Aesthetic Qualities of Cross Laminated Timber

Aesthetic Qualities of Cross Laminated Timber

PhD Thesis by

Anne Kirkegaard Bejder

Department of Civil Engineering,
The Faculty of Engineering and Science,
Aalborg University, Aalborg, Denmark

River Publishers
Aalborg

ISBN 978-87-92982-23-0 (e-book)

Published, sold and distributed by:
River Publishers
P.O. Box 1657
Algade 42
9000 Aalborg
Denmark

Tel.: +45369953197
www.riverpublishers.com

Primary supervisor:
Poul Henning Kirkegaard
Deparment of Civil Engineering
Faculty of Engineering and Science
Aalborg University

Secondary supervisor:
Anna Marie Fisker
Deparment of Civil Engineering
Faculty of Engineering and Science
Aalborg University

Financed by: Skagen Nordstrand K/S, Danish Agency for Science, Technology and Innovation, Aalborg University.

SUMMARY

The common thread through this thesis is the aim of bringing the aesthetic, poetic and sensuous qualities of materials into focus. This is done with the belief that materials are more than merely the means of construction, i.e. more than a building system. The thesis takes its point of departure in the great importance wood has had as a building material throughout history as a naturally occurring, strong, light and workable construction material with various multi-sensuous qualities and great applicability.

Over the last two decades, wood as a building material has gained renewed focus, partly due to its sustainable profile. In parallel to this, new production methods and further refined timber products have been developed. Among these are the engineered timber-based product Cross Laminated Timber (CLT) that show enhanced structural properties compared to unrefined timber. However, the question is what happens to the aesthetic qualities of wood as a building material in this process? What does it mean to the experience and perception of CLT that it is processed to products whose properties differ significantly from those of wood in its raw form?

Based on the hypothesis that CLT possesses an undefined aesthetic potential that may innovate how we construct and perceive timber architecture, the overall aim of the thesis is to inquire into the architectural and aesthetic qualities of CLT.

Through three chapters this thesis examines and discusses 1) the architectural qualities of CLT, 2) the materiality of CLT, and 3) how one can deal with these qualitative aspects in the design process. This leads to: firstly, the development of an explicit model to help structuring the analysis and evaluation of the *materiality of CLT*, and secondly, a clarification and articulation of the aesthetic qualities essential for how CLT is applied and perceived within an architectural context.

Based on the research conducted through this thesis, it is the author's belief that it is possible to go beyond the utilisation of CLT as a mere technical product or a simple building system. By engaging into the deeper layers of the material, and by clarifying and articulating its qualities that are related to how it is *perceived*, it is possible to achieve a pragmatic yet poetic and sensuous future timber architecture.

Keywords: *Cross-Laminated Timber, materiality, technology, materials, timber architecture.*

This PhD project is a co-financed project between the Danish Agency for Science, Technology and Innovation, Skagen Nordstrand K/S, and Aalborg University.

RESUMÉ

Den røde tråd gennem denne afhandling er målet om at bringe materialets æstetiske, poetiske og sanselige kvaliteter i fokus. Dette ud fra den tro, at materialer er mere en blot et middel at bygge med - mere end blot et byggesystem. Denne afhandling tager sit udgangspunkt i den betydning træ har haft som byggemateriale op igennem tiden, som et naturlig forekommende, stærkt, let og bearbejdeligt byggemateriale med adskillige multi-sanselige kvaliteter og mange anvendelsesmuligheder.

Gennem de seneste to årtier har der været en fornyet interesse omkring træ som byggemateriale, dels på grund af træs bæredygtige profil. Parallelt med denne fornyede interesse er der blevet udviklet nye produktionsmetoder og yderligere forfinede træprodukter. Blandt disse er det 'designede' træ-baseret produkt Krydslimet Massivtræ (KMT), der viser forøgede strukturelle egenskaber i forhold til ubearbejdet træ. Men spørgsmålet er, hvad der sker med de æstetiske kvaliteter ved træ som byggemateriale i denne proces? Hvad betyder det for oplevelsen af KMT, at det er forarbejdet til produkter, hvis egenskaber afviger væsentligt fra dem af træ i sin rå form?

Ud fra hypotesen at KMT besidder et udefineret æstetisk potentiale, der kan være med til at forny den måde vi bygger med og oplever træ arkitektur, er det overordnede mål for denne afhandling at undersøge KMT's arkitektoniske og æstetiske kvaliteter.

Gennem tre kapitler undersøges og diskuteres 1) KMT's arkitektoniske kvaliteter, 2) KMT's materialitet, og 3) hvordan man håndterer disse kvalitative aspekter i designprocessen.

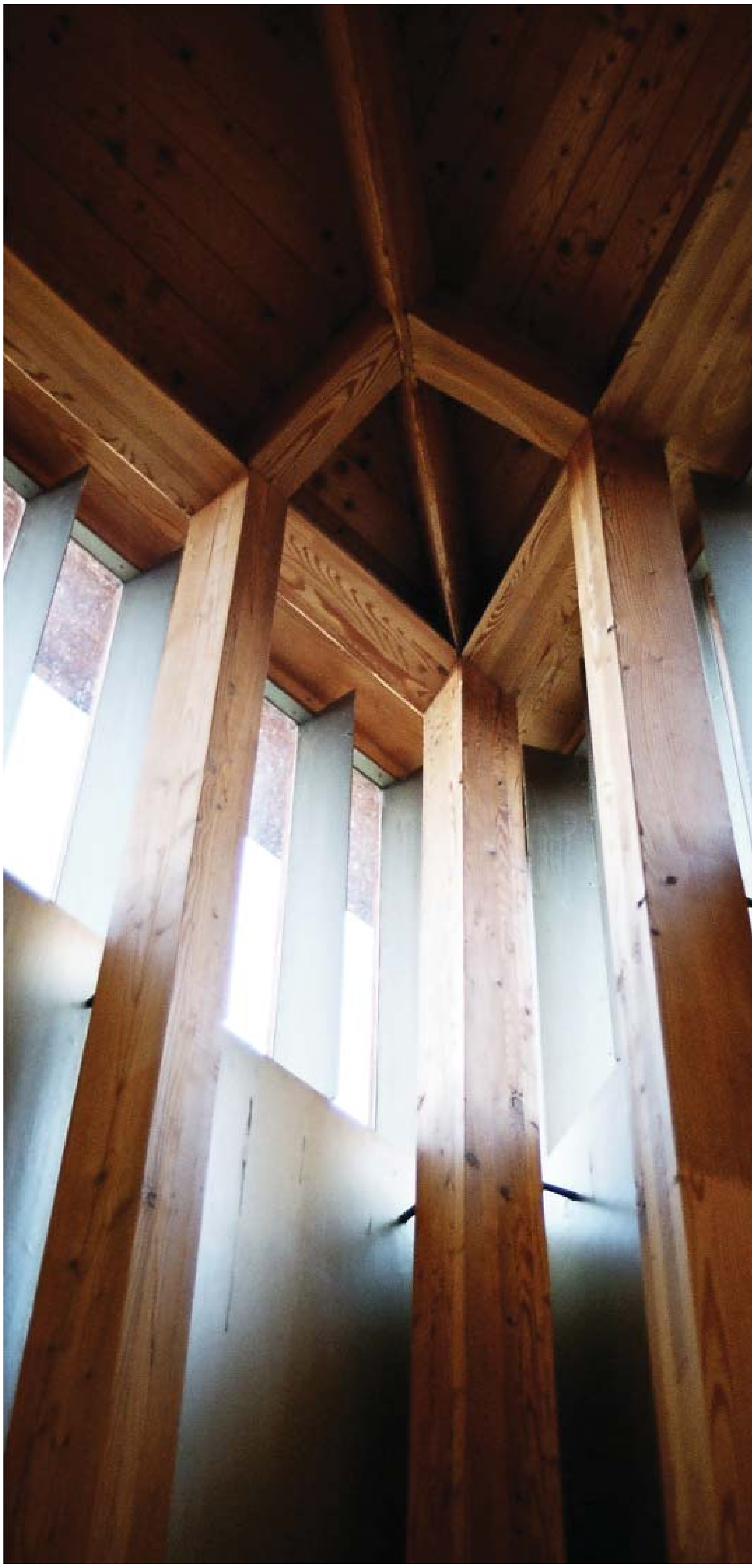
Dette fører frem til: For det første, udviklingen af en eksplicit model som kan hjælpe med til at strukturere en analyse og evaluering af KMT's materialitet, og for det andet, en klarlæggelse og italesættelse af de æstetiske kvaliteter som er essentielle for, hvordan KMT anvendes og opleves i en arkitektonisk kontekst.

Ud fra den forskning der er udført gennem denne afhandling, er det forfatterens overbevisning, at det er muligt at nå ud over anvendelsen af KMT som et rent teknisk produkt eller et enkelt byggesystem. Ved at dyrke de dybere lag af materialet og ved at klarlægge og italesætte de kvaliteter der er relateret til, hvorledes materialet opleves, er det muligt at opnå en pragmatisk og samtidig poetisk og sanselig fremtidig træ arkitektur.

Nøgleord: *Krydslimet Massivtræ, materialitet, teknologi, materiale, træ arkitektur.*

Dette PhD projekt er financieret af tre parter: Styrelsen for forskning og innovation, Skagen Nordstrand K/S og Aalborg Universitet.

1



1
A warm and evocative atmosphere in the small chapel in Sumvitg, CH, 1988, by Peter Zumthor. (Photo: Ida Wraber)

2
In Esherick House, 1959-61, Louis I. Kahn (1901-1979) creates a sparkling atmosphere with contrast between the warm-coloured apitong wood and large window panes. The modularity and linearity of the boards bring a human scale to the space and give the room direction (Dezeen 2011).

3
The tactile surface of wood (Pallasmaa 1987).

4
A material in constant change. Facade detail, chapel in Sumvitg, CH. 1988, by Peter Zumthor. (Photo: Ida Wraber)

5
Wood's ability to be adapted to its context. Summer house Kisteglad, Hellersøya, NO. 1965 by Wenche Selmer (Tostrup 2006).

6
The uniqueness of each piece of wood. Jointing detail in Esherick House by L. Kahn (Mattarnold 2011).

2

3

4

5

6

1 INTRODUCTION

It is the most humanly intimate of all materials. Man loves his association with it, likes to feel it under his hand, sympathetic to his touch and to his eye. Wood is universally beautiful to Man.

With these words the American architect Frank Lloyd Wright (1867-1959) suggests that there exists a unique relation between man and the material wood (Wright 1975). But what is it about wood that is so exceptional? Why wood?

Touching a piece of wood one feels its growth rings and knots as well as its warm and living surface. The surface may be sanded to a level and smooth surface, or it may stand coarse and rough with marks left by the tool [ill. 3 & 6]. Wood occurs in a variety of different sorts, each having specific qualities and characteristics. Thus, according to its structure and proportion of pigments, oils, resins, etc., it will fell, look and smell differently. Its colours can vary from deep-black shades to red, yellow and white and depending on sort, age, and treatments, its colours and structures can appear indistinct and faded or living and glowing [ill. 3-6]. With its origin in a living organism, wood as a building material has a unique relation to man. We find this in its scale and modularity – which exemplify to us the natural limitations of the material [ill. 2], and in its 'fingerprint' i.e. the grain pattern which illustrates the uniqueness of each piece of wood [ill. 3 & 6]. Likewise, this intimate relation to man manifests itself in its unique adaptability to be adjusted and shaped – to fit the hand, the body or the landscape [ill. 5]. Over time, its colours will change when exposed to weather and wind [ill. 4], and the shape it is given will transform in the case of extensive use. Likewise, cracks will occur, it will begin to give, squeak and creak.

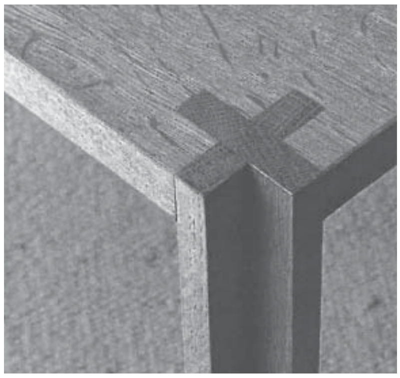
Hence, wood is a material in constant change. It is a living material that through its multi-sensuous characteristics within scent, sound, tactility and appearance, induces experiences which trigger all senses. With the small chapel in Sumvitg, Switzerland, Zumthor manages to embody these poetic qualities of wood perfectly. Through a composition of surfaces, structures, colours and light, Zumthor effectively utilises timber to create a beautiful and evocative atmosphere [ill. 1].

Besides being a sensuous material, wood is in many ways a 'straightforward' material, meaning that it is relatively easy to shape, it can be applied for multiple purposes, and in all scales. Hence, we find its qualities utilised in all kind of projects ranging from primitive implements, art and utility items, to furniture, housing, ship building and bridges. Likewise, used as a building material this variability in application is conspicuous.

