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I, John Arnaud, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture.

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Analysis for Responsible Construction in Romania

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Committee member: Aarati Kanekar, Ph.D.

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Analysis for Responsible Construction in Romania

A thesis submitted to the

Graduate School

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in partial fulfillment of the

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Master of Architecture

in School of Architecture and Interior Design

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by

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Abstract

When designing and building in any environment it is necessary to ensure that techniques, products, and human resources are responsibly managed. This is especially true when considering built development in rural Romania. In the past decade the Romanian government and the European Union have begun efforts to sponsor innovation, redevelop and modernize the workforce and building industry, and there is certain potential to implement innovative means of construction. Use of wood as a building material has been long established. Contemporary techniques in responsible forestry and cross laminated timber have enabled ways of building that are both efficient in implementation and environmentally responsible, if not beneficial. By implementing innovative wood fabrication techniques in a socio-economic climate like that of rural Romania there is potential for developing strategies that responsibly contribute to the international research community, wood building product development, and the Romanian construction, or broader, economy. This thesis explores the construction climate of Romania, cross laminated timber, and wood as a building product in an effort to set the stage for a larger programmatic development and architectural design in the commune of Pietroasa, Romania. The project will be focused on developing an environmentally and socially responsible tourist lodge, micro cabin development, and campground in a pristine, Romanian mountain pasture. In addition to the responsible tourist development an urban site in Pietroasa Commune, Bihor County will be developed and likely include a brewery, public town square, gathering spaces, and fabrication facility. The brewery and town square will be used to increase the amount of available tourism infrastructure. The gathering spaces will be used for education of public and select patrons in both hospitality/tourism practices and emerging building techniques. The fabrication facility will be used for prefabrication and implementation of

emerging wood construction techniques to aid in the construction of the tourist lodge and associated facilities in the pristine mountain land.

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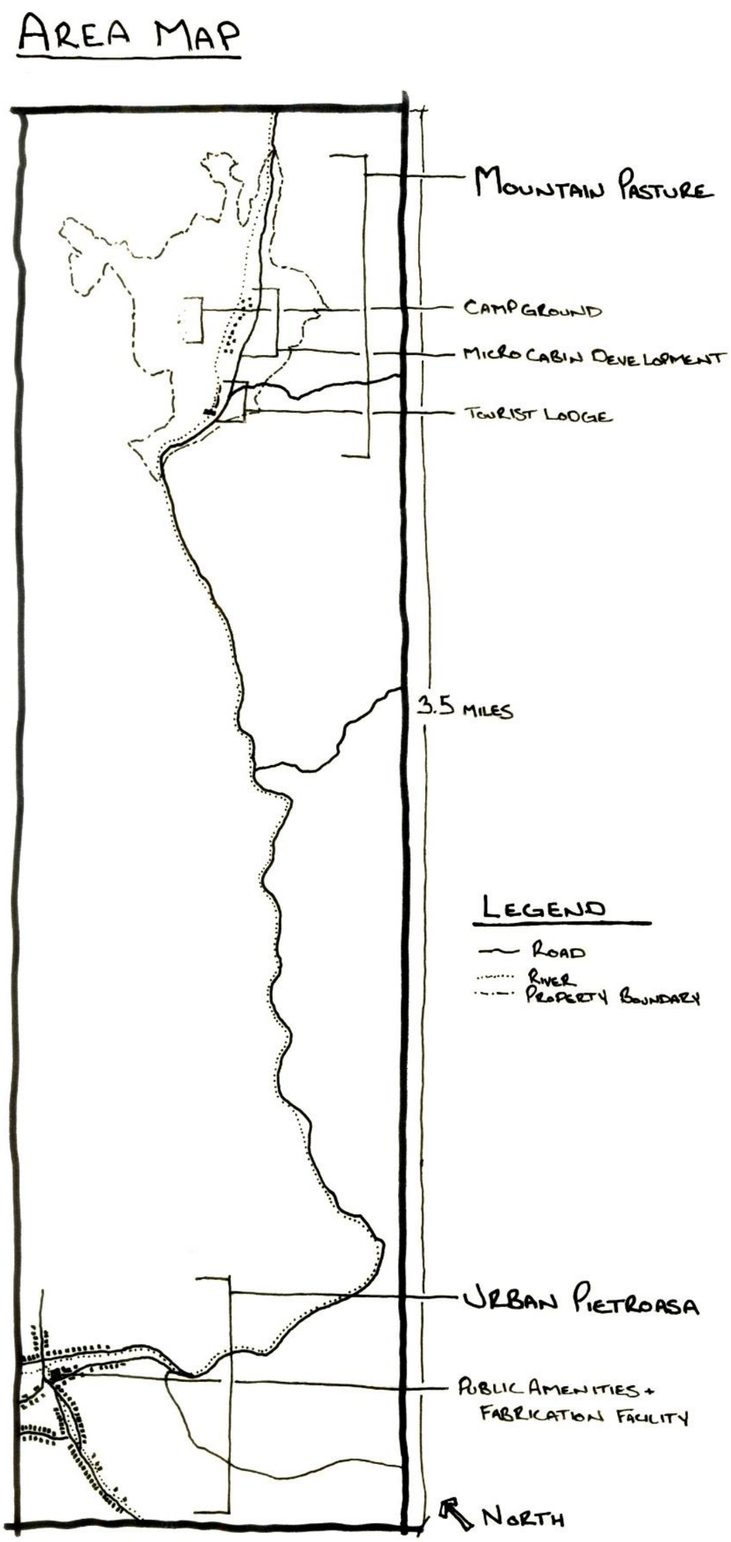

Fig. 1.1 – Urban Pietroasa is located roughly 3.5 miles south of the mountain pasture.

In order to develop, design, and build responsibly there are many factors that need to be carefully considered. The commune of Pietroasa in Bihor County is uniquely situated in a country that is thirty years out of a neoliberal revolution and a decade out of a building recession which creates many social, environmental, and economic issues that factor into what defines 'responsible' for the locale and the built project. Among these issues the state of the construction industry, the environmental impact of building materials, and the techniques with which materials are implemented are critical when considering the design and construction of a built environment.

