# 論文の内容の要旨

論文題目　The value of CLT: a multidimensional approach for building implementation inside Japanese context

（CLTの価値観　ー日本における建築物実現に関する多元的アプローチ）

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**Motivation:**

Timber construction technology has undergone substantial changes in the last two decades with the development of new materials and a better understanding of timber properties. One of the most symbolic products of this re-evaluation of timber construction is the material known as Cross Laminated Timber (CLT). In Japan, high domestic demand for construction requires an equally large supply of building products, of which timber products have a significant share. Hence, local CLT producers see the Japanese building industry as an opportunity for further market expansion. However, despite efforts by local authorities and non-governmental associations, only a modest expansion of domestic CLT could be seen after almost five years of commercialisation.

**Objective:**

This thesis investigated what improvements are necessary to forward Japanese CLT implementation process from the manufacturing and utilisation points of view. The proposed measures aim to improve value generation possibilities of CLT-based building systems inside the local context by using a multidimensional approach. The approach includes the simultaneous assessment of dimensions from technical, function economic and environmental aspects of construction. The final results of the thesis provide information to decision-makers, indicating primary issues to address through policies, product development, architectural design and education strategies.

**Method:**

The research scope was defined including the main stages of CLT production chain from the forest resources to the finished buildings to investigate Japanese CLT implementation process. The reason for defining a comprehensive scope lies in the concept most of "mass timber", frequently associate with CLT building elements and construction. In fact, mass timber panels category, in which CLT is included, are the only wood-based engineered products that can simultaneously constitute structural and enclosure systems, without the addition of other products. Hence, mass timber systems are characterised by the intense use of timber per area unit of construction. Owing to the timber intensive characteristic of mass timber systems and consequence and therefore higher burden for the supply of raw timber material, it requires an in-depth examination of the forest situation. Furthermore, timber intensive characteristic acts as a multiplier of the employed mass timber panels main features, meaning both of its strengths and weaknesses are magnified when utilised. Therefore, it is crucial to evaluate how different options and rates in which CLT panels could be utilised in construction impacts final value generation possibilities and threats.

After the research scope was defined, two primary production activities contained in it were identified, and an analytical model for the thesis was proposed. The model allocated four main fields of study, and two production activities (from cradle to factory gate and from factory gate to construction). At the top general inputs for timber construction were set (timber resources and buildings demand) and at the bottom, specific outputs for CLT (CLT manufacturing and CLT building) were placed. The general fields were briefly analysed by statical data, while the specific fields were analysed in depth by related literature, case studies, questionnaires and interviews. Next, general recommendations and an action plan were proposed and detailed based on the analysis of the main fields of the research scope, targeting to improve value generation possibilities for CLT-based building systems inside the local context within a maximum time range of 50 years, accounting for the average rotation time of Japanese planted forests. Finally, a series of lifecycle assessments evaluated the impacts of CLT panels and CLT-based building systems from a multidimensional view, considering different possibilities for value generation.

**Original findings:**

The leading valuation strategy for CLT panels and buildings is focused on stressing technical (statics) and environmental (climate change mitigation) subjects. That means CLT should provide optimal load bearing capacity, both in- and out-of-plane, combined with low environmental impact, thus being referred as a climate change mitigation option. To generate the technical value of CLT mentioned above it is crucial to have sufficient offer of quality timber supply. Furthermore, an abundant supply is required, due to timber intensive characteristics of CLT utilisation in mass timber systems. Likewise, the high timber mass of CLT-based building systems provides a high feedstock energy potential that if recovery at end-

of-life stage will generate a net carbon surplus, thus attenuating the environmental impacts of the construction.

However, at the time of this research, Japanese CLT is still not able to generate the same values. Firstly, the lower properties of the currently available Japanese Cedar supply limits the technical value of domestic CLT. To make matters worse, finite forest resources in Japan cannot guarantee the provision of quality material in the long range. Second, building industry, regulations and general public awareness about environmental issues are still in an initial stage of development in the country. Therefore, Japanese CLT cannot generate value from the environmental point of view either. Under these circumstances, the study concluded that to forward the implementation process of domestic CLT in Japan and improve its value generation possibilities three tasks need to be accomplished. 1) To reach a consensus and communicate the value generation possibilities of domestic CLT through the chain of production. 2) To develop social awareness about environmental issues and forward the idea of environmental impact evaluation into the building industry. 3) To promote the forestry sector to guarantee an abundant supply of quality material in the long range and increase the technical performance of domestic CLT panels and assemblies.