Roland Schweitzer expresses it in this way:

When used as a building material, wood could respond to all requirements, seemingly as a matter of course. No other material could be employed in such diverse ways.
(Schweitzer 2004)

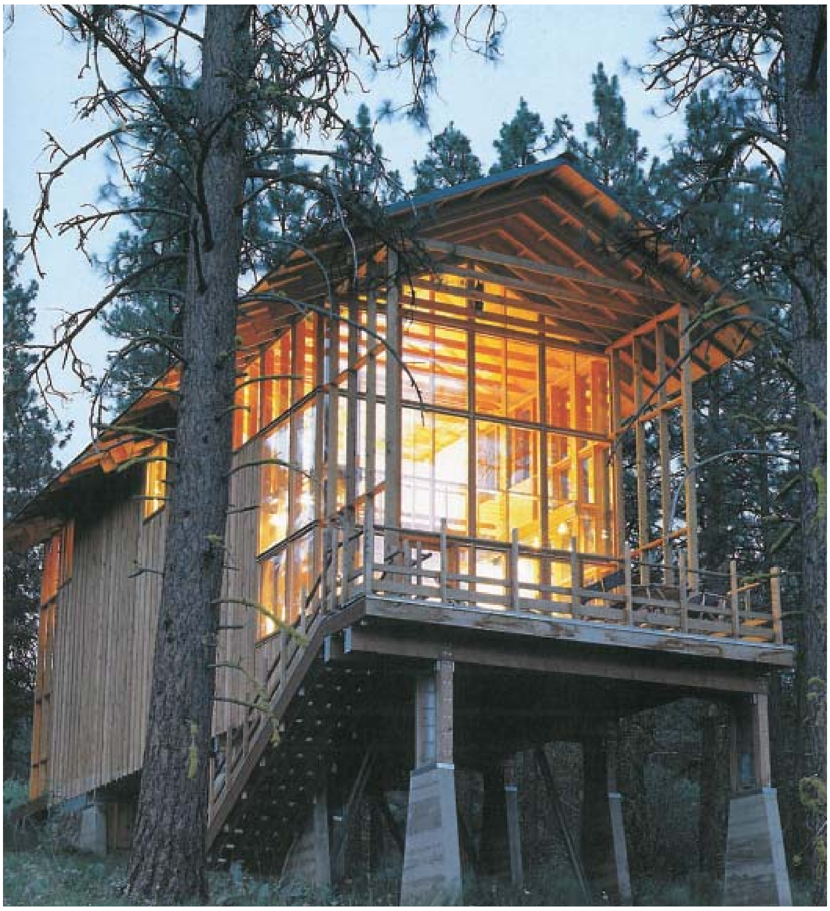
Looking at the multiplicity in the use of wood in timber architecture by Alvar Aalto, Frank Lloyd Wright, Louis Kahn, Tadao Ando, Sverre Fehn, Kengo Kuma, Peter Zumthor, Renzo Piano, Wenche Selmer, Richard Leplastrier, Thomas Herzog, and Hermann Kaufmann, among many others, this is clearly evident. With its original linear shape, wood is by nature a structure – a *skeleton* to support. But put together, long pieces of wood become more than a structure: they become the protecting layer – the *skin* of the building [ill. 7]. Hence, depending on the wood species and the context climate, wood can be applied for all elements of the building project – bearing structure, interior and exterior cladding, roof, floor, and ceiling. Elegant examples of such houses made of wood through and through can be found in the works of the Norwegian architect Wenche Selmer and the Danish architect Hanne Kjærholm [ill. 10-12].



8

9

7



7
'Pine Forest Cabin', exemplify wood as a structure as well as a skin. USA, 1999, by Cutler Anderson Architects. (Carta, Ferrua 2005)

8
The delicate detailing of the meeting between table top and leg. (Blaser 1992)

9
The characteristic ornamentation of a house in Tomsk. (Blaser 1994)

The variability within application and expression is to a great extent the result of the high workability of wood: the easiness by which one can work it from raw material to countless shapes and purposes. Wood's workability may manifest itself in very different ways, e.g. from the complex filigree decorations of the housing in Tomsk, to the precise and delicate jointing in Werner Blaser's furniture [ill. 9 & 8]. In Tomsk, the ornamentation lies in the shapes the timber is given, thus the quality of wood that is expressed here is in fact its workability i.e. its ability to be shaped [ill. 9]. By comparison, Blaser seems to focus on the inherent ornamentation of wood. Here, the ornamentation lies in the grain pattern and colour variations, as well as in the tectonic meeting between table top and leg – the meeting of two materials [ill. 8].

There are 30.000 known wood species, of which 1500 to 3000 are used for commercial or engineering purposes worldwide and about 500 of these are traded on international markets (Herzog 2004). This alone illustrates the huge diversity and potential of timber. Put together with its multi-sensuous qualities, great applicability and workability illustrated above, as well as its qualities within strength and rigidity, and its sustainable profile (Falk 2010), timber manifests itself as an exceptional material of endless possibilities.

The timber projects and qualities of wood, which are referred to above, are all manifestations of the *inherent* properties and limitations of wood. But what happens when timber takes new forms and appearances or putting it differently, when these well-known properties changes? Since the beginning of the industrialisation of the wood industry, there has been an explosive development within technology and timber products. Many of the novel 'engineered' timber products are invented to compensate for some of the material's natural faults and limitations (Bell et al. 2006, p. 108). Hence, in combination with other materials and by means of high-developed technology, wood has gained improved capacity in regards to strength, fire- and sound protection, etc. But what does it mean to the *experience* and *perception* of the material – as a creator of space, as a structure, and as a surface – that it is processed to products whose properties might differ significantly from those of the material in its raw form?

10-12
For this house on the small island Læsø in Denmark, Kjærholm utilises the great applicability of wood. Here, wood constitute the bearing structure, exterior and interior sheathing, and roofing. By using different formats, paint in colourful contrasts, and creating patterns in the sheathing, Kjærholm manages to create a varied yet balanced and coherent mode of expression. (Hvass 2007)

10

11

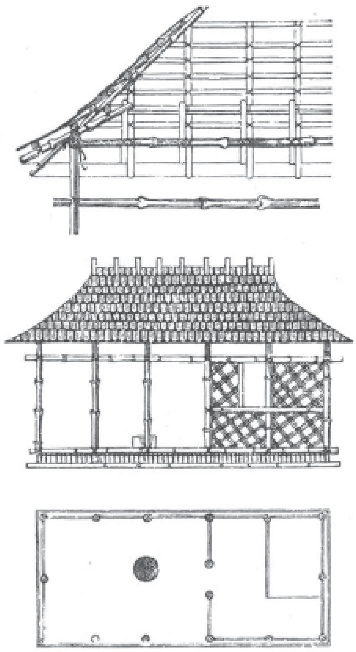
12

With these matters forming the overall theme of the thesis, the following sections provide an introductory overview of how timber architecture has developed from past to present day.

1.1 TIMBER ARCHITECTURE THROUGH TIME

Wood is one of the oldest materials used for construction. Long before architecture became something more than merely building, wood has been one of the primary sources for providing shelter. In all probability, simple post-and-beam constructions have been among the earliest building methods. In its simplest form, bare hands are all that is needed for creating a shelter (Affentranger 2005), as also illustrated by the French architect and theorist Viollet-le-Duc's (1814-79) idea of the 'first building' [ill. 14] (Weston 2003). Other suggestions on the origin of building also point to a wooden skeleton as the primary construction. An example is the one proposed by the Roman architect and theorist Marcus Vitruvius Pollio (approx. 75 – 15 BC) already in the first century BC [ill. 15], and the 'Caribbean Hut' which led the German architect and architectural theorist Gottfried Semper (1803-79) to define his 'four motives of building', of which roofing/carpentry constitute the one [ill. 13] (Semper 2004). Traces of timber structures go back as far as to the Palaeolithic period (between 450.000 and 380.000 BC), found at Terra Amata in France (Slavid 2006, p. 6), and several examples of timber houses, that can be dated back to the Neolithic period, have been found worldwide, e.g. China, Central- and Northern Europe (Pryce 2005, Slavid 2006, Liu 2011).

Historically, the variety in application and expression of wood can be exemplified by the architectural breadth between the traditional Chinese heavy and richly ornamented roof resting on a simple and open column structure [ill. 16], the light and elegant Japanese house [ill. 17], the massive log cabin found at timber-rich regions like e.g. Canada, Norway, Sweden, Austria, Switzerland and parts of Russia [ill. 18], and the visually lighter half-timbering found in most parts of Europe, including Denmark, Britain, France and Germany [ill. 19]. In their application of timber, these examples reflect different approaches to construction materials and architecture in general; from the pragmatic to the symbolic motivated. A similar duality can be found in mankind's relationship to forests and trees. According to Ritter and Dauksta, the forest and trees have played an essential role in the development of civilisation; on a practical level as being an important natural resource for agricultural tools, for the construction of ships, buildings, etc., and on an emotional level by 'challenging our understanding of the place of humans in nature' (Ritter et al. 2011).
From the sixteenth century, an increase of the population in cities caused the need for larger buildings to satisfy new functions, in particular related to transport and industry. Concurrently, the continuous growth of cities led to several destructive fires – the Great Fire in London in 1666 being



13

14

15

among the most extensive – which resulted in strict restrictions upon timber constructions (Pryce 2005, p. 268). Thus, the search for new materials that could enable larger constructions and that were less combustible began. Until the beginning of the nineteenth century, wood was still the most applied building material in Central, Eastern, and Northern Europe, North America, South-East Asia and Japan (Pryce 2005, pp. 18-19). However, with the Industrial Revolution (18th and 19th centuries), the development of materials like cast iron, steel, and concrete opened up for new ways of building. And with the early twentieth century European Modern Movement, which standard-bearer counts architects like Gropius, Mies van der Rohe, and Le Corbusier, materials like glass, steel, and concrete were hailed as the materials of the time and came to mark most twentieth century architecture (Pryce 2005, Slavid 2006).

13
The Caribbean hut from the island of Trinidad was for Semper the confirmation of his four-motive thesis (Semper 2004).

14
Viollet-le-Duc's visualisation of a primitive hut made of saplings (Weston 2003).

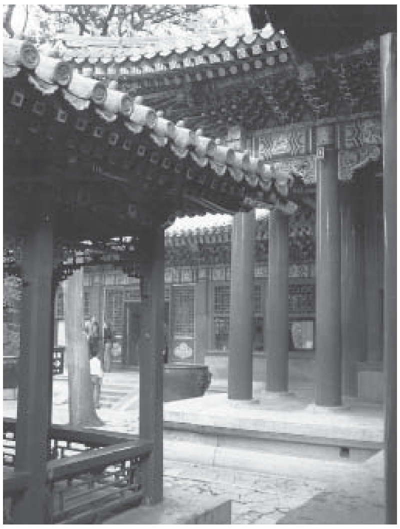
15
According to Vitruvius the first shelters was made of forked posts with 'woven' walls between (Weston 2003).

16
Imperial palace, formerly Forbidden City, China (Herzog 2004).

17
Katsura palace, Japan (Herzog 2004).

18
Log cabin (Blaser 1985).

19
Half-timbering (Blaser 1985).


16


17

18


19


20

21

Nevertheless, despite being in the shadow of heavy materials, timber architecture continued to develop, although outside the gaze of the architectural press (Pryce 2006). Particularly, it has been applied for cheap housing, temporary buildings like barracks and emergency housing, summer houses, vernacular building, footbridges, etc. (Storvang 2000). Though, as mentioned on page 14, also internationally acclaimed architects continued to utilise wood. Among others, Frank Lloyd Wright and Alvar Aalto applied wood as a part of their Modern mode of expression, although mainly for 'sensitive architectural details' [ill. 20-21] (Pryce 2005, Slavid 2006). Moreover, timber remained one of the most favoured construction materials of house-builders as well as within prefabricated buildings, on economic grounds and due to its strength-to-weight ratio (Pryce 2005, Bell et al. 2006). Hence, from the mid nineteenth century onwards, timber constructions developed into lightweight frame constructions like balloon- and platform framing and to different panel constructions of which a still increasing part of the production takes place in protected environments at the factory. Early examples of these prefabricated houses are Walter Gropius and Konrad Wachsmann's *General-Panel-System* from the early 1940s, and Jørn Utzon's *Espansiva* from the late 1960s, while examples of contemporary prefabricated timber houses counts *System3*, 2008, by Oskar Leo Kaufmann and Albert Rüf, and *Plus House*, 2007, by Claesson Koivisto Rune architects, among many others. Thus, through time timber architecture has changed from being based on craftsmanship to the industrialised building components of today.

As timber architecture mainly developed within these areas, today, timber is often associated with either temporary and less durable buildings, cheap prefab buildings, romantic/nostalgic buildings based on craftsmanship, or simply as sensitive facing. Either way, it does not seem to do timber and its architectural potential full justice. In order to gain better insight into the potential of timber in architecture, the following section provides a more thorough review of constructional and formal developments within timber architecture.

20
Villa Mairea (1937-39) (Slavid 2006).

21
With the oversized wooden beams at Tallisin West (1937) Wright seems to be focused on emphasizing the poetic qualities of wood rather than giving a realistic demonstration of wood's physical capabilities. (Photo: Author)

1.1.1 Developments in timber architecture – material, construction and form

Traditional timber architecture often manifests itself as a unique symbiosis of material, construction and form, as also expressed by Mies van der Rohe:

Where does the structure of a house or building appear with greater clarity than in the wooden buildings of the ancients, where do we see more plainly the unity of material, construction and form? Here the wisdom of whole generations lies hidden. What a sense of material and what expressive power speaks from these buildings. What warmth they radiate and how beautiful they are! They sound like old songs.
(Blaser 1985, p. 9)

However, does this 'transparency' only applies for these 'ancient wooden buildings' or does it characterise timber architecture in general, through time and developments? With a point of departure in this threefold relation, the following provides a short overview of developments within timber architecture. Divided into three main groups – log construction, post-and-beam construction and panel construction – the relation between material properties, construction principle and its appurtenant architectural characteristics is described.

Log construction

The log construction [ill. 24] represents one of the oldest methods of constructing wooden houses. Large wooden logs are stacked to form the walls which give the log house its characteristic heavy and horizontal expression. The building envelope consists of this single layer of stacked logs, which constitutes the cladding, load-bearing and space-enclosing functions simultaneously (Deplazes 2005). Hence, in the log construction, the surface is a part of the construction – structure and surface merge. Despite the log's filigree nature, the log construction has – with its massive body – many similarities with the *solid construction*, which the Swiss architect Andrea Deplazes describes as a solid and homogeneous body made from (vertical) walls that form the directly enclosed interior space with a distinct separation between interior and exterior (Deplazes 2005). The log itself can either have the round shape of a peeled log or be edge sawn for a more solid and precise stacking connection (Bell et al. 2006).

Seen from an ecological perspective, a downside of this type of construction is the fact that it requires large logs of high quality wood. For that reason, the log house is most often to be found at timber-rich regions like e.g. Canada, Norway, Sweden, Austria, Switzerland and parts of Russia. Besides, as the log is loaded perpendicular to the grain, the entire structure is affected by variations in moisture content, leading to swelling and shrinkage. Consequently, settlement movements is an important factor in the detailing, e.g. at openings (Deplazes 2005).

The most distinguishing detail of the log house is its corner joints, where the horizontal logs interlock with a cradle-, dovetail-, or cross-lap joint [ill. 22-23] (Bell et al. 2006, Pryce 2005). Together with the friction resistance in the bed joints, by which the wall acts like a plate, the cogged

22
Detail corner joint. (Photo: Ida Wraber).

23
Detail corner joint. (Photo:Author).

24
Log construction (Deplazes 2005).

25
A traditional Swedish log house (Photo: Ida Wraber).

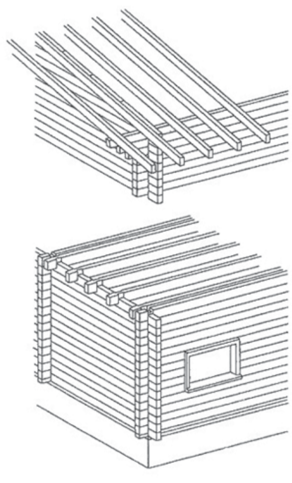
26
In Peter Zumthor's modern interpretation of the log house, Zumthor extends the ends of the corner joints to form outdoor spaces as an integrated part of the building. Haus Luzi, Switzerland (2002) (Heikkinen, Zumthor 2007)

27
Also inside Haus Luzi the characteristic lap-joints of the log construction form an expressive detailing. Heikkinen, Zumthor 2007)

22

23

24



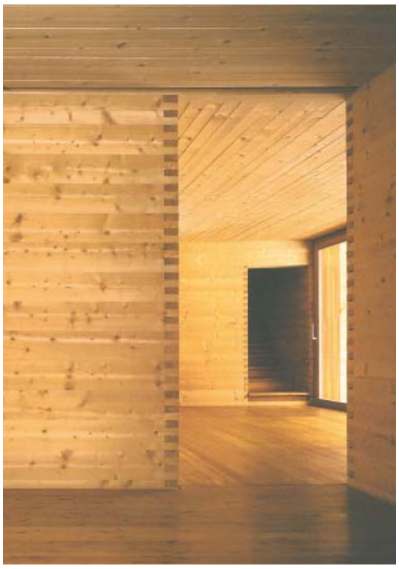
joints at the corners provide a stable structure (Deplazes 2005). The shape of the log and the design of the corner joint vary significantly according to building traditions as well as tools and technology available. The latter is evident comparing the traditional rustic log cabin with Peter Zumthor's refined version of the modern log house [ill. 25-27].

With its simple, multi-functional building envelope and the exposed lap-joints, the log construction expresses a constructional logic and transparency in the relation between material properties, construction principle and architectural expression.

25

26

27



Post-and-beam construction

In this case, the post-and-beam construction refers to several construction principles which basically have that in common, that the load-bearing structure is as a skeleton composed of vertical and horizontal members (post-and-beam, also known as post-and-lintel). Hence, the examples referred to here range from the historic post-and-beam structures of heavy solid members [ill. 30], to half-timbering constructions with panels filled with e.g. wattle and daub or brick [ill. 28, 32, 33], and the modern frame constructions with its continuous columns and primary and secondary beams at same level [ill. 29, 34, 35]. Depending on the construction principle, the structure is braced by diagonal struts of either heavy timber or light steel, wall plates or solid cores that extend through all storeys (Deplazes 2005). A range of materials can constitute the infilling, depending on material available, traditions, climate, and various demands for the building envelope. These construction principles also exemplify the development in jointing techniques over time. From the traditional wood joints locked with wooden pegs [ill. 32] or mortise and tenon joints [ill. 30], to the modern jointing of posts and beams using mechanical fasteners like gusset plates and bolts, etc. [ill. 34].

These construction principles have in common that they belong to the archetypical form of *filigree construction*. The filigree construction is a lattice made from (horizontal and vertical) linear members. The lattice is an open framework reduced to the essentials and infill panels to close the structure partially. With structure as its primacy, the lattice does not directly define an interior space. Likewise, the transition between interior and exterior is floating (Deplazes 2005), of course depending on the transparency of the infilling. All three construction principles express a constructional logic with their exposed posts and beams. Besides providing the bearing structure, these also constitute the characteristic rhythmic expression; the structure *is* the expression – the ornamentation – of the building [ill. 31]. Hence, also within these construction principles, the relation between material, construction and form is clearly expressed.

28
Half-timbering (also called Timber-frame construction). (Deplazes 2005)

29
Frame construction (Deplazes 2005).

30
Post-and-beam construction joined with mortise and tenon joint. (Photo: Ida Wraber)

31
In Jørn Utzon's prefabricated building Espansiva (1969) the columns and beams constitute the atmosphere of the room with their constructional logic and by creating a clear rhythm through the house. (Espansiva-Byg A/S 1971)

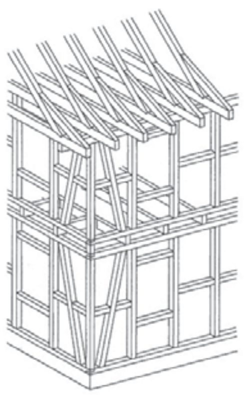
32
Detail half-timbering construction joined with wooden pegs. (Photo: Author)

33
Half-timbering construction with infilling of brick. (Photo: Author)

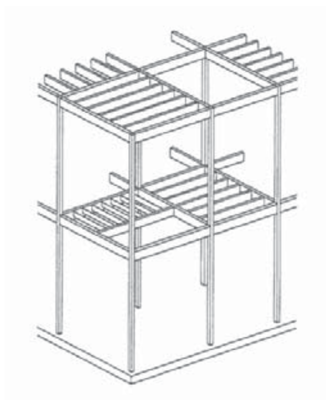
34
Detail frame construction joined with mechanical fasteners.

35
Solid yet slender glue-laminated columns and beams constitute the frame construction of the school Klaus-Weiler, Fraxen, Austria (2003) by Dietrich & Untertrifaller. (Photo: Author)

28



29




30


31


32


33

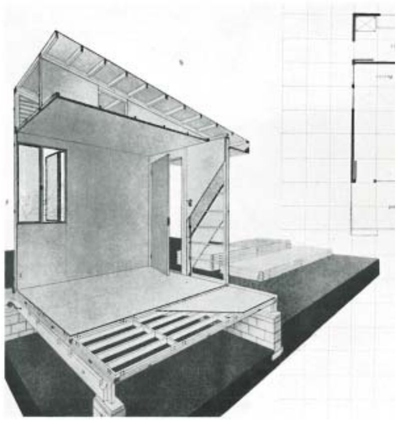
34

35

Panel construction

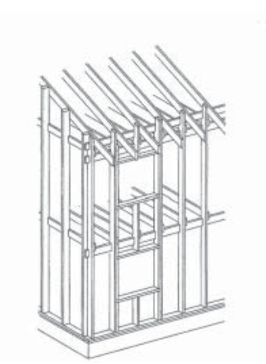
In the 1830s Chicago, George Washington Snow was the man behind a further development of the post-and-beam method; the so-called balloon frame construction (Bell et al. 2006, Affentranger 2005). Whether this construction principle belongs to the post-and-beam construction or the panel constructions is debatable. However, as it has several architectural characteristics in common with the panel constructions and moreover forms the basis for the further development of the platform frame construction – which in principle leads to the first panel construction – the balloon frame construction is placed within this group. One of the most decisive innovations generated by this construction principle is the use of lighter prefabricated, standardised timber components. Usually, the structure is based on the 5 x 10 cm (2 x 4 inches) studs placed with a distance of approx. 40 cm (16 inch) (Slavid 2006). The studs are jointed with nails and stability is achieved by stiffening wooden sheathing such as plywood. The studs for the balloon frame construction run from sill to roof with intermediate floor structures nailed to them [ill. 36]. The building is constructed horizontally on the floor as whole wall panels; including the openings, and then erected wall by wall (Bell at al. 2006, Affentranger 2005).

The further development – the platform frame construction – is based on the same principles as the balloon framing, but is built one story at a time [ill. 37]. Each story is constructed horizontally, erected and then closed by a horizontal division after which the process is repeated. Based on the mill cutting wood in standard dimension and the factory produced nails, these construction principles require less skilled labour compared to traditional timber constructions. Still today, the platform frame construction is the most applied construction method within housing in the USA (Deplazes 2005, Bell et al. 2006, Slavid 2006). An increasing part of this process happens in a protected environment on a factory and is transported to the site. In that way, the time for construction work on site can be reduced, and the building is less dependent on the weather conditions. These large building 'components' are made on a factory as plane elements (2D) [ill. 39 & 40] or as entire box elements (3D) [ill. 41-42]. The stage of completion can vary from raw elements to ready-

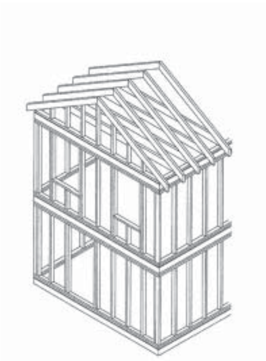


39

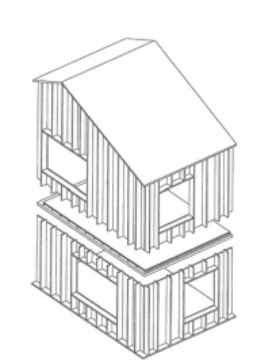
36



37



38



36
Balloon -frame construction (Deplazes 2005).

37
Platform-frame construction (Deplazes 2005).

38
Panel construction (Deplazes 2005).

39
Wachsmann and Gropius' 'General Panel System' (1941) was a panel construction fully adapted with insulation, windows, mechanical installation, etc. The system provided a prefabricated building component which could be erected fast on site. (Wachsmann 1959)

40
Constructing a panel construction on factory in Denmark. (Photo: Author)

41
Prefabricated box elements are lifted into place and assembled on site. (KLH 2011)

42
Especially the box elements sometimes result in a 'locked' architectural mode of expression since this system usually offers a very controlled variation, as here at Impulszentrum in Graz, AT (2004) by Hubert Riess, where the module of the box is easy recognizable in the final design. (Photo: Author)

43-44
Haus W, Salzburg, AT (2001) by Ebner-Grömer architects, is characterized by its simple form with a double-pitched roof, all covered by a continuous wrapping skin. This feature is even emphasized with the large windows that flush with the façade and in the detailing, e.g. the precise transition between roof and façade which appear as a fold rather than an actual joint. The windows follow no construction-given system. (Photo: Author)

made elements including insulation, windows, wiring, and exterior or interior finish material. On site, the elements are merely erected and clad if necessary (Bell et al. 2006, Deplazes 2005). Through the second half of the twentieth century, a wide range of industrially produced timber products have been developed, among these are ribbed panel structures, or cross-laminated solid wood panels and composite wood panels [ill. 38] (Musso 2005, Affentranger 2005). Here, the load-bearing element is no longer the linear member but a slab. Besides, these construction principles offer several enhanced technical properties and nearly unlimited freedom in placement of openings (Musso 2005, Deplazes 2005).


40

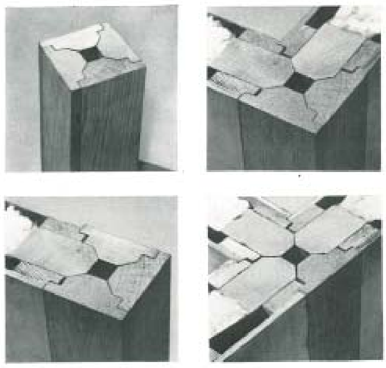

41


42

43

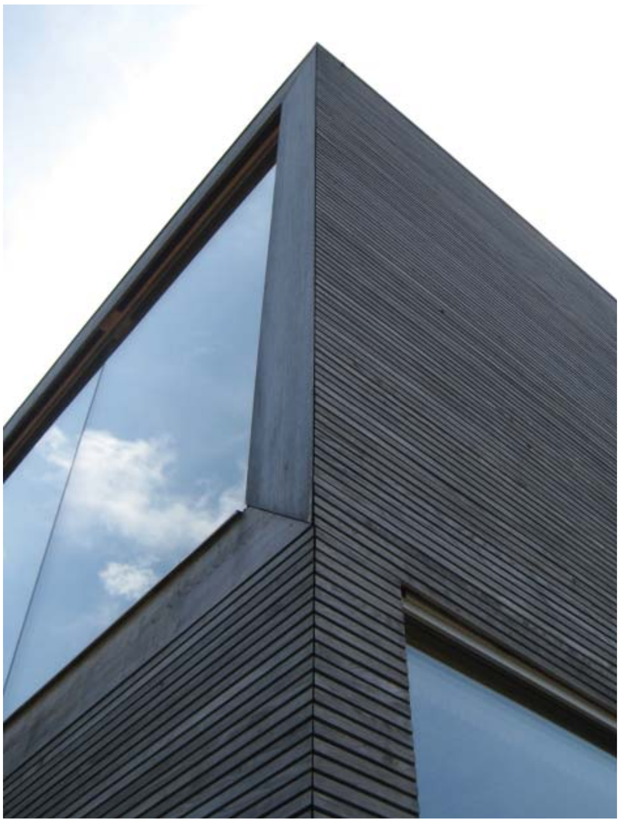

44


These construction principles have in common that the bearing structure – the skeleton – disappears into the layered building envelope. Timber in its 'natural' form – the stick-shape given by the linear tree trunk – is concealed behind stiffening plates (plywood, plasterboard, etc.) and claddings of various materials (wooden boards, -plates, -shingles, fibre-cement boards, metal plates, etc.). The constructional logic characterising the log- and post-and-beam constructions is not present within these 'panel constructions' where the bearing skeleton and the enclosing skin split into independent functions. The inherent rhythm and system provided by the skeleton in the post-and-beam constructions is replaced by flexibility in window placement, as well as by an architectural expression characterised by the contrast between the visually massive wall and the transparent openings [ill. 43-44]. The tectonics of these constructions are based on the principle of stacking storeys one upon the other, by which the architectural detailing is defined by the jointing of plane- or box elements [ill. 41-42] (Deplazes 2005, Bejder 2006). Gropius and Wachsmann's development of a universal method for joining a given number of wall elements – a part of their *General-Panel-System* – is an early evidence on this [ill. 45]. The split between the bearing structure and the surface entails huge freedom in the design of the enclosing skin which precisely characterise much of modern timber architecture [ill. 46-47].