This thesis investigates how these issues can be responsibly considered while creating built

development in the commune of Pietroasa. The project will be focused on developing an environmentally and socially responsible tourist lodge, a micro cabin development, and campground in a pristine, Romanian mountain pasture. In addition to the responsible tourist development an urban site in Pietroasa Commune, Bihor County will be developed and likely include a brewery, public town square, gathering spaces, and fabrication facility. The brewery and town square will be used to increase the amount of available tourism infrastructure. The gathering spaces will be used for education of public and select patrons in both hospitality/tourism practices and emerging building techniques. The fabrication facility will be used for prefabrication and implementation of emerging wood construction techniques to aid in the construction of the tourist lodge and associated facilities in the pristine mountain land.

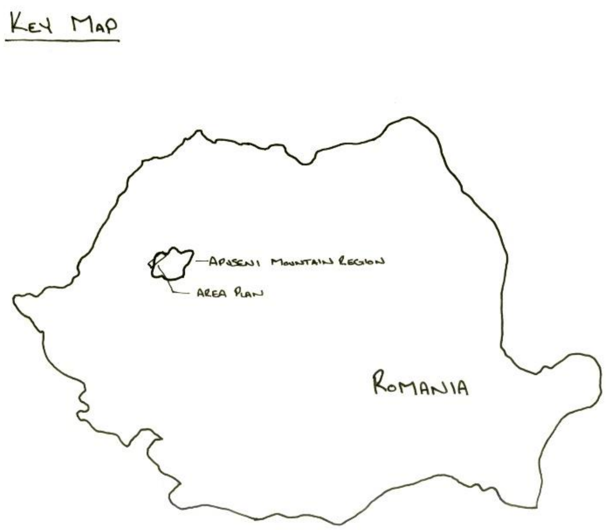

Fig. 1.2 – Pietroasa is located in the Apuseni Mountain region in northwest Romania.

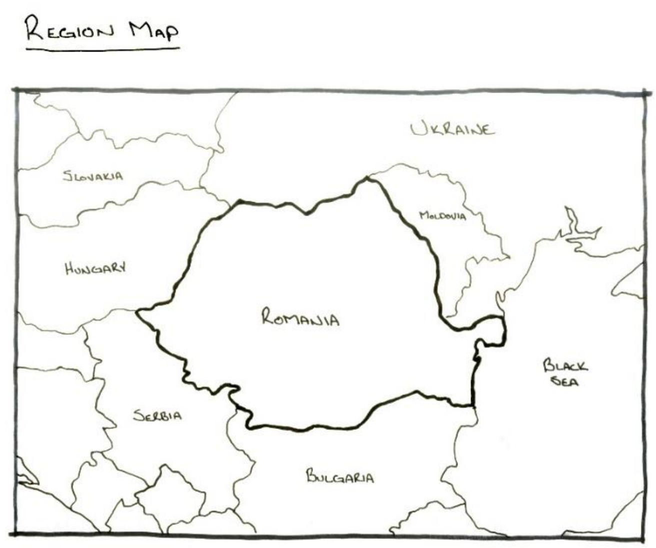

Fig. 1.3 – Romania is located in the unique economic climate of Eastern Europe.

CHAPTER 2 - THE CLIMATE OF THE ROMANIAN CONSTRUCTION SECTOR

2.1 - Perspectives of Research in the Romanian Construction Field 2014-2020

In 2010 the European Union devised a ten-year strategy called Europe 2020 that is aimed at improving competitiveness, productivity, and sustainability throughout the European Union. Some of the goals of the strategy include maintaining 75% employment, reducing poverty, promoting education, reducing green house gas emission, increasing use of renewable energies and efficiency of energy use, and finally maintaining research, development, and innovation as components of the European Union economy.[1] In 2014 the Horizon 2020 program was adopted in order to implement the research, development, and innovation called for by Europe 2020. Horizon 2020 offers €80 billion of funding, with minimal red tape, over its seven-year existence and aims to ensure Europe "produces world-class science, removes barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation.[2]" Similarly, the Romanian constitution explicitly requires that the state provides for, "stimulation of national scientific and technological research." The aim of state involvement in research, development, and innovation activities is to promote, "sustainable economic development, increase quality of life, protect and enrich the national scientific heritage, and participate in the world heritage of knowledge."

The construction and related material industries are important parts of both the European Union and Romanian Economy. In the European Union the construction and related material industries make up 10% of the GDP and almost 30% of industrial employment. These fields have strong social impacts on quality of life for citizens, in terms of both employment and

[1] "Europe 2020 Strategy," (European Commission, 2017)
[2] "What is Horizon 2020?," (European Commission, 2017)

sustainable occupation of the environment. It is therefore imperative that research and innovation of construction and related materials are made a priority. While the connections between the built environment and the research goals of Romania and the European Union as outlined in the constitution and various programs may seem strong, research and development of construction and materials is never directly mentioned. Although never directly mentioned many of the program directions can be applied to the built environment. For example, one outlined direction of Horizon 2020 promotes scientific excellence through development of research infrastructures; there is opportunity for Romanian researchers to begin to integrate their research infrastructures at the pan-European level.[3] In terms of the built environment this could be done through collaborative projects or through use of experimental materials by Romanians with the support of international partners. Another Horizon 2020 direction is aimed at "tackling of climate changes, efficient utilization of resources and of the raw materials.[4]" This tackling of climate change could include design measures and material research in ways to make the built environment more efficient in terms of energy performance and environmental protection. Similarly, efficient utilization of resources and raw materials could also be explored through material and technique research.

2.2 - Human Resources in the Construction Sector in Romania

While the construction industry is a major employer that makes up a significant part of Romania's economy, the industry generates roughly 10% of the GDP, the current workforce is not sufficient in quantity or skill. This mismatch in skill and demand of the work force can be

[3] Mihai Vrabie, Sergiu-Andrei Baetu, "The Perspectives of Research in the Construction Field in Romania During the 2014-2020 Period," *Constructii*, No. 2, (2013): 5.