**Original contribution:**

The study contributed to the field of CLT construction in three ways. 1) It proposed an original method to evaluate the chain of production of Japanese CLT from the forest to the finished building, based on the TFV theory of production. The proposed method could be used in Japan or different locations at any stage of CLT implementation, aiming to maximise its value generation possibilities. 2) It demonstrated the potential of combining various dimensions from different subjects to comprehend and facilitate the development of measures that can be beneficial considering the whole chain of production of CLT. Additionally, it also provided a way to increase the political relevance of lifecycle-based environmental impact studies. 3) It proposed and detailed an action plan that, if followed by the leading actors from CLT chain of production, would be able to revert the threats and weaknesses found throughout the research, within a time range of 50 years.

**Future of CLT and mass timber systems:**

By using an LCA methodology, the study could verify the significance of the energy recovery strategy for CLT mass timber systems to achieve a positive environmental evaluation. Nevertheless, the assumption of energy recovery of CLT elements during the end-of-life stage of construction is strictly theoretical. Owing to the recent history of CLT, real case studies which can prove the feasibility of the energy recovery of panels and studies demonstrating the net negative carbon balance are still lacking. Additionally, environmental benefits of timber utilisation such as energy recovery and carbon fixation are assumed based on the conditions of a growing forest stock or equilibrium between timber resources consumption and regeneration.

Therefore, based on the information analysed throughout this research, Japan presents an adverse context for the environmental performance of CLT, due to the short lifespan of constructions, smaller than the rotation time of Japanese forests, worsened by lack of a growing young forests stock.

Based on the findings of this study, the author believes that the understanding of timber products for mass timber construction such as CLT has to change from the idea of a "building material" to the idea of an "asset" for companies and society as a whole. In other words, the idea of impermanence, usually associated with wood could evolve into the idea of permanence for mass timber elements. This new approach determines that once a high-embodied energy CLT panel is produced, its service time is extended as long as possible. To accomplish that goal, optimised solid timber building systems, designed prioritising the reuse, recycling and finally recovery would allow to cascade CLT panels, while generations of forests are grown and used as necessary. Ultimately, the concept of CLT panels as an asset would lead to an improved lifecycle model and a new business opportunity. That is, in a scenario which emphasises the re-utilisation features and extended service time for mass timber building elements, CLT manufacturers could lease their products or solutions, instead of selling the product to the clients. Especially, the continuous reuse of the limited Japanese forest resources would be an efficient and sustainable method to allow for the revitalisation of domestic forestry and timber industry, assuming an increase in the demand in the next decades. Furthermore, customers would not need to worry about the construction and demolishing processes, as even considering the culture of a short average lifespan of residential constructions in Japan, buildings could be disassembled by the manufacturers and the elements reused for other buildings. Although it may sound extreme for the timber products industry, the concept is employed for steel frame disaster relieve constructions. A domestic developed building system application designed for reuse could even employ the stronger and more affordable imported raw-timber or CLT panel as its extended lifespan and cascading effect would be able to offset the initial emissions from transportation and manufacturing.

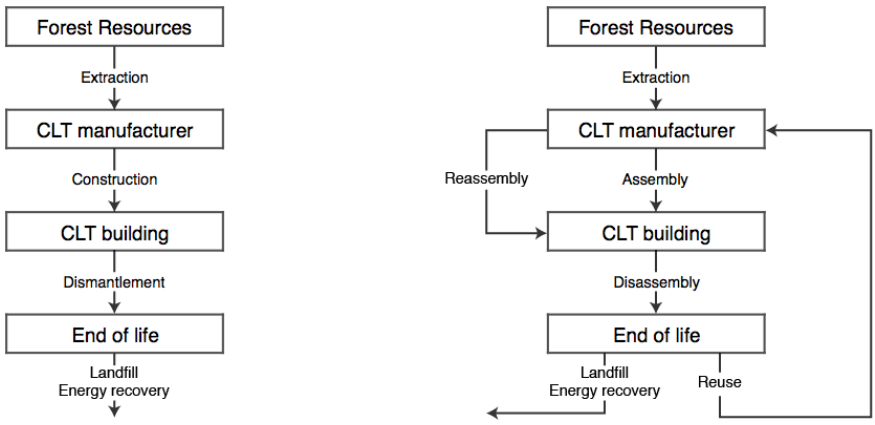


*Figure. Present (left) and foreseen (right) lifecycle model for CLT buildings.*