45

46



47

45
Wachsmann developed an X-shaped wedge connector to link the panels together. (Wachsmann 1959)

46
Exterior of the preschool in Langenegg, Austria (2004) by Fink &Thurnher Architekten. (Photo: Author)

47
Interior of the preschool in Langenegg, Austria (2004) by Fink &Thurnher Architekten. (Photo: Author)

From 'skeleton rationale' to 'wall rationale'

This overview of the development within timber architecture shows that over time, different types of construction have been developed and hereby, the mode of expression in timber architecture has changed as well. Timber architecture ranges from structures characterised by constructional logic and with a clear relation between material properties, construction principle, and formal expression, to 'structure-less' constructions, whose functional components disappear in the envelope of the wall construction. Florian Musso expresses this as a change from a 'skeleton rationale' to a 'wall rationale' (Musso 2005). These developments within timber architecture have been initiated by various factors – cultural, political, environmental, contextual, etc. However, one factor seems particularly decisive, and that is the continuous development within tool and technologies, which have influenced the timber products (from heavy logs to dimensional lumber and plates) as well as the binding material (from wooden pegs to nails and glue). This impact of technology on timber products is further elaborated in the following.

1.1.2 Timber and technology

The German architect Konrad Wachsmann (1901-1980) introduces his book 'Building the wooden house' with the words:

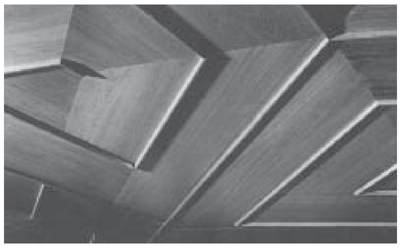
Today, the wooden house is produced by machines in factories, not by the craftsman in his shop. A traditional, highly-developed craft has evolved into a modern machine technology; new applications and new forms are being developed.
(Wachsmann 1930/1995)

His statement substantiates the above described relation between developments in tool and technologies and developments in timber architecture. As tools for processing timber have led to firstly, a refinement of the one-dimensional trunk to become the log, the board, and the batten, and later on to the development of two-dimensional surfaces and elements, such as veneers, plywood, particle boards, and recently, massive timber elements (Falk 2011), so has timber architecture developed as well.

In the hands of gifted architects and engineers, this development and refinement of timber products has led to innovation within applications, form and material expressions in timber architecture. An architect to be mentioned in this context is Frank Lloyd Wright (1867-1959), who saw the machine as a means of reaching a new architecture of simplicity, clean lines and surfaces (Patterson 1994). By utilising the characteristic long

48

49



50

slender and flat format of prefab standard boards and battens, Wright enhances horizontality in broad fascias and facades [ill. 48]. Likewise, he utilises the modularity and linearity of the boards to form a shift in direction in the ceiling and hereby define different zones in the living room, as seen in e.g. Jacob's house (1937). Besides, by combining slender battens with sheets of veneer, Wright transforms the flat surfaces to plastic configurations [ill. 49-50] (Patterson 1994).

Another significant example is Erik Gunnar Asplund's (1885-1940) interior in Woodland Crematorium (1935-40) where Asplund creates 'a room in the room' with a large continuous skin of plywood, and furthermore, utilises the possibility of shaping plywood to let the wall and bench melt together and form an organic unity [ill. 53]. In this way, plywood as a material and the ability to shape it, offers Asplund a 'way of giving new life to traditional forms and uses' (Weston 2004). Likewise, Alvar Aalto (1898-1976) makes use of new technologies to explore new forms and expressions in wood. Through experiments with lamination and bending techniques, Aalto manages to create strong yet visually light and elegant furniture of curved sheets of plywood and bended laminated elements [ill. 51-52]. Hence, these projects exemplify how properties given by the applied technology – through formats, surface characteristics, and possibilities within shaping, etc. – become generators of new forms, new applications and new expressions in timber design. The examples also demonstrate a paradox, which Weston describes as follows:

The invitation to sit on Asplund's bench is directs and sensuous, and made all the more appealing by the ease with which plywood appears able to assume such a shape. The actual effort of forming it in this way is considerable, but the result seems entirely 'natural', both to the intended use and to a material made of thin laminations.
(Weston 2003, p. 140)

48
Wright used long flat boards to underline horizontality in the fascias of the Suntop Homes (Patterson 1994).

49
Plywood panels expressed in linear format with horizontal battens (Patterson 1994).

50
Plastic configuration of battens and veneer. (Patterson 1994)

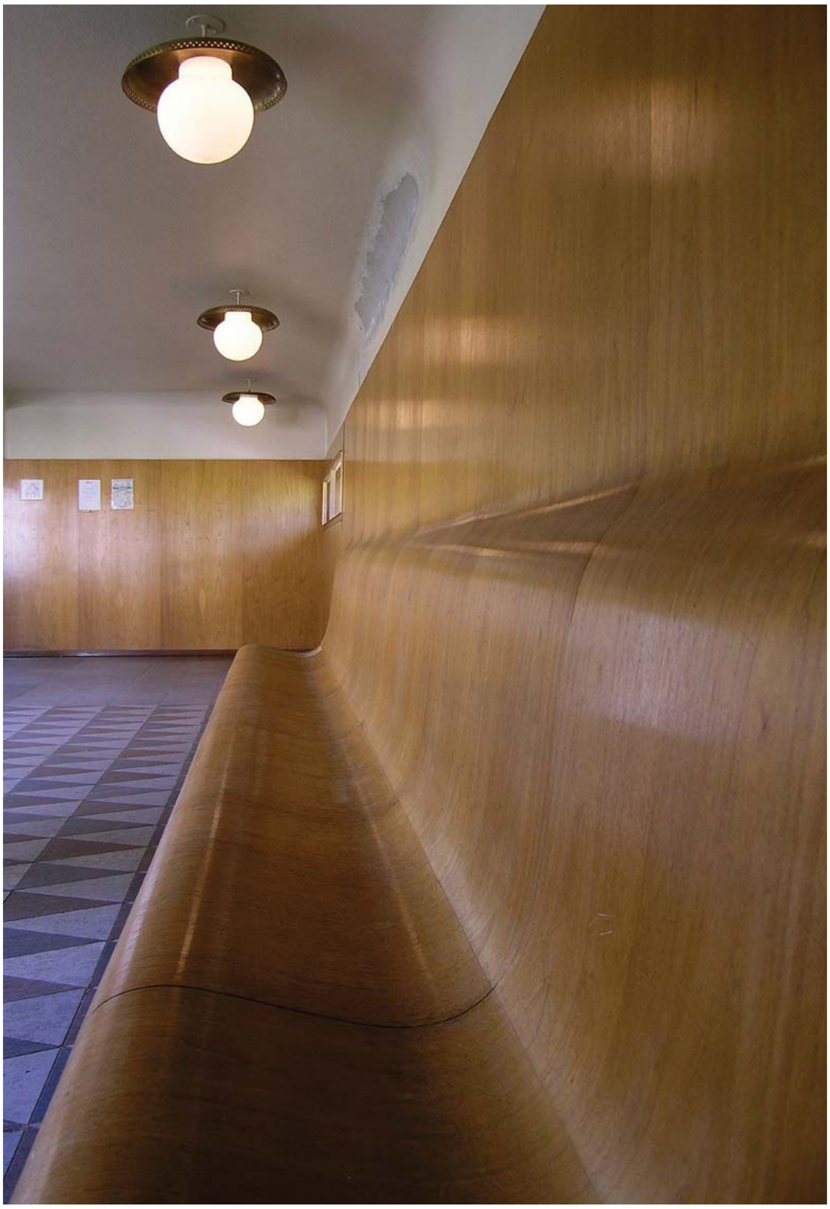
51-52
Chairs of curved sheets of plywood by Aalvar Aalto. (Pallasmaa, Sato 2007)

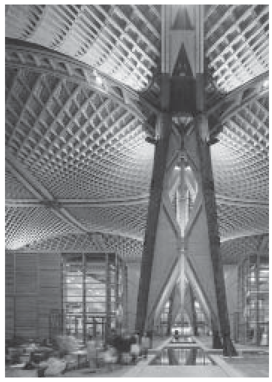
53
Interior in curved plywood, Woodland Crematorium (1935-40), Stockholm, by Gunnar Asplund (seier+seier 2011).


51


52

53





54

Thus, the type and degree of technology used during production and processing of timber is not only essential to how we *technically* can build, but it also has great significance for the *perception* of the product. With developments of products such as glued laminated timber, Orientated Strand Boards (OSB), particle boards, fibre boards and plywood, and due to developments within composite materials, such as wood-plastic compound materials, injection moulding techniques, etc., it is now possible to form amorphous and 'impossible' forms (Schittich 2005, p. 27). The form may be perceived as simple but the means to reach the product may be quite complex [ill. 54].

This also demonstrates to us, that *constructing* timber architecture is more than the mere act of jointing pieces together. The theorists and architects Karl Bötticher (1806-1889), Gottfried Semper (1803-1879), and Marco Frascari (b. 1945), describe 'construction' as consisting of two aspects – Bötticher by introducing *Kerneform* (core-form) and *Kunstform* (art-form), which provide the inspiration for Semper's distinction between the *technical* and *symbolic* aspects of construction, and Frascari draws a line between the actual *construction* and the mental *construing* (Frampton 1995, Frascari 1984). This duality seems indeed to be present when it comes to timber architecture, as it has been illustrated through this introductory section. Timber construction is the ancient primitive building, it is the constructional logic of the log house and the post-and-beam structure, it is the skeleton and the skin of the panel element. But timber construction is more than that. It is the evocative atmosphere of Zumthor's small chapel, and as Mies van der Rohe expressed it, timber architecture 'speaks expressive power', 'radiates warmth', and 'sounds like old songs'.

Through this first section (1.1) it has been illustrated briefly how wood has been applied and has developed throughout history and up until today. The following section takes its point of departure in an renewed interest in wood as a building material.

54
With development in tools and technology the appearance of timber architecture has changes as well. E.g. from the roughly shaped traditional Swedish log house (photp: Ia Wraber) to refined filigree structure of the Expo canopy, DE (2000) by Herzog + Partner (Slavid 2005).

55
Net carbon emissions in producing various materials (Falk 2010).

56
Example of the growth of forest in Sweden (Massivträ håndbogen 2002).

1.2 THE REVIVAL OF TIMBER ARCHITECTURE

Where section 1.1 has provided a brief overview of the history of timber architecture, this section focuses on timber architecture of today, which is characterised by a renewed interest in wood as a building material, legislative changes, and technological developments.

1.2.1 A renewed interest in wood as building material

Over the last two decades, the interest in wood as a building material has increased significantly (Affentranger 2002, Steurer 2006, Tykkä 2010). This tendency is seen in countries with great traditions of timber constructions like Austria, Finland, Norway, Sweden, and Germany (Jensen 2007, Tykkä et al. 2010, Gold, Rubik 2008) but also in countries like Denmark, where architectural traditions are mainly based on heavy materials like bricks and concrete (Affentranger 1997, Lind 1998, Storvang 2000). The reasons for this renewed interest in wood as a building material are many:

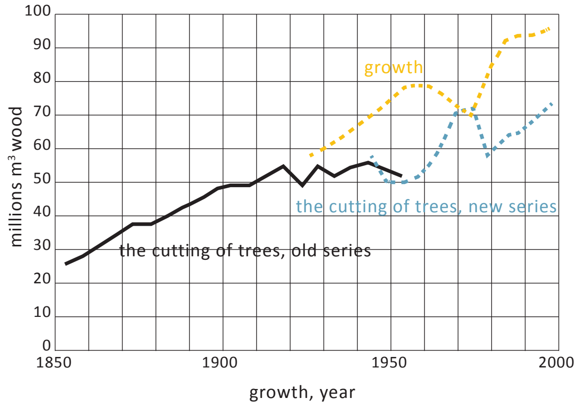
- Overproduction in the European forests [ill. 56] (Affentranger 2002),
- The interest of the wood industry to regain market share after losing out to the concrete industry in the post-war era (Affentranger 1997),
- Wood's favourable environmental profile compared to materials like brick, concrete and steel [ill. 55] (Falk 2010, Werner, Richter 2007),
- A romantic conception based on a 'longing for nature' (Affentranger 1997),
- A trend towards a bigger awareness to the products one interact with in everyday life, etc.

55

Net carbon emissions in producing a tonne of various materials

Material	Net carbon emissions (kg C/t)	Near-term net carbon emissions including carbon storage within material (kg C/t)
Framing lumber	33	-457
Medium-density fiberboard	60	-382
Brick	88	88
Concrete	265	265
Steel (virgin)	694	694

56



Hence, the increased interest in wood as a building material seems to be motivated by several factors – technological, political, economical, environmental, and emotional. Places like Vorarlberg in Austria, and the areas around Chur and Lausanne in Switzerland, exemplify this revival of timber architecture through several fine and innovative projects by architects like Peter Zumthor, Herzog & de Meuron, Burkhalter & Sumi, Baumschlager & Eberle, Herman Kaufmann, Oskar Leo Kaufmann & Albert Rüf, Cukrowicz-nachbaur architects, Fink-Thurnher architects, etc. [ill. 57-60] Likewise, this increased interest manifest itself in the research activity taking place at e.g. Institute for Timber Engineering and Wood Technology, Graz University of Technology, Austria; IBOIS – the laboratory for timber construction of the École Polytechnique Fédérale de Lausanne, Switzerland; and Lueleå University of Technology, Sweden.

58

Moreover, new solutions for dealing with issues related to sound transmission and fire in timber buildings have been developed, which means that these no longer constitute the same barrier for building with wood. The most crucial initiative promoting timber architecture is the change in building regulations regarding fire i.e. shifting from material-based to function-based requirements (Roos et al. 2010). Hence, from 1997 it has been allowed to build up to four stories residential and commercial buildings in Finland and timber has been allowed as a structural element for buildings taller than two stories in Sweden and Denmark since 1995 and 1999, respectively, (Tykka et al. 2010, Roos et al. 2010). Besides, several other initiatives have been taken to encourage timber architecture. Examples of these are listed in the following.

59

57

60

57
Interior Hittisau firestation and culture house (2000) by Cukrowicz-nachbaur architects. (Photo: Author)

58
Preschool in Vorarlberg, AT. (Photo: Author)

59
Interior of the school Klaus-Weiler, Fraxen, Austria (2003) by Dietrich & Untertrifaller. (Photo: Author)

60
Exterior of the school Klaus-Weiler, Fraxen, Austria (2003) by Dietrich & Untertrifaller. (Photo: Author)

1.2.2 Initiatives encouraging timber architecture.

Programs to promote wood-based construction have been introduced in several European countries over the last decades (Tykkä et al. 2010). Examples of initiatives in particularly the Nordic countries are listed here:

- The Nordic Wood programme (1993-2001) has been initiated by the Nordic innovation centre with the aim of developing timber architecture focusing on multi-storey houses with bearing constructions in wood. The project mainly focuses on technical aspects of multi-storey timber buildings such as acoustics, fire, durability (Dragheim, Kreiner 1999; Thelandersson 1997).

- Another project focusing on dense wooden buildings is the Finnish 'Modern Wooden Town'. The timber construction concept developed within this initiative has become widely applied since the late 1990's (Tykkä et al. 2010).

- Norwegian Wood is a Norwegian project (2004-2008) with the aim of further developing timber architecture by testing new ideas through practical building projects. In 2006, leading engineers and architects within timber architecture was gathered in order to establish and realize sustainable urban timber construction projects[1] (Norwegian Wood (1) 2011, Tykkä et al. 2010).

- The Swedish project Trästad 2012 ('wood city 1012') is a cooperative project between 16 municipalities, a number of county administrative boards and the Swedish Träbyggnadskansli. The projects focus on sustainable urban development, among others through wood based construction (Trästad2012 2011).

- Another Nordic project is the Nordiske Træbyer ('Nordic wood cities'), initiated around 2004. The common agenda has been to enhance the use of wood in constructions. The seven cities taking part in the project are Vejle and Skagen (DK), Växjö (Sweden), Trondheim (Norway), Karleby and Oilo (Finland), and Egilsstadir (Iceland).

- Furthermore, several homepages focus specifically on timber construction with guidance and information about producers of timber products, as well as qualities and issues of technical and architectural character (Trefokus 2011; PUUinfo 2011; proHolz 2011; Træinfo 2011; Arkitrae 2011).

---

1 For an overview of the projects see: http://www.arkitektur.no/?nid=6319 (Norwegian Wood (2) 2011).

-	Likewise, the large number of awards that has been given to particularly remarkable timber architecture, bear witness to the significance timber architecture is assigned today. Among these are: The Wood Awards (GB), Deutscher Holzbaupreis (DE), Spirit of Nature Wood Architecture Award [ill. 61-63] (FI), Træprisen (DK), Träpriset (SE), and several regional wood awards in Austria (AT) including e.g. Vorarlberger Holzbaupreis, Steirischen Holzbaupreis, Holzbaupreis Hessen, Oberösterreichischer-, and Der Niederösterreichische Holzbaupreis.

61-63
The Austrian architect Hermann Kaufmann received the 'Spirit of Nature Wood Architecture Award' in 2010. An example of his work with and appreciation of wood is the community centre of Ludesch which is characterized by many fine details. (Photo: Author)

Nevertheless, despite the generally increased interest, legislative changes, and numerous initiatives promoting timber constructions, timber still accounts for a limited part of the market share for construction. In Germany, timber accounts for only 14% within the segment of detached and semi-detached houses in Germany, and similar situations are seen in other European countries (Gold, Rubik 2008, Tykkä et al. 2010). Thus, if the opportunities are present – structurally and legally – is it then a question about demand? Do people actually want to live, work, and basically be in timber buildings?

61

62

63

1.2.3 Attitudes towards timber architecture

According to a survey regarding consumer's attitude towards timber as a construction material[2], the most decisive criteria for choosing a particular building construction are cozy living, comfort and health issues like allergy prevention and air quality (Gold, Rubik 2008). These are the same qualities that the interviewees positively associate with timber construction, thus indicating that people actually have a very positive attitude to timber as a construction material. However, the second most important criteria when choosing a building construction are factors such as quality and value stability, fire protection, environmental issues, easy maintenance, low costs, and aesthetics. The survey shows, that people have doubts about the very aspects such as stability, modernity, longevity, and price of timber as a construction material (Gold, Rubik 2008).

Another study focuses on architects' and structural engineers' perception of timber constructions[3] (Roos et al. 2010). Advantages of timber mentioned here include its aesthetic qualities, pleasant indoor climate and atmosphere, as well as its strength-to-weight ratio, energy efficiency, and environmental requirements. Drawbacks of timber that are mentioned here, include poor form-stability and movement related to changes in moist content, while the expected sound transmission properties are cited as the most serious disadvantage of timber buildings. The fire related properties of timber is seen by some as shortcomings of wood, while others regard these as advantageous by noting that massive timber structures show a predictable reaction to fire such that total collapse is less likely than it is for e.g. steel (Roos et al. 2010, p. 875). All together, these studies describe a seemingly positive attitude to timber constructions, especially in regard to indoor climate, aesthetics, and the more intangible qualities as 'cozyness' and atmosphere. However, the studies also show a great skepticism and prejudice when it comes to the technical capacity of timber, e.g. related to moist, fire, sound, and durability. This prejudice may very well be one of the major reasons why timber still plays a modest role in the building sector, when comparing it to the predominant construction materials brick and concrete.

The engineered timber product Cross laminated timber (CLT), which was shortly mentioned within panel constructions, has shown improved technical qualities, e.g. regarding sound transmission, fire, structural capacity (Schickhofer et al. 2006). Thus, it could be interesting to have a closer look at the potentials of this novel timber product.

---

2 This survey regarding consumer attitude towards timber as a construction material is conducted in 2008 by Stefan Gold and Frieder Rubik. The study is based on a quantitatively evaluated telephone survey, performed in 2006, with a sample of 1004 persons, representative of the German population over 18 years of age (Gold, Rubik 2008).

3 The survey is based on qualitative interviews with 11 architects and 15 engineers from Sweden (Roos et al. 2010).

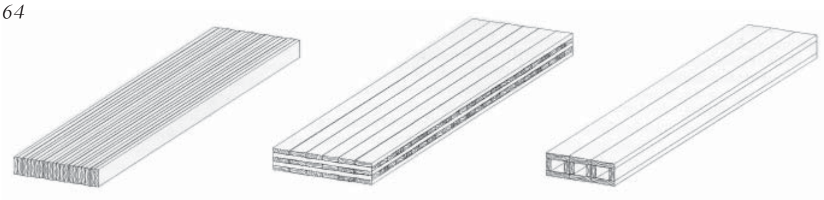
1.3 CROSS-LAMINATED TIMBER

1.3.1 Massive timber elements

Since massive timber elements gained increased focus back in the mid 1990s, different types of massive elements have been developed. Like glue-lam, massive elements are based on timber of smaller dimensions and of a lower quality, which ensures a far better utilization of the raw material. Generally speaking, the group of massive timber elements can be divided into three subgroups based on different construction principles; boards placed side by side, boards placed crosswise and as box elements [ill. 64]. The boards are connected by various binding materials, such as nails, wooden dowels, glue or distorted steelbars (Hansen, 2001). Depending on the construction principle, the elements have different physical properties and appearances. E.g. referring to the lamellae placed side by side, it is the slender edge that will be visible contrary to the cross-laminated and the box elements, which will show the broad side of the lamellae.

Taking Denmark as an example, the interest in massive timber increases at the end of the 1990s. This is mainly inspired by several building projects using massive timber elements in Switzerland, Germany and Sweden. In 1998, the Danish Forest and Nature Agency together with Associerede Ingeniører Aps and Dansk Træemballage A/S (DTE) initiated a test production of massive timber elements. One reason for this initiative is the assumption that an increased use of wood in construction will improve the possibility of a more intensive forest management, thereby improving the CO2-balance. Another reason is the increased common concern for environmental problems and interest in materials' influence on health. In addition, the fact that wood used for bearing constructions needs to be of a certain quality brings massive timber constructions into focus (Hansen 2001, pp. 7-8). Often Danish timber is of a doubtful quality, but when used for massive timber constructions, the 'poor' quality can be improved, thus making Danish timber more competitive and applicable. The collaboration resulted in a publication that seeks to clarify the potential of massive timber in Denmark and moreover, it presents a number of experimental buildings constructed in massive timber (Hansen, 2001). Common to the majority of these projects are, however, that the massive timber elements are covered with other materials, mainly plasterboards. Though, over the next years a few detached houses are erected where massive elements function not only as bearing structure, but also constitute the final interior surface [ill. 65-71].

64



64
Different construction methods of massive timber (Hansen, 2001).

65
House constructed of single-laminated massive timber elements. Vejle, DK (2005) by SHL architects. (Lilleheden 2012)

66
Interior of the house in Vejle by SHL architects. (Lilleheden 2012)

67
Detail connection single-laminated massive timber elements in house in Ebeltoft, DK (2001), by architect Birkkjær & Birkkjær. (Photo: Author)

65

66

68
Interior of annexe in Skagen, DK (2005) by architect Jesper Nielsen and ingineer Henrik Almegaard. Construction of cross-laminated timver elements. (Photo: courtesy of Jesper Nielsen)

69
Exterior of the annexe in Skagen, DK. (Photo: Author)

70
The first single family house constructed of massive timber in Denmark. Ebeltoft, DK (2001), architect Birkkjær & Birkkjær. (Photo: Author)

71
Cottage home constructed of cross-laminated timber elements, DK (2006) by architect Jesper Nielsen. (Photo: Author)

The houses in Ebeltoft and Vejle are constructed of glued laminated elements with lamellae placed side by side [ill.64 a]. These elements have a width of 325 mm and a length between 2-6000 mm. Along both edges, a groove is milled and the elements are joined by a loose tongue and screwed together [ill. 67]. The 325 mm module constitute the overall expression of the interior and entails a clear rhythm similar to that of log or post-and-beam constructions. Likewise, its anisotropic structure implies a constructional logic, e.g. exemplified by the heavy lintel above the openings [ill. 66]. One of the main advantages of this product is its size which makes it possible to handle these building units without using heavy machinery. On the other hand, one of its main issues is the sensitivity of the panels to changes in moist and temperature. These glued elements are more moisture sensitive than nailed units, as a single lamella cannot deform without a 'neighbour lamella' being affected. This can cause a relatively large deformation of the unified wall. As opposed to these projects, the buildings in Skagen and Them are constructed of cross-laminated timber elements (CLT). These CLT elements consists of five layers of lamellae which are glued together with each layer placed perpendicular to each


67


68


69

70


71



72


73


74


75

76

77

78

79

other. Due to this glued cross-laminated structure, the CLT element is far more dimensionally stable compared to the elements with lamellae glued together side by side. Moreover, its distinctive structure implies that the element can take up forces in all directions. Hence, holes can be cut in the element without ensuing lintels need to be added [ill. 68]. In return, these buildings do not express constructional logic, as structural elements such as the lintel and ridge beam are integrated in the massive element. In order to achieve a more thorough insight into this timber product, the following provides a general overview of how the CLT element is created.

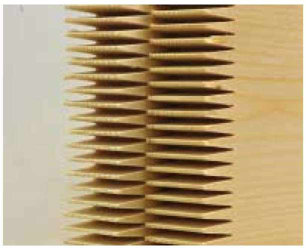
1.3.2 A CLT element comes into being

The following description of the production process of CLT elements is based on the Austrian company KLH Massivholz. The product kreuzlagenholz (KLH) was developed in 1996 and the company founded in 1997. In 2003, the company expanded to Scandinavia and in 2005, the subsidiary company KLH UK was founded. The basic idea was to make better use of timber by-products i.e. the side-boards. The information given below is partly gained through a visit at KLH's office and production hall in Austria, on October 10th 2011, and partly based on data from their homepage www.klh.at.

The (raw) spruce boards are delivered from the sawmill in the length corresponding to the width of the final CLT element [ill. 72]. Boards are then joined by 'finger-joints' [ill. 80-82] to become lamellae with a length corresponding to that of the final CLT element. According to the static requirements, three to nine layers of boards and lamellae are then placed perpendicular to each other, and glued (using solvent-free and formaldehyde-free PUR adhesive) together under high pressure [ill. 73]. Normally, the lamellae in the outer layers of the cross laminated elements consist of "better" wood with a higher strength class and a finer looking surface than the lamellae in the middle, as the outer layers determine the strength of the finish element and the visual appearance. The size and form of the elements are given by restrictions regarding production, transport and assembly. Currently, elements up to 16,5 m in length, 2,95 m in width and 0,5 m in thickness can be acquired as a standard. According to the type of building project, the outer layer of the elements can be acquired in different standards. The three standard qualities of KLH are non-visible quality, visible industrial quality or living space quality. Moreover, special

72-79
Production of a CLT element at KLH. (Phtos: courtesy of KLH)

80



81

82

80-82
Boards are joined by 'finger-joints' to lamellae. (Photo: courtesy of KLH)

surfaces of different wood species can be provided on request. The large format CLT elements are cut to size and shape, and holes are milled into the elements with great accuracy using CNC-technology [ill. 74-76]. The shape of the element and openings can be regular as well as irregular, thus it is possible to customise each element to each project specifically. Finally, the elements are packed on a lorry in the order corresponding to the subsequently assembly process [ill. 77]. On site, the massive timber elements are lifted in place. The large format and accuracy in cuttings enable a fast assembly [ill. 78-79]. For more information of formats, surface qualities, technical properties, etc. see e.g.: www.klh.at, www.klhuk.com, www.clt.info, www.binderholz.com, www.finnforest.com/products/leno). A concise overview of qualities and issues related to these massive and large format elements is presented in the next section.

1.3.3 CLT – design qualities and issues.

The qualities and issues presented below provide a brief introduction to the general potential of the CLT element. As the theme of this thesis is the aesthetic qualities in timber architecture, naturally, aspects related to this subject area are in focus. Aspects related to e.g. the technical capacity of CLT as well as to sustainability are merely treated superficially.

The CLT element offers a large format plate with a maximum size of 16,5 x 2,95 x 0,5 m (for detached and low-rise buildings three to five layers (KLH: 94-128 mm) is the most commonly applied). As each layer is placed perpendicular to each other, and glued together under high pressure, the elements obtain significantly enhanced structural capacity. One of the most essential advantages of the CLT elements is their static mode which makes them able to be used in a building as stabilising plates without being mounted with stiffening sheets. Due to its distinctive glued cross-laminated structure, each element constitutes a constructive stable plate-unit that is able to take up forces in all directions. These constructional qualities have the effect that with simple joints, one can make a structural stable construction that has good qualities for taking up vertical as well as horizontal forces. In relation to larger multi-storey buildings, where the joint sturdiness has to be documented, the building system of solid wood elements also has an inherent quality for regrouping the strengths if key units should fail (note). Besides, the glued cross-laminated structure entails that shapes and openings can be regular, irregular as well as amorphous, and the openings can be placed almost at random. Hence, the CLT elements allow for great freedom in the building design. All in all, the CLT element provides a plate that is multi-functional in more than one sense. The CLT element can be used for walls, floors/ceilings and roofs, it constitutes the bearing structure, and besides, it also functions as weather protection as well as interior finishing, by which the layered make-up of the building envelope is simplified/reduced (Santos 2008). Through the last 10-15 years, these qualities of CLT have been utilised in several building projects, ranging from the world's tallest residential building of timber in London [ill. 83-84], through office buildings, schools

83
Nine-storey apartment building, Murray Grove, London, UK (2008) by Waugh Thistleton Architects Ltd. (Photo: courtesy of KLH, AT)

84
Assembly of CLT elements for the apartment building at Murray Grove. (Photo: courtesy of KLH, AT)

85
Residential building in Judenburg, AT. CLT construction. (Photo: Author)

86
Office building in Leoben, AT (2009) by Nussmüller Architekten. CLT construction. (Photo: Author)

87
Kingsdale School, Music & Sports (2007) by dRMM architects. (KLHUK 2012)

88
Office building in CLT elements (2008) by David Grindley Architects. (Grindley 2012)

89
Sauna house of CLT elements, Presseggersee, AT (2004) by Architects Ronacher. (Ronacher 2012)

90
Single-family house, Ennstal, AT (2002) by Koller & Stigler. (Photo: courtesy of KLH, AT)

83

84

85

86

87

88

89

90

[ill. 87], kindergartens, industrial- and commercial buildings [ill. 86, 88], to low-rise residential buildings [ill. 85], detached housing [ill. 90], and various smaller buildings [ill. 89]. Parallel to these practical 'studies', several research studies have described and continues to test and develop the qualities of CLT. Among others, these studies deal with:

- Technical properties of CLT (Massivträ: Handboken 2006, Brandner, Schickhofer 2008, Stürzenbecher et al. 2010, Falk, Buelow 2011, Vessby et al. 2009).
- CLT as part of hybrid constructions [ill. 93] (Falk 2011),
- Joining methods (Follesa et al. 2010),
- Vibration behaviour (Bogensperger et al. 2010),
- Fire behaviour ((Frangi et al. 2009),
- Sustainability (Werner, Richter 2007).

The most crucial issues of CLT are those related to moist and acoustics. Problems related to deformations caused by moist during the assembly have resulted in that, today, much care is being shown e.g. by keeping the construction covered during the entire assembly process [ill. 91-92]. In return, the ability of wood to absorb and release moist in connection with the season as well as variations of 24 hours, has positive effects on the indoor climate (Massivträ: Handboken 2006). Some of these aspects are further elaborated in (Bejder et al. (2) 2008) (appendix 4). Hence, most research performed regarding CLT is focused on its technical properties. Exceptions are (Falk 2005, Buri, Weinand 2008, Santos 2008), who also focus on CLT's architectural qualities and applications.

Altogether, the CLT element provides a multi-functional plate that possesses enhanced technical properties – which were the aspects that people participating in the studies (conducted by Gold, Rubik 2008 and Roos et al. 2010) were most sceptical about. But what about its aesthetics? As pointed out in (Bell et al. 2006), many of the 'engineered' timber products are invented to compensate for some of the natural faults and limitations

91

92

of the material. But what happens to the aesthetic qualities of the wood in this process? Does CLT lead to new forms, new applications and new expressions in timber architecture, as earlier product developments in timber have done (e.g. boards, battens, veneer, plywood)? About massive timber elements like CLT, the Swiss architect Christoph Affentranger writes the following:

This makes building with wood simpler, but at the same time forfeits the pioneering spirit and the intimacy of the craft, materials and design, which Peter Zumthor for example, has perfectly mastered.
(Affentranger 2005, p. 34)

And the Swiss architect Andrea Deplazes writes:

(…) the sheet tectonics of current timber building will be read exclusively structurally, and not materially, as is the case with traditional timber building. (…), but also involving so-called thick-laminated sheets, will be seen as 'man-made material' – above all when they are neutralized inside and out by coloured paint – and will take up a position similar to homogeneous concrete in massive building, which can occupy all the tectonic elements of a building structurally without ever being able to express itself as a material.
(Deplazes 2001, p. 81)

In both cases, these engineered timber plates are compared with traditional timber buildings, and despite pointing out several qualities in the articles, the architects seem to be of the opinion that the plate element has lost its 'ability to express itself as a material' as well as the poetic qualities of wood. Does that mean, that CLT is merely a structural element – has it lost the multi-sensuous and poetic qualities of wood?

93

91
Assembly of 8 Storey Timber Building, Limnologen, SE (2007). (panoramio 2012)

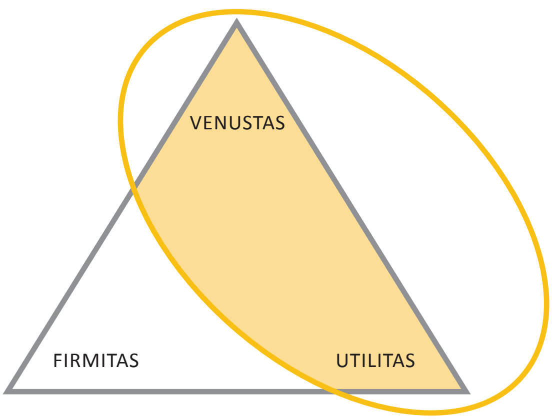
92
Assembly 9-storey appartment building, Murray G, London, UK. (KLHUK 2012)

93
Flyinge riding hall, SE. (Photo: courtesy of KLH, AT)

Through this introduction different aspects related to timber architecture have been presented. Looking at how timber architecture has changed through time, in relation to material, construction and form, has revealed a shift from the constructional logic characterising the log- and the post-and-beam constructions, to the structure-less multi-layered panel constructions. Besides, it has been illustrated how developments in tools and technology have led to new ways of working with timber. This does not only concern timber as a structural material, but also in regard to the perception of the material. The introduction has furthermore clarified, that despite an increased interest in wood as a building material, and a general positive attitude to the material among professionals and non-professionals, timber constructions only constitute a fairly small part of the overall building industry.

With novel engineered timber products like CLT, timber as a construction material has gain increased technical properties, and this has led to construction of even multi-storey apartment buildings. However, with the enhanced technical properties also comes the question of what it means to the experience and perception of this material, as a former of space and as a surface, that it is processed to products which (structurally) are beyond wood's nature? Thus, the overall theme of this thesis is to inquire into the understanding of the role of materials in architecture, and through this be able to clarify and discuss the aesthetic qualities of the engineered timber-based product CLT.

94



94
Project focus in relation to the triad of Vitruvius.

1.4 RESEARCH QUESTIONS, AIMS AND SCOPE

CLT is mainly characterised and known by its physical qualities and rarely acknowledged by its aesthetics. Based on the hypothesis that CLT possesses an undefined aesthetic potential that may expand how we construct and perceive timber architecture, the matters that are to be investigated through this thesis are:

1) *Is the engineered timber product CLT merely a structural material or does it also possess the sensuous and poetic qualities of wood? And, what happens to the aesthetics of a material as it is processed to products which (structurally) are beyond its nature?*

In order to be able to answer these questions, it is first and foremost necessary to build a realm of understanding related to the role of materials in architecture:

2) *What is the role of materials in architecture, and how do we perceive materials? How does CLT affect the architectural expression in general and the experience of the room?*

CLT is mainly characterised and known by its technical properties. A reason for this might be that the 'soft' values of a material can be difficult to describe and 'put a price on'. Therefore:

3) *How can one ensure, that both quantitative and qualitative aspects are integrated and properly balanced within a given architectural context?*

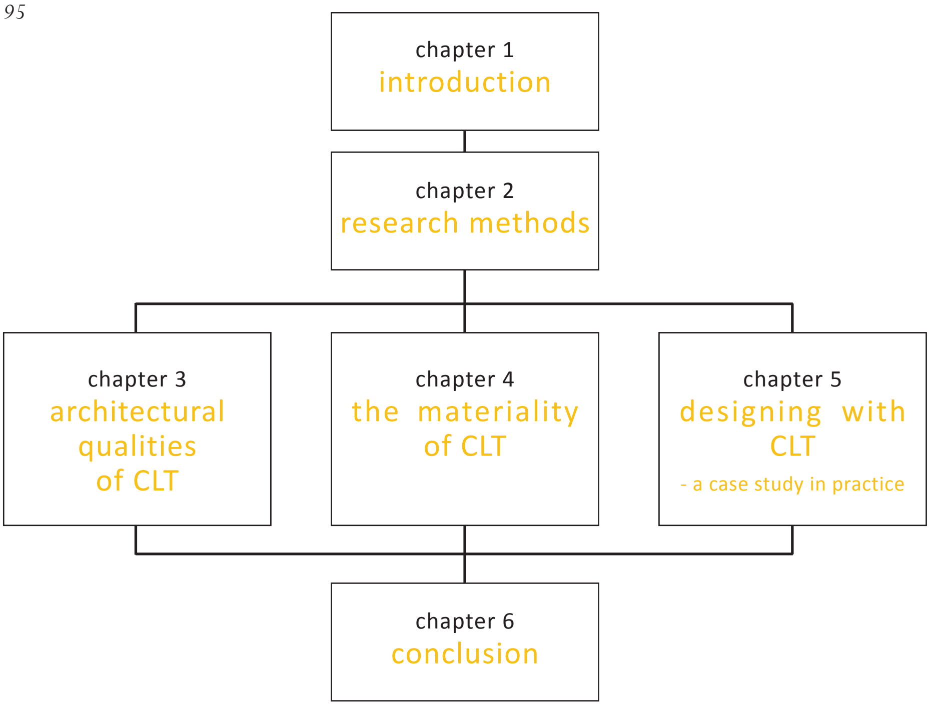
As mentioned, most research within CLT have been focused on the technical qualities. A lack of research within the 'softer' aspects of CLT is what underlies this research. Thus the focus will be on clarifying what CLT is able to do in relation to creating architecture – related to applicability, spatiality, experiences, perceptions and aesthetics in general. Therefore, in relation to the triad of Vitruvius, the project focus can be visualized as illustrated in [ill. 94]. The frame of reference regarding the application and research performed within CLT is mainly limited to the European countries, and in particular the Nordic countries and Austria.

1.5 STRUCTURE OF THE THESIS

This thesis is a collection of papers comprising two primary journal papers (appendix 1 – 2), three smaller journal papers (appendix 3 – 5), and two conference papers (appendix 6 – 7). As the papers have been written at different stages in the research process, some variance in the use of terms and wording will appear. This mirrors the process of development through the research process and are unavoidable side-effects of the paper based structure. Likewise, the papers demonstrate a development in research focus through the research process. The common thread is, however, the focus on clarifying and articulating the 'soft' values in (timber) architecture, and to ensure that these qualitative aspects are not neglected in favour of the tangible and measurable (quantitative) aspects. Chapter 1 provides an introduction to the topic, research area and concludes with research questions and aims of the thesis. Chapter 2 gives an overview of the research design. Chapter 3, 4 and 5 seek to answer the research questions with references to the published/submitted papers. Chapter 3 deals with the architectural aspects of CLT. Chapter 4 comprises the primary research of the thesis which deals with the experience and perception of CLT, also referred to as *materiality*. Chapter 5 is a description of the project's practical part, the cooperation with Skagen Nordstrand, as well as some preliminary inquiries conducted during this period. Chapter 6 brings together the knowledge gained in the previous three chapters to an overall conclusion, and suggestions for future work. [ill. 95] provides a visual overview of the thesis and its content.

95
Structure of the thesis.

95



2 RESEARCH METHODS

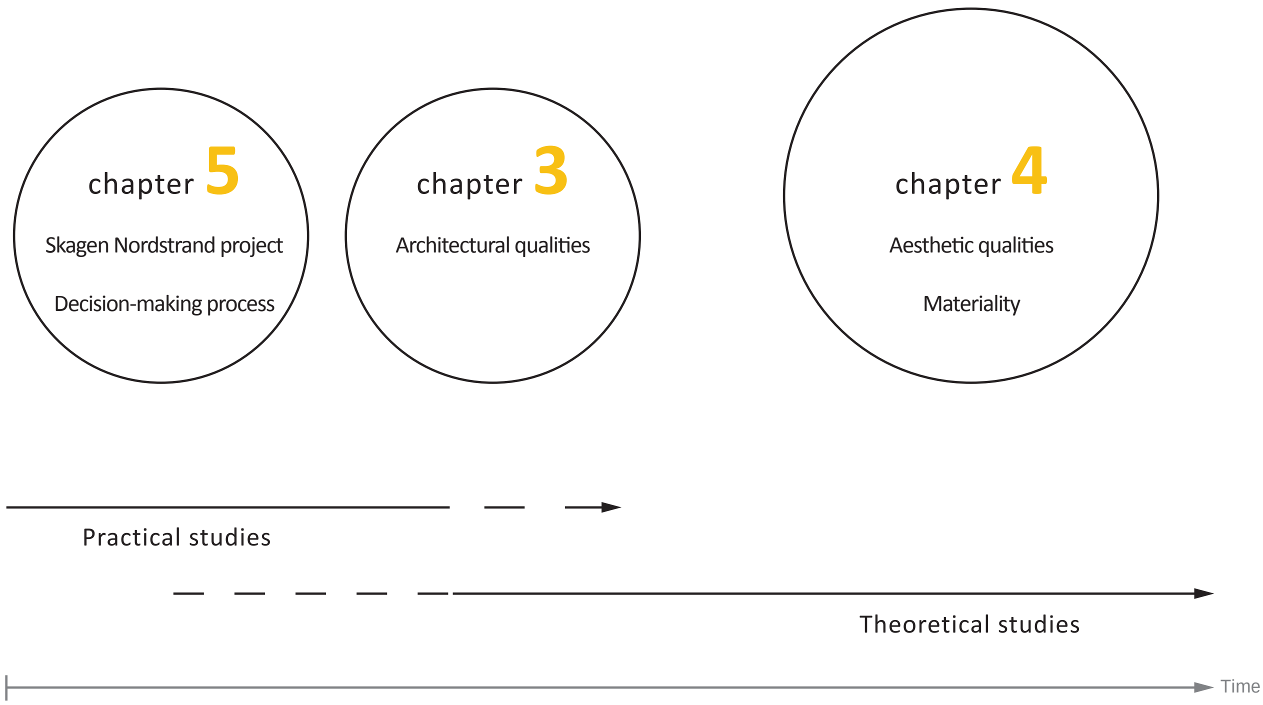
The timeless task of architecture is to create embodied and lived existential metaphors that concretise and structure out being in the world. Architecture reflects, materialises and eternalises ideas and images of ideal life. Buildings and towns enables us to structure, understand and remember the shapeless flow of reality and, ultimately, to recognise and remember who we are. Architecture enables us to perceive and understand the dialectics of permanence and change, to settle ourselves in the world, and to place ourselves in the continuum of culture and time.
(Pallasmaa 2005, p. 71)

As these words of Juhani Pallasmaa clearly express, architecture is characterised by great complexity. On the one hand, architecture is a very practical matter. The basic task of architecture is to provide shelter – it is to form a structure stable enough to withstand impacts from its inhabitants, as well as from weather and wind. Likewise, the buildings are to keeps us warm and provide a comfortable indoor climate regarding air quality, acoustics, light, etc. A complex, yet tangible and measurable task. But architecture is also what frames our daily life – its task is to fulfil human needs, the articulated as well as the unspoken. Moreover, architecture is a sensitive matter which must relate to its context, its culture, its time, and its users, and as Le Corbusier expressed it, architecture has the intangible business to 'establish emotional relationships by means of raw material' (Le Corbusier 1927/1946, p. 10). Research within the field of architecture is a similar complex matter that may include several different disciplines - the natural sciences, the social sciences and the humanities (Mo 2003).

So, how do we address the process within architectural research? According to James Snyder – who edited the book Architectural Research from 1984 – research can be defined as 'systematic inquiry directed toward the creation of knowledge' (Groat, Wang 2002). The *systematic inquiry* indicates that research is an amount of information that has been categorised, analysed and presented in a systematic way, which also means that a reduction of information has taken place. According to Groat and Wang, all research is a reduction of some kind. Choosing one method over another is just a matter of choosing one reduction strategy over another (Groat, Wang 2002). Therefore, the first step in the research process is to make a plan for how to collect, categorise, analyse and present the data, which is to answer the research questions. However, before doing so, a brief overview of the background of this PhD project is needed.

With the Skagen Nordstrand project as its point of departure, this PhD project positions itself in between the practical and the theoretical field. [ill. 96] illustrates the content of this thesis in relation to the practical/ theoretical field, as well as in relation to the progress of the process. As described earlier, the PhD process is initiated with a practical field study (the Skagen Nordstrand project) and by time, the research has become gradually more theoretically founded. The primary research topic and findings are addressed in chapter 4, whereas chapter 3 and 5 address different preliminary studies. Why the structure of this final PhD thesis does not follow the timewise progression is due to the current order being found more suitable for this final presentation of the findings and their interrelation. The cooperation with the estate company also means that this thesis and its findings are to relate to and also be useable for, both the company Skagen Nordstrand (on a practical level) and for the scientific society (on a theoretical level).

96

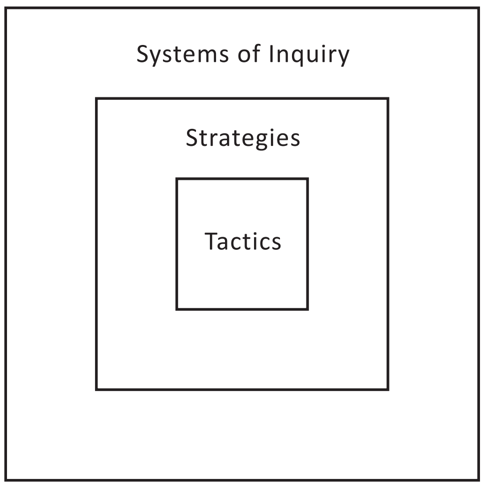


2.1 RESEARCH DESIGN AND PROCESS

Robert Yin describes research design as 'a logical plan for getting from here to there' (Yin 2003, p. 20). Here refers to the set of questions to be answered, and there is the set of conclusions (answers) about these questions. The research plan is the logic that links the collected data – and the conclusions drawn from these – to the initial research questions, and hereby ensures that the evidence address the questions asked (Yin 2003). Hence, the research design constitute the abovementioned plan for how to collect, categorise, analyse and present data in a systematic way. In Groat and Wang's terminology, research design is the strategy which constitute the process of inquiry that is more specific than the broad epistemological perspectives, such as positivism, critical theory, phenomenology, etc. (system of inquiry), and more general than the specific techniques of interviewing, literature reviewing, data collection and analysis, etc. (tactics). These three levels are termed the system of inquiry, strategies and tactics. Through a conceptual model of concentric frames, Groat and Wang explain these three levels of the systematic inquiry and their interrelation [ill. 97]. The system of inquiry frames the choice among a range of strategies and the strategy frames the choice among a range of tactics. There should be continuity and coherence between the three levels but they do not predetermine their subcategories (Groat, Wang 2002).

Within the system of inquiry, one basically distinguishes between two types of systems of understanding: qualitative and quantitative. The qualitative systems assume a subjective reality and are characterised by the thought that each phenomenon consists of a unique combination of qualities which cannot simply be described by means of counting or measuring, etc. The qualitative study focuses on understanding and interpretation, hence, the perspective is usually humanistic – often phenomenological.

97



96
Content of the thesis in relation to the practical/theoretical field.

97
A system of inquiry frames both strategies and tactics according to Groat and Wang. (Graphics from (Groat, Wang 2002))

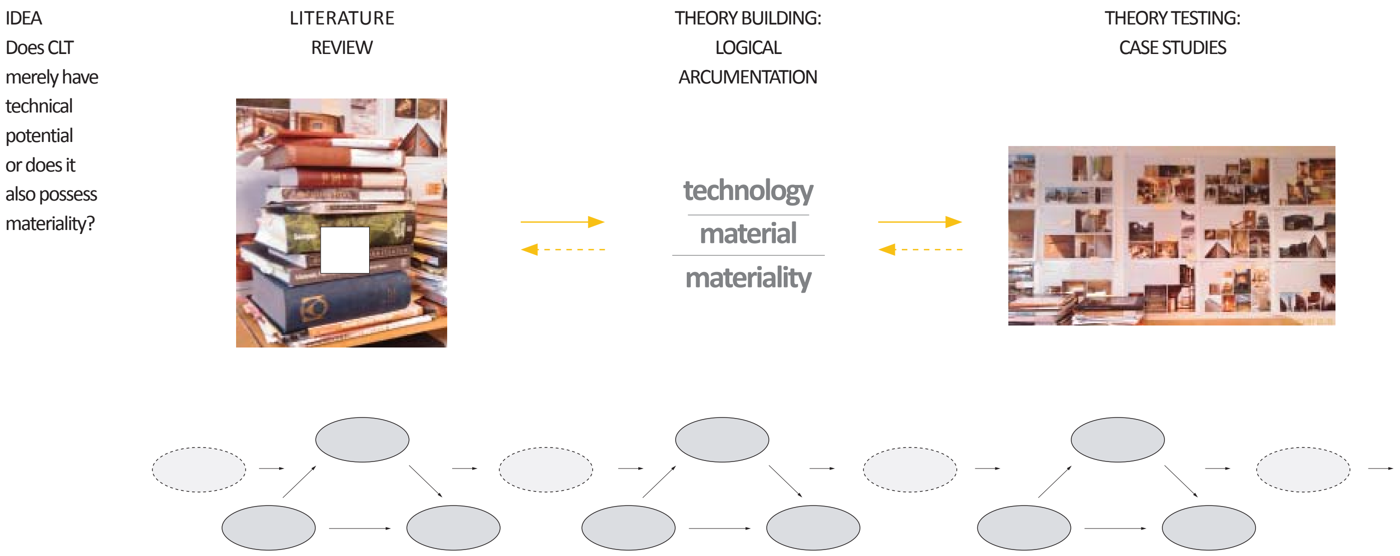
The quantitative systems, on the other hand, assume an objective reality. They often follow general formal standards and have the common 'rule' that everything (of scientific value) can and must be measured or weighted, etc. The quantitative study focuses on measurable facts and predictions, hence, the perspective is often natural scientific – e.g. positivistic (Groat, Wang 2002, Andersen 2005). As the primary focus of this thesis is to reach a better understanding of the experience and perception of materials, the thesis mainly relates to the qualitative systems of understanding and the interpretative sciences, in particular phenomenology. An exception is a preliminary study, where the potential of a quantitative decision-making method is tried out (addressed in chapter 5).

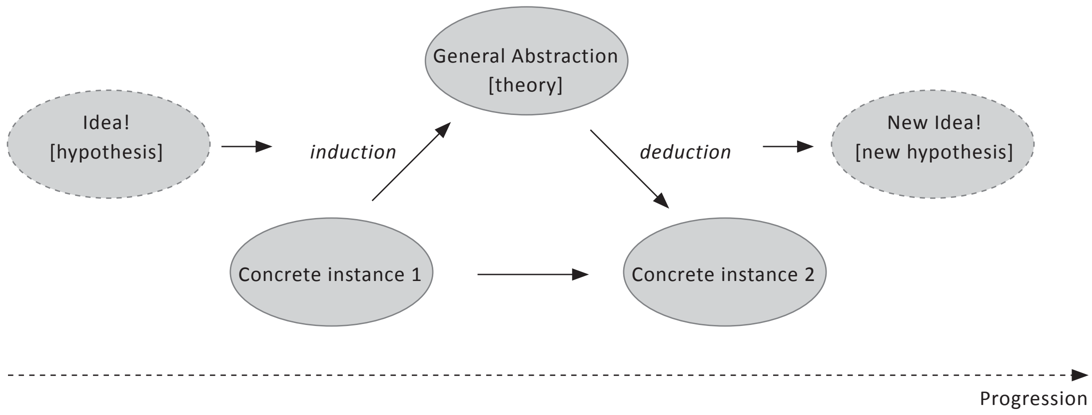
As a part of describing the strategy that is to guide the inquiry from here to there, Lars Brodersen's model of knowledge creation is applied. Based on the theories of the American philosopher and scientist Charles Sanders Peirce, Brodersen constructs a model that describes scientific progression. The model takes its point of departure in the idea/hypothesis which basically is based on the researcher's common sense and earlier experiences (Brodersen 2007). Following three steps, this idea/hypothesis is either proved or rejected which may then give rise to a new idea/hypothesis [ill. 98]. *Concrete instance 1* is the known instance and *concrete instance 2* exemplifies the findings. The scientific approach consists in reaching general abstraction (a theory) through induction and then test this theory through deduction (Brodersen 2007). The idea about working systematically (applying a method) through the combined inductive-deductive approach is, according to Brodersen, that the progress happens in a scientific manner. Going directly from *concrete instance 1* to *concrete instance 2*, the result would be random and non-scientific (Brodersen 2007).

98
Illustration explaining the difference between the scientific and a non-scientific progression. Going directly from concrete instance 1 to concrete instance 2, the result will be random and non-scientific. (Basic graphics from (Brodersen 2008))

99
A sequence of loops that has been carried out through the inquiry into the materiality of CLT.

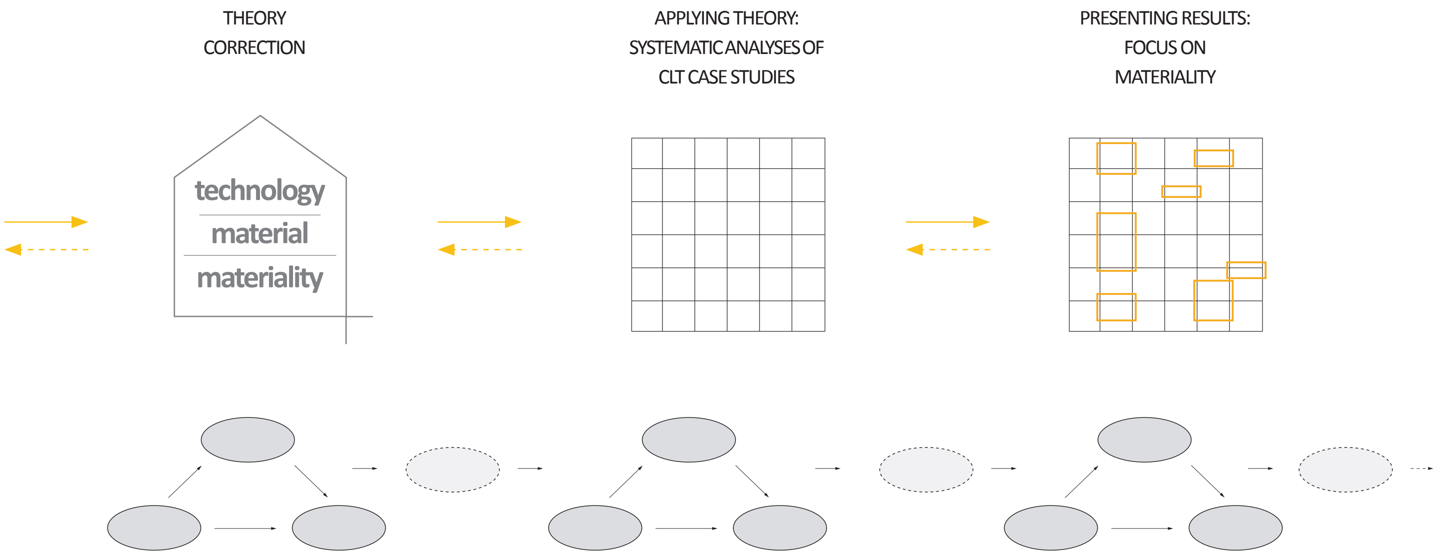
99





98

This model of 'knowledge creation' can be applied for the research project in its entirety, but also for the different inquiries conducted through the process and which together constitute the project. Looking at the project in its entirety, *concrete instance 1* exemplifies the mainly technical clarification of the properties of CLT, and *concrete instance 2* is our increased knowledge with the clarification of CLT's architectural and aesthetic qualities. The model can also express the many loops one takes going from here to there. Referring to the primary inquiry – the study of the *materiality of CLT* (addressed in chapter 4) – several of these loops are carried out before the final conclusion is reached [ill. 99]. And referring to Linn Mo's statement that 'theory is always in the process of development (Mo 2003, p. 13), even the conclusion reached here gives rise to



a new hypothesis which may be examined in the future. These loops are briefly described below and exemplified in [ill. 99].

The initiating idea/hypothesis is based on the question about CLT only having technical potentials or if it also possesses *materiality*. The inquiry starts out with a literature review with the focus of reaching a thorough insight in theories related to materials and their role in architecture through time. Based on this information a model is developed through the 'logical argumentation' approach (Groat, Wang 2002). Through intuitive analyses of timber architecture (traditional as well as contemporary), the theory is tested and the model refined. This iterative process with testing and refining runs the whole process through. As an acceptable model is reached, a number of CLT projects are chosen for the case study analysis. In this inquiry, the case studies are utilised as 'illustrative examples highlighting larger abstract principles' (Groat, Wang 2002). The cases are chosen so they together constitute a wide architectural spectrum but at the same time are comparable. Based on the model, a systematic analysis is then conducted (see appendix 8). In this phase, all cases are treated and analysed on equal terms in order to see all the potentials. In the following phase, the data gained through the systematic analysis is sorted for the final documentation of the results. Qualities related to the experience and perception of the material – its *materiality* – are in focus. Likewise, one main case is chosen to exemplify the overall qualities and other cases are then included in order to substantiate or elaborate points or to draw new points.

In order to reach an understanding about how CLT is *perceived* as a material, several strategies could have been chosen. It could be based on questionnaires sent to people working with or living in buildings made of CLT, or to architects, engineers, and contractors working with CLT, and through these questionnaires learn from their knowledge about and perceptions of the material. Other strategies could be in-depth interviews, or experiments where test subjects experiencing architecture constructed of CLT are observed. Dependent on the number of respondents/subjects, this empirical data could form the basis for quantitative – e.g. statistical – clarifications of essential qualities, or for exhaustive qualitative analyses. When literature surveys, model development, and case study analyses are chosen as the methodical approach for this inquiry, it is due to the wish to gain a heightened insight into the theoretical background of the subject of materials and their role in architecture. Likewise, in-depth analysis of a relatively small amount of cases form the basis of the analysis of the *materiality of CLT*, as the aim is to clarify essential aspects – not to clarify how often these aspects appear. Hence, the cases are chosen on the grounds that they exemplify a wide architectural spectrum in their use of CLT, and that the CLT is exposed to some extent. For this inquiry, the data have primarily been gathered through literature studies and study trips, and the results are documented through text, photographs, and drawings.

2.2 RESULTS AND COMMUNICATION

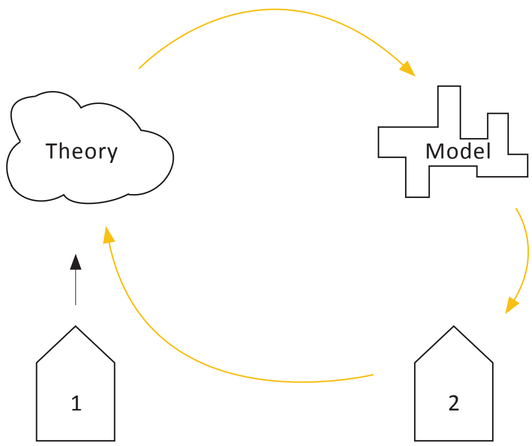
The findings of the inquiries conducted through this PhD are presented through papers during the process (appendixes 1-7), and finally, collected in this summary. The thesis targets two groups; primarily the scientific community (mainly researchers with interest within the architectural field), and secondarily practice (architects and Skagen Nordstrand).

100
The iterative process between theory review, model development, testing the model, model correction, testing, etc.

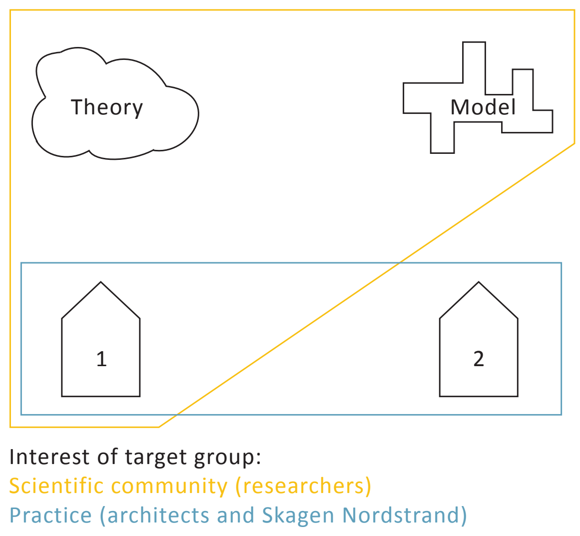
101
The findings are to relate to and be useable for, both the company Skagen Nordstrand (on a practical level) and for the scientific community (on a theoretical level).

[ill. 100] illustrates the process related to the inquiry described in chapter 4 with (1) indicating our knowledge about CLT in the beginning of the process. Through an iterative process of theory review, theory developing (model), theory testing, theory correction, etc., this results in our increased knowledge about CLT (2). In relation to the target groups, the findings of most interest to other researchers is regarded to be the model development, whereas the findings of most interest for practice most likely will be the increased knowledge about the *materiality of CLT* [ill. 101]. The communication of the *materiality of CLT* will, however, not be particularly aimed at this target group as it is beyond the scope of this thesis.

100



101



3 ARCHITECTURAL QUALITIES
OF CROSS LAMINATED TIMBER

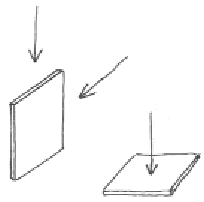
Every efficient design has its own unique characteristics. New methods of working with wood have changed the appearance of buildings. Now, a new model needs to be developed.
(Wachsmann 1930/1995)

Konrad Wachsmann wrote these words in the introduction for his book 'Building the Wooden House'. Although, the words are more than 80 years old and the 'new methods' he refers to are old and well-known by now, his words are just as pertinent today as they were then, as products and methods of working with wood continuous to develop. The aim of this thesis is not to reach a final model for how to apply CLT, rather the purpose is to identify its 'unique characteristics'. As its title indicates, the aim of this chapter is to clarify essential *architectural* qualities of CLT. Here 'architectural' refers to the material as a form-giving element, herein the transformation from separate elements to elements unified in spatial compositions. Moreover, the chapter deals with aspects like workability and accuracy as results of high-technology production, architectural freedom due to the technical properties of the material, as well as its tactile and visual qualities when exposed as interior surface. In other words, the chapter aims at clarifying what possibilities CLT provides for the designer.

The qualities and challenges of CLT, outlined in this chapter, are based on knowledge gained during discussions in the interdisciplinary design team related to the Skagen Nordstrand project (where CLT was chosen as the building system), as well as through literature surveys and study trips. In the article *On the architectural qualities of Cross Laminated Timber* (appendix 6), four overall aspects are found particularly significant for the architectural potentials of CLT. These are *the plate, the simple building system, the workability,* and *the details.* These aspects are further elaborated and illustrated in the following.

3.1 THE PLATE

As described in the introduction, the CLT element constitutes a massive three-nine layers plate in dimensions up to 16.5 x 2.95 m. Due to its cross-laminated structure, the element can take up forces in both directions, i.e. both in-plane and perpendicular to the plane, for which reason it can function as a shear wall as well as a slab [ill. 102]. This means, that the CLT element allows for new ways to build with wood – structurally as well as spatially. This change in timber architecture is characterised by the change from being based on 'sticks' to being based on 'plates'.



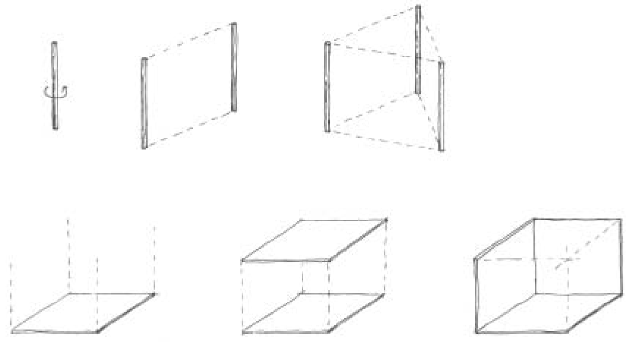
102

3.1.1 The plate as a generator of form

Traditionally, timber building design has been based on several pieces of (structural) timber that are characterised by the long and slender format of their origin – the log. Thus, the architectural expression of timber architecture has originally been dictated by the 'stick', as it was exemplified by the post-and-beam as well as log construction, in the introduction. Alone, this stick defines a point – an object one can move around, but in itself, the stick does not define a space. Two sticks define a line, whereas three or more sticks together can define a sense of space [ill. 105]. As

103

104



105

102
The CLT element functions as a shear wall as well as a slab.

103
The house in Ennstal is characