http://www.thecanadianencyclopedia.ca/en/article/evergreen-brick-works/ (accessed June 22, 2014).

CONCLUSION

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1 Day, Christopher. (2004) *Places of the soul: Architecture and design as a healing art*. (2). 172. Architectural Press of Elsevier. 2004: p.172

2 Ibid. 65.

3 Ibid. 34.

4 http://www.sirewall.com/history/ (accessed July 28, 2014).

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