[4] Ibid., pg. 7

tracked back to the decline of the Romanian real estate and construction sectors in late 2008, as the quantity of work in these sectors diminished the demand for highly skilled labor was significantly reduced. This lack of demand for highly skilled workers caused a majority of experienced works to migrate from the country. In order to resupply the human resources needed in the construction sector several steps, especially with regards to training, are needed.[5]

At The Bucharest University of Economic Studies Cezar Simion-Melinte suggest several administrative means of action to foster sustainable competitiveness of the construction workforce in Romania; the actions suggested are to be carried out at a federal level. These means for improvement are organized into four courses of action.[6]

1. Simion-Melinte first suggests 'tax deductibility for expenditure on training' needs to be implemented, increasing the accessibility of training for both the workforce and the ability to train and update employees and techniques for employers.[7]
2. Second, "reorganization of vocational education" is recommended. It is recommended that the educational system both modernize and examine curriculum to maintain relevance with contemporary trends as well as implementing programs that encourage on the job training like internships, working experience, and partnerships with organizations like employers' associations and trade unions.[8]

[5] Cezar Simion-Melinte, Daniel Constantin Jiroveanu, Andi Iulian Lungu, "Means of Action for the Sustainable Competitiveness of Human Resources in the Construction Sector in Romania," *Review of International Comparative Management*, Volume 16, Issue 2, (May 2015): 180.

[6] Ibid., pg. 183
[7] Ibid., pg. 183
[8] Ibid., pg. 183

3. Third, in order to incentivize and appropriately employ trained individuals undeclared work needs to be stopped.[9]
4. Finally, they suggest more thorough testing at the university technical education level to ensure the most educated are able to ensure 'quality of implementation both in design and execution.[10]'

The key emphasis of Simion-Melinte's first, second, and fourth courses of action are training and education. The main objectives of training are; adapt employees to a particular job and workplace, obtain professional qualifications, continuously updating skills and knowledge, and acquiring advanced knowledge of modern materials, methods, and procedures. It is suggested that achievement of these objectives can be best promoted and even instituted by private industry. Methods private industry can use to promote these training objectives include; participation in training courses in the domestically or internationally, on the job traineeships for vocational adjustment, offer internships, apprenticeships, and customized training.[11]

[9] Simion-Melinte, "Means of Action…", pg. 183
[10] Ibid., pg. 183
[11] Ibid., pg. 180

2.3 - Lumber Production in Romania

Since 1989 the lumber industry, as well as many others, has undergone great restructuring in Romania. This lumber industry includes companies that manufacture and sell no and low processed wood products, raw lumber being a no processed product and wood furniture being a low processed product. Ownership of companies and facilities changed and so did the forces that drive production and demand. In order revitalize and maintain the industry in a sustainable way progress in management of natural resources and production techniques will be necessary.[12]

After the Romanian Revolution of 1989 many state-owned companies were sold to private investors. While many companies were purchased at low cost by private entities with intent of investment the reality is the investment was never realized and many companies went out of business. There was little investment in modern equipment, lack of focus on performance and efficiency, and as product sales dropped and cost increased inventory became excessive. The majority of businesses that survived were younger companies that sold relatively unprocessed logs and timber.[13]

In order to maintain sustainable timber harvesting practices competency in biology, habitat protection, land management, indigenous peoples' rights, and production techniques are all essential.[14] Unfortunately, little of this existed in Romania and lack of legislation after the

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[12] Ilie Budica, Silvia Puiu, Bogdan Budica, Dalina Ochetan, "Analysis of Exports of Logs and Lumber of Romania Between 1989-2010," *Economy Transdiciplinarity Cognition,* Vol. 16,(January 2013): 104.

[13] Ibid., pg. 101

[14] Robert H Falk, "Wood as a Sustainable Building Material," *Journal: Forest Products*, Vol. 59, No. 9, (September 2009): 10.

fall of the socialist government created an environment where many of Romania's forests were exploited. In 2000 Forest Code was introduced and began regulating consumption of the country's forests as a valuable asset. Like in many countries with similar regulation, Romanian entities needing lumber began importing wood from nearby states because of the lower cost.[15] Since 2000 some Asian countries, namely China, began importing lumber from Romania. "Romania is one of the few countries in Europe that liberalized exports of lumber for China.[16]" This business from the East along with the up turn of the European economy around 2010 created a resurgence in lumber production. While this resurgence did increase production it only retuned to nearly that of before the privatization of 1989. Exports of lumber are, however, more than three times that of what they were before privatization.[17]

This all taken into consideration there are several barriers that stand between the current state of Romania's lumber production and domestic harvest, production, and use. First, a common understanding of sustainable forestry practice and implementation through regulation is needed. Production of furniture and other processed wood products, like building products, needs to be reestablished; this will require modernization of dated facilities and construction of new ones. Finally, skill and efficiency in harvest and production have to be increased to make Romanian wood products a cost competitive option.[18]

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[15] Budica, "Analysis of Exports…", pg. 102
[16] Ibid., pg. 104
[17] Ibid., pg. 102
[18] Kell Jones, Julia Stegemann, Judith Kykes, Peter Winslow, "Adoption of Unconventional Approaches in construction: The Case of Cross-laminated Timber," *Construction and Building Materials*, Vol. 125, (30 October 2016)

2.4 - Adoption of Unconventional Approaches in Construction

In the next 32 years the global population is projected to grow by 9.6 billion people, this means more than doubling todays population of 7.2 billion. In order to preserve non-renewable resources, it is essential that methods that rely on renewable resources are developed to accommodate the growing population. Construction is among the most resource intensive industries in the world; it is therefore vulnerable to future resource shortages and at risk of exploiting remaining non-renewable resources. It will be necessary to adopt innovative, new building techniques to combat these issues. The construction industry is, however, often slow to adopt unconventional techniques. Many of these barriers are driven by efforts to keep cost competitive, slow adaptation of existing expertise, and lack opportunities to experiment with new techniques. A system of understanding barriers to the adoption of unconventional approaches can be used to investigate and propose new techniques that could be a solution to consumption of non-renewable resources.[19]

While concerns about use of natural resources have become widely accepted and the consumptive nature of construction is understood, many organizations are hesitant to adopt more efficient construction techniques and practices, especially unconventional ones. Standard, low bid, methods of letting construction contracts limit opportunities for adoption of new techniques. This cost driven process incentivizes reliance on existing, established, and tested techniques because of minimal, financial risk associated with using a trusted method. Organizations develop know-how and this know-how becomes their competitive advantage. While innovation and improvement have inherent benefits, they are often sought through incremental improvement

[19] Kell, "Adoption of Unconventional Approaches…"

of established methods. For this reason, the novel methods that may be necessary to reform the use of renewable resources in construction are seldom utilized or explored.[20]

In order to propose an unconventional method of construction for the developments in the commune of Pietroasa, Romania an analysis of the factors that drive the push for traditional construction methods is needed; the COM-B system can be utilized to do this. "The COM-B system (Capability, Opportunity, Motivation—Behavior) is a model of behavioral precondition that can help diagnose why actors demonstrate resistance to changing their behavior[21]." The COM-B system was developed in healthcare, has been applied to facilities management, and can be used to explore decision making in construction innovation. The general premise of the COM-B system is that capability, opportunity, and motivation all directly affect behavior.[22]

Capability – In terms of construction innovation capability must be assessed as whether or not a project (referring to both the physical components of a project and the team involved) has the resources to pursue an innovative method. Resources necessary for capability include expertise in design and specification, expertise in assembly, ability to physically deliver using the innovative method, and access to the materials necessary.[23]

Opportunity – Opportunity addresses whether or not the environment of the project allows for innovation. This includes whether or not constraints like schedule, budget, and project team will allow for innovation. A key factor to consider when evaluation opportunity in a construction project is the role of the team member leading the project at the time. The opportunity for innovation changes as leadership changes throughout a construction project, it is

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[20] Kell, "Adoption of Unconventional Approaches…"
[21] Ibid.
[22] Ibid.
[23] Ibid.

critical to understand all party's interests and risk when assessing opportunity for implementation of innovation techniques.[24]

Motivation – Capability and opportunity both affect motivation. Motivation is understood as whether or not the decision maker is inclined to select or advocate the innovative

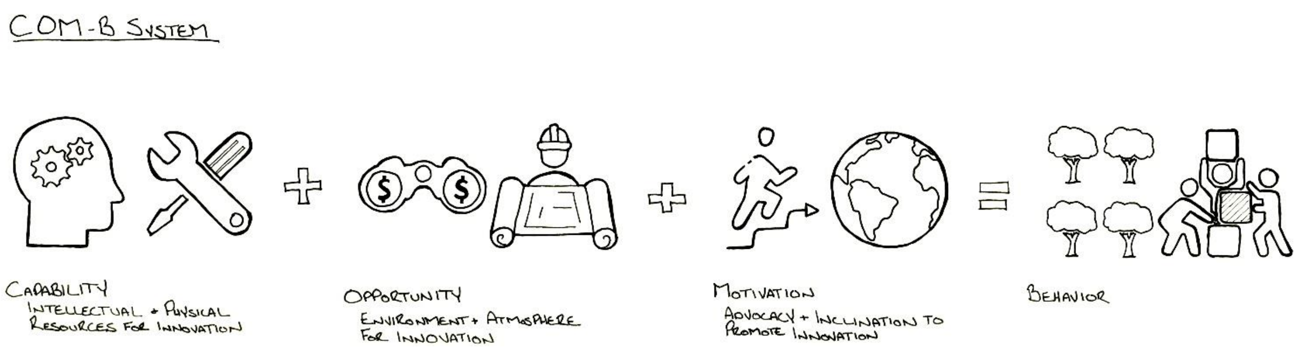

Fig. 2.1 – The COM-B system can be used evaluate factors that contribute to adoption of innovative techniques in construction.

project and what their motivators are is important in assessing motivation in a construction project.[25]

Responsible development in the commune of Pietroasa, Bihor County, Romania could be uniquely situated to implement previously unconventional approaches to construction in an effort focus on use of renewable resources and materials. A committed effort to build an environmentally responsible tourist lodge would create the opportunity needed to implement unconventional innovative methods. The utilization of a fabrication facility in the more urban area of Pietroasa would provide the capability to implement the methods and train the workforce needed. The motivation would come from organizational commitment to a project that is truly focused on environmentally and socially responsible development. These factors of capability,

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[24] Kell, "Adoption of Unconventional Approaches…"
[25] Ibid.

opportunity, and motivation would lead to a behavior that strives to implement methods that, while they are unconventional are driven, by a honest commitment to responsibility.

CHAPTER 3 - WOOD AS A BUILDING MATERIAL

3.1 - Overview

Globally building construction consumes 24% of the materials extracted from the earth's surface.[26] 90% of the noncombustible rocks and minerals extracted are sought by building industries and this extraction comes at the price of high emissions.[27] In 2010 buildings accounted for 19% of greenhouse gas emissions, this includes both the direct effects of building production and operation of a building and the indirect effects of production of materials and installation.[28]

As a building material wood has some distinct environmental advantages over other materials. "Wood is light and mechanically resistant, has a good thermal conductivity coefficient, creates a comfortable environment and has good thermal and noise insulation properties.[29]" Wood is renewable, has low amounts of embodied energy, and has low if not negative carbon impact depending on how it is processed. Additionally, "if harvested sustainably wood is resource that will be available indefinitely." In terms of global warming potential, air, and water emissions wood is far safer than other materials.[30]

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[26] Silvia Santi, Francesca Pierobon, Giulia Corradini, Raffaele Cavalli, Michela Zanetti, "Massive Wood Material for Sustainable Building Design: the Massiv-Holz-Mauer Wall System," *The Japan Wood Research Society*. No. 28, Issue 62, (June 2016): 416.

[27] Silviana Marica, Valentia Cetean, Gheorghe Lazaroiu, "Unitary Management and Environmental Performance by Monitoring and Protection of Mineral Resources for Construction Materials from Romania," *Building and Environment*. Issue 43, (2 February 2007): 1082.

[28] Santi, "Massive Wood Material…", pg. 416

[29] Ibid., pg. 416

[30] Faulk, "Wood as a Sustainable…", pg. 7

3.2 - Embodied Energy

In addition to its performance characteristics, there are environmental benefits of using wood as a building material especially when compared to mineral based building materials like steel, concrete, and brick. Even heavily processed wood products have substantially lower amounts of embodied energy than mineral based products.[31] A study has shown that wood wall systems contain 10%-20% less embodied energy than a concrete wall system.[32] Embodied energy is the amount of energy required to harvest or extract, transport, manufacture, and deliver a product. Wood requires minimal amounts of energy to process. The energy to produce trees, raw wood, comes primarily from photosynthesis a process powered by the sun. The harvesting, transportation, and manufacture of wood products is where some fossil fuels are consumed. The quantity however, is significantly less than that of other mineral based materials where fossil fuels are heavily consumed to mine, transport, and power several processes of manufacture. In the milling and production of wood building products biomass is often used as an energy source. Biomass includes the bark, sawdust, and other by-products of processing. In the United States nearly half of the energy consumed for manufacture of wood products is from biomass energy, in fact the "U.S. wood product industry is the nation's leading producer of bioenergy, with biomass accounting for about 60% of its energy needs.[33]" Of the processes involved in producing wood products kiln drying is the most energy consuming. Kiln drying is typically powered by burning biomass waste and is regarded as carbon neutral.[34]

[31] Faulk, "Wood as a Sustainable…", pg. 7
[32] Santi, "Massive Wood Material…", pg. 417
[33] Faulk, "Wood as a Sustainable…", pg. 7
[34] Ibid., pg. 7

It is estimated that 25% of the energy used by the building industry in embodied energy from transportation and manufacture of building materials.[35] In consideration of this embodied energy one study looked at how to reduce emissions in the production and delivery of a cross-laminated timber product. It was found that the majority of the reducible emissions were in transportation of product; both from harvest or saw mill to production facility and from production to final delivery. It was found that production should be local to the harvesting and milling.[36] This helps eliminate transportation of unwieldly raw timber and unsorted waste produce and allows long distance transportation of carefully packed and organized final components.

3.3 - Carbon Impact

The effects of carbon on global climate and ecosystems have become known and widely accepted. Forests play an essential part of the global carbon cycle, they contain the trees and plants that absorb carbon dioxide, sunlight, and water to produce energy for growth and omit oxygen as a byproduct. Without human intervention the life cycle of a tree includes growing, thereby converting carbon dioxide into oxygen. Upon the death of the tree some carbon is released as the wood deteriorates and much remains in the form of biomass. When wood is burned carbon is immediately released into the atmosphere. If a tree is processed into building material the carbon is sequestered in the processed wood and preserved. The carbon remains sequestered in the building until the wood removed during some form of demolition. Wood

[35] Marica, "Unitary Management and Environmental…", 1083
[36] Santi, "Massive Wood Material…", pg. 426

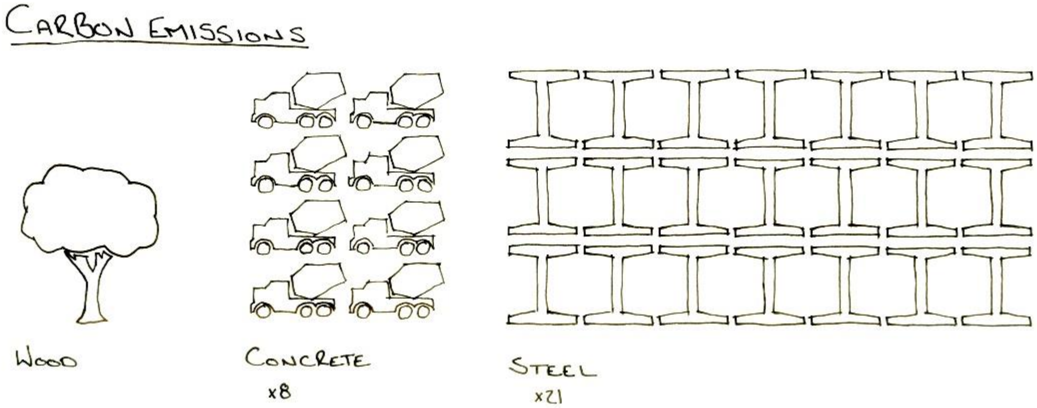

Fig. 3.1 – Concrete and steel emit eight and twenty-one times as much carbon in production as wood building products.

building products can then be easily repurposed, if not repurposed the wood, and sequestered carbon, are often sent to a landfill where they remain until they deteriorate.[37]

In comparison with steel and concrete the carbon emitted to produce one ton of building product is significantly lower for wood. About eight times as much carbon is emitted to produce one ton of concrete and about twenty-one times as much carbon is emitted to produce one ton of steel. Some solid wood building products can often be carbon negative, not only because of the minimal amount of energy required for production, but also because of the naturally mitigated carbon emissions.[38]

3.4 - Wood Harvesting and Management

In order to assure that wood remains a renewable resource it is critical that forest management and harvesting are carefully executed. It is critical to maintain diversity in forests in order to ensure long term health of our forests.[39] The Consortium for Research on Renewable Industrial Material studied how different harvesting cycles affect carbon sequestration in trees.

[37] Faulk, "Wood as a Sustainable…", pg. 9
[38] Faulk, "Wood as a Sustainable…", pg. 10
[39] Ibid., pg. 10

Their research showed that shorter harvest rotations create greater carbon sequestration than longer rotations.[40]

It is common for users and specifiers of wood products to seek assurance that the products they are purchasing and prescribing are sustainable produced and managed. There are over 50 certifications that seek to ensure this. As of 2009 13% of the worlds managed forests had these certifications and the growth of this management is accelerating. In North America 33% of forests are certified and 50% in Europe. Forest Stewardship Council [FSC] is a reliable, independent, international, non-governmental, non-for-profit, organization that can certifies responsible forestry, land management, and provide chain-of-custody information to trace wood products to their source. Additionally, the Programme for the Endorsement of Forest Certification [PEFC] is an organization that issues certificates to certify certifications and can be used to ensure legitimacy of lesser known certifications.[41]

[40] Faulk, "Wood as a Sustainable…", pg. 7
[41] Ibid., pg. 11

CHAPTER 4 - CROSS LAMINATED TIMBER

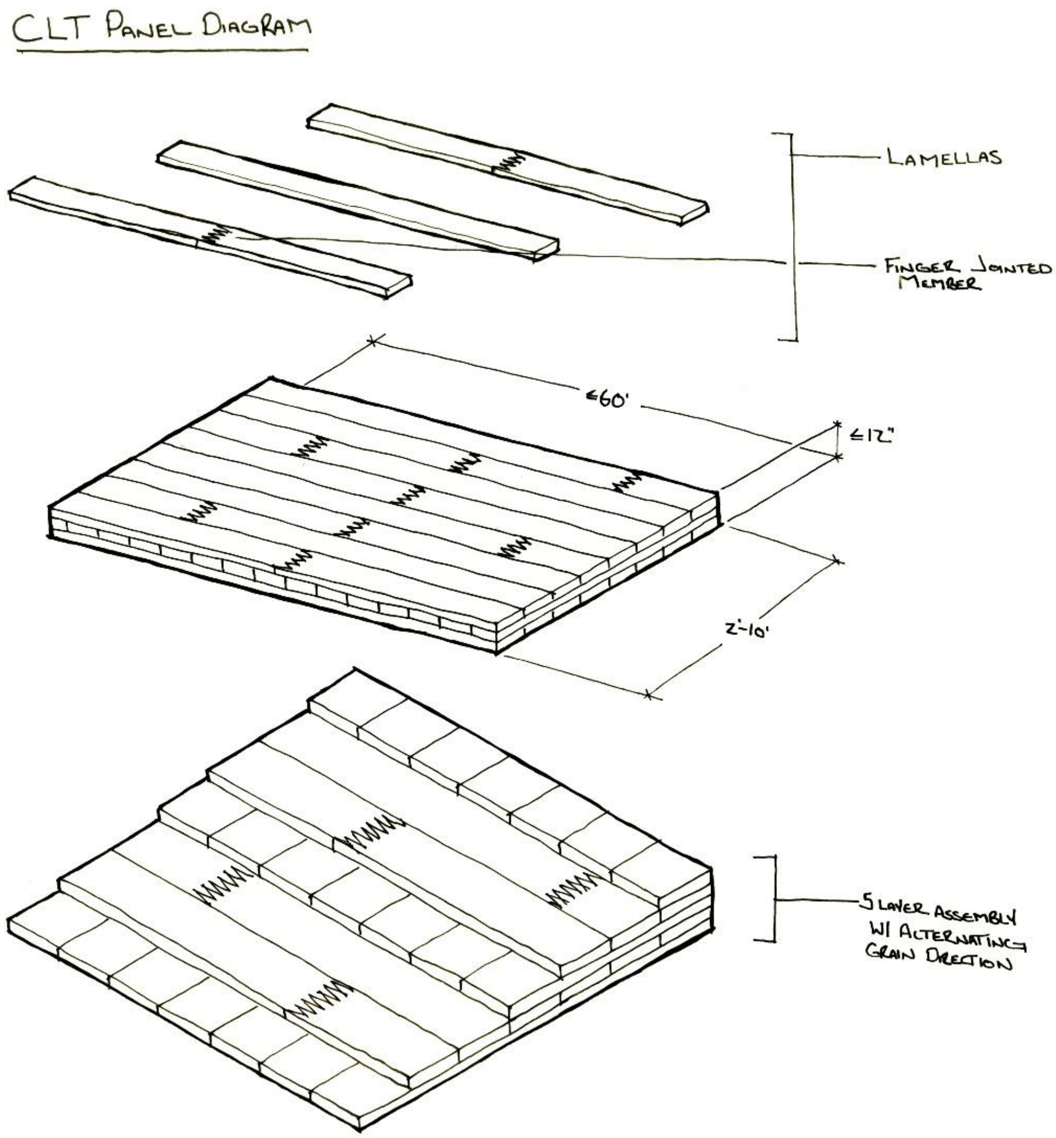

Fig. 4.1 – Construction diagram of a CLT panel.

4.1 - Overview

Cross laminated timber (CLT) is an engineered wood building product that has many similarities to glue laminated timber. CLT is an orthogonal laminated sheet product that is produced by layering panels of ½” -2” thick boards joined side by side. The layers are oriented in 90° alternating grain directions and uneven numbers of layers are used, typically 3,5, and 7

layers. A typical complete panel can measure nine feet by sixty feet and eight inches thick, seldom more than one foot thick.[42] In Europe, Norway spruce is most commonly used in CLT production. Hardwoods and other species, especially those sourced locally to production facilities, can be used for CLT as well. Performance of CLT panels of homogenous composition, a single of species throughout all layers and members, can be quickly calculated. The advantage of using cross laminated timber over other more traditional means includes the ability to fabricate large, full size building elements, walls, floors, and linear members, in one piece. Additionally, because of their structure CLT panels are able to bear loads both in and out of plane, as well as make many standard spans without reinforcing structure and make large spans with light reinforcing structure.[43]

Although it is not employed as often as traditional construction methods cross-laminated timber is experiencing growing popularity on a global scale. Part of this growth in popularity is due to the renaissance of timber construction in cities. Since the beginning of the twentieth century materials like brick, concrete, and steel have been favored because of their non-combustible nature. In the last decade timber has begun recapturing market shares of residential, office, and education buildings. This is in part due to efforts to promote more sustainable building practices that seek natural, local, low energy materials and techniques.[44]

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[42] R. Flatscher, G. Brandner, A. Ringhofer, G. Schickhofer, A. Thiel, "Cross Laminated Timber (CLT): Overview and Development," Eur. J. Wood Prod. Issue 74, No. 331, (2016): 334.

[43] Ibid., pg. 331

[44] Brandner, "Cross Laminated Timber," pg. 341

4.2 - Barriers

There are, however, several barriers that stand between cross-laminated timber construction and a level of industry acceptance that competes with mineral based materials. While mechanical properties of different wood species can be applied, one current barrier from widespread international use is lack of standardized computational models to enable fast, predictable analysis of local species and their structural qualities.[45] Additionally, as of 2015, there are no international standards that regulate product testing and design. While individual nations and organizations have developed standards of regulation and specification there are differences in performance and testing; especially in regards to fire performance, moisture and heat durability, and structural design properties.[46] Finally, a universal connection system that enables economic assembly and maintains the strength of the system through the joints and connections is yet to be developed.[47]

4.3 - Production

The idea for a laminated product in wood construction is not new, the core concept for the method is essentially that of plywood and core board. Cross-laminated timber shares the same in-plane dimensional stability as these products, but because of the scale of the product the in-plane thickness and strength allow it to serve as a stand-alone building element and structure.

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[45] Brandner, "Cross Laminated Timber," pg. 347

[46] "North American CLT vs. Imported Product: Stringent Standard Assures Consistent Value and Performance," *The Engineered Wood Association*, (July 2016): 3.

[47] R. Brandner, G. Flatscher, A. Ringhofer, G. Schickhofer, A. Thiel, "Cross Laminated Timber (CLT): Overview and Development," Eur. J. Wood Prod, Issue 74, No. 331,(2016): 347.

Development of CLT was motivated by the sawmill industry seeking a higher value use for side boards and undesirable lumber from milling operations. Industrial scale production in Europe has grown to be comparable to that of glulam.[48]

Production begins with preparation of base material, wood stock from a mill. Boards are first graded for strength then trimmed to lengths of usable boards and milled to square at desired board width and thickness. Once squared the lengths of board are finger jointed to produce what are referred to as 'lamellas.' These lamellas are then joined along their narrow face to form a single layer panel. Lamellas are joined in a flexible manner, often with a dowel type fastener; ring shank nails, hardwood screws, or dowels. These dowel connections enable the completed panel to be quasi-rigid. This quasi-rigidity allows some movement within the panel and can aide in preventing checks or structural imperfection. Once the lamellas have been mechanically joined into panels they are then laminated into multilayered panels. This wide face lamination is attached by means of an adhesive. Typically used adhesives include melamine-urea-formaldehyde, polyurethane, or polymer isocyanate. Application of adhesives is often carried out mechanically, many production lines include a through feed or line-wise application system. Once adhesive is properly applied a press type pressure device is used to secure the panels while the adhesive dries. Most often the pressure device is in the form of a hydraulic press, vacuum press, or screw type press. Once panels have been completed they are trimmed to final size. No finish is typically applied, however in some applications an additional layer of OSB, GWB, acoustic panel, or engineered wood product is applied. In many applications immediate cutting, joining, and labeling of panels is done in the factory, however, some customizing centers without

[48] Brandner, "Cross Laminated Timber," pg. 334

panel production facilities have been established. These customizing centers are often in cooperation with assembly and carpentry companies.[49]

Several variables can be used to affect the specific performance of a panel. First, wood can be selectively graded for it's panel application and location within the panel. When joining stock to create lamellas the orientation of the finger joints can be altered, orientation of finger joints is typically modified to hide the joint on a particular face. Lamellas can be panelized with no gaps or shown imperfection. This can be done to minimize air leakage [although air leakage of CLT assemblies is typically less than that of traditional building methods] or for appearance on outer layers. While lamellas can be bonded along their narrow faces there is limited additional mechanical strength gained, especially in the core layers, and this creates added stress from swelling and shrinking of the wood. Finally, layers of engineered products can be included in the lamination of the final panel. This can be to accommodate a finish on an exterior face or for structural reasons toward the core of the panel.[50]

4.4 - Characteristics

As mentioned previously the structural nature of cross-laminated timber allows it to be quickly implemented as full building components. For these same reasons cross-laminated timber allows a high degree of prefabrication. Panels themselves are entirely fabricated in a factory setting and the panelized nature of the product enables additional systems to be installed before delivery or separately assembled with a high degree of certainty.[51]

[49] Brandner, "Cross Laminated Timber," pg. 337
[50] Ibid., pg. 337
[51] Ibid., pg. 333

In terms of building performance cross-laminated timber acts as a more effective air barrier than traditional light weight wood framing construction. The mass of the wood assembly enables it to store thermal energy.[52] Other advantages of cross-laminated timber include cost competitiveness and efficiency because the engineered product can often use smaller dimension material than its counterparts.[53]

4.5 - Design

In terms of design potential and considerations the structural nature cross-laminated timber allows great opportunity. Positioning of doors, windows, and other openings can be done with flexibility because no additional structure or framing is required.[54]

The relatively light weight nature of cross-laminated timber, especially as compared to steel or mineral based systems, makes it ideal for low weight applications, like when building on soils with weak load bearing capacities or when building on existing structures. Additionally, because of the engineered assembly cross-laminated timber exhibits a high degree of dimensional stability in plane. Swelling and shrinking have to be considered in the thickness, out-of-plane direction, the change of dimension is comparable to that of solid timber.[55]

Acceptable span distances of cross-laminated are determined by the panel thickness. Panels 3", 6", 9", and 12" thick can have spans of 11', 15', 19', and 22' respectively. These spans equal or exceed spans of similar unsupported concrete slabs.[56]

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[52] Brandner, "Cross Laminated Timber," pg. 333
[53] Santi, "Massive Wood Material…", pg. 417
[54] Brandner, "Cross Laminated Timber," pg. 333
[55] Ibid., pg. 333
[56] "Cross Laminated Timber Design Guide," Structuralam, CrossLam Design Guide Imperial, Version 11: 3.

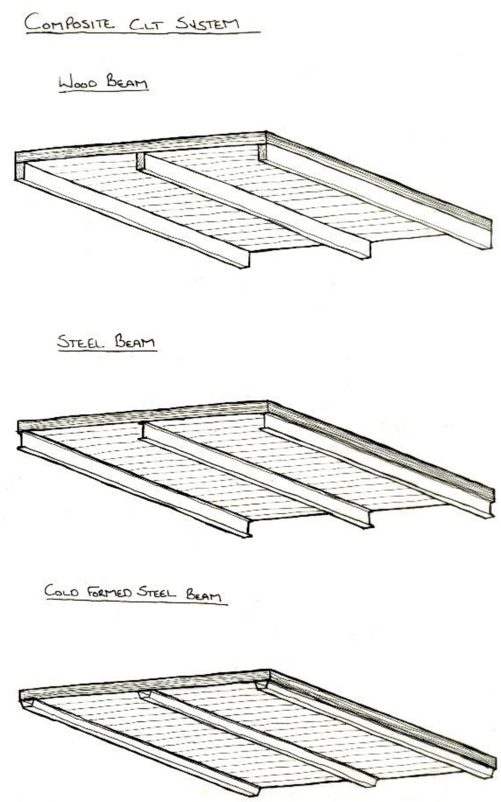

Fig. 4.2 – CLT panels reinforced with wood, steel, and cold formed steel beams.

Unsupported spans that exceed the acceptable distance for a particular CLT product can be realized through the implementation of a composite structural system. Additional beams can be arranged to carry excessive loads. Typically, additional support structure is of timber, engineered wood products, or steel members.[57] One experimentation combined CLT panels with cold-formed trapezoidal steel beams to create a composite system. The steel beams were attached to the panels through use of screw fasteners or inserts that were epoxied in place. The composite system was complementary to the light and modular properties of standardized CLT and allowed additional structural beams to be installed during panel fabrication rather than on site. The added strength from the steel inserts not only enables longer spans, but because of its light weight, it greatly increases seismic action of the panel.[58]

A critical consideration when designing with cross-laminated timber is panel joints and connections. Due to its stiffness and high bearing capacity the strength of a CLT assembly is largely dependent on the strength of the connections. This is especially true when considering horizontal actions from wind and earthquakes. In most current applications of CLT joints are

[57] Brandner, "Cross Laminated Timber," pg. 334

[58] Cristiano Loss, Buick Davidson, "Innovative Composite Steel-Timber Floors with Prefabricated Modular Components," *Engineering Structures*, Issue 132: 696.

handled through the use of self-tapping screws and metal connections, typically angle brackets and tie downs. The metal brackets are commonly applied in a punctuated pattern, rather than a continuous profile cut to length, and are fastened with nails or screws. The rigid nature of a CLT panel makes it imperative that all connections maintain an amount of ductility; connections that allow movement also allow dissipation of energy applied to the structural system.

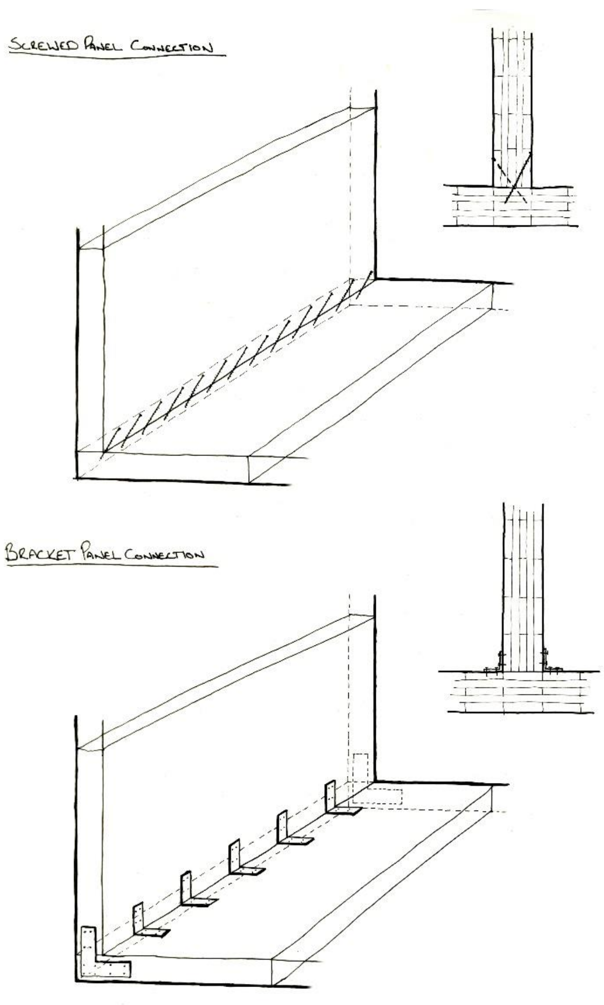

Fig. 4.3a,b – Typical attachment methods of CLT panel.

Experimentation has shown that in the application of a horizontally loaded wall system fastened with commonly used connections, the connections failed at just 16% of the bearing capacity of the CLT panel itself. While the reliable yielding of fasteners before the bearing capacity of the panel is reached is critical, this shows that there is an area of opportunity in the design and application of joints and connections. Additionally, a design for a connection system should consider the potential for systemized prefabrication and plug and play nature of CLT panels themselves and be flexible in application for several connection types.[59]

[59] Brandner, "Cross Laminated Timber," pg. 347

CHAPTER 5 - CONCLUSION

Through investigation of Romania's construction industry, the environmental nature of wood as a building material, and cross laminated timber as a building technique it is clear there is potential for responsible development with a focus on progressive building techniques in rural Romania; specifically, the commune of Pietroasa, Bihor County, Romania. Romania's construction sector is in a state of retooling; this includes equipment and facilities as well as retraining a workforce. This leaves the industry in a state of incubation where new innovative methods can be applied and workforces trained. In terms of the architectural program there is an opportunity, if not need, for a fabrication facility that focuses on innovative contemporary building methods. Additionally, to best serve Romania's workforce and economy this fabrication facility should have a focus on education and vocational training. Wood, which is well established, as a building material has been recently shown to be extremely environmentally friendly, if not carbon negative. This can be further improved upon by modifying the supply chain from raw timber to final product. Implementing a secondary fabrication facility for cross laminated timber near the site of final assembly would allow basic CLT panels to be fabricated near the site of timber harvesting, likely outside of Romania. The secondary fabrication facility, located centrally in the commune of Pietroasa, could receive the basic panels and process them for final assembly of a touristic lodge on the pristine mountainous site. The secondary processing could include cutting openings, prefabricating complete wall sections, prepping for attachment (possibly through innovative joint conditions), and applying protective and finish coatings. The COM-B method suggests in this instance the *opportunity* and *motivation* to implement an innovative and responsible technique are present. The *capability* to implement responsible techniques would be created through the development of the secondary processing

facility which should then lead the desired behavior; the creation of a responsible touristic lodge that embraces a pristine mountainous site and is constructed through implementation of an innovative building technique.

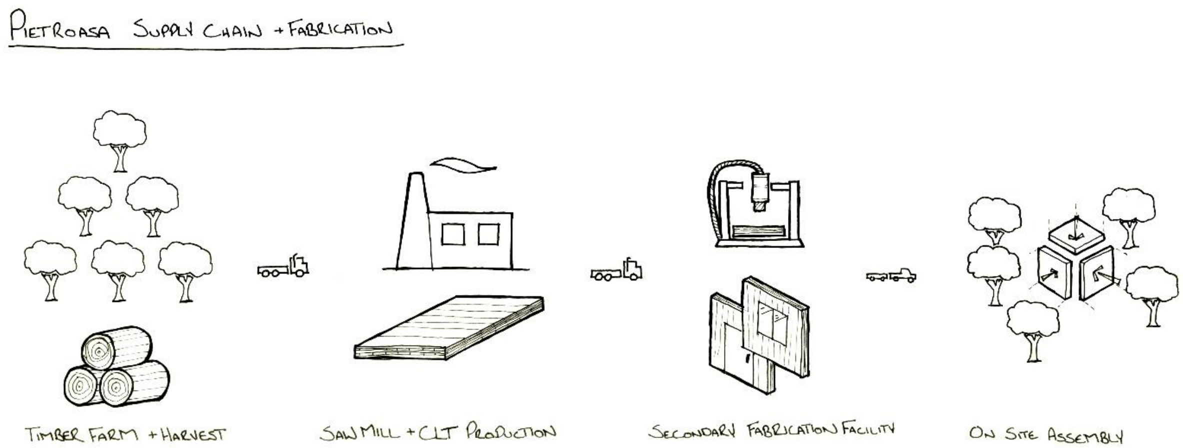

Fig. 5.1 – Supply chain of raw material, harvesting, primary manufacturing, secondary fabrication, and final assembly.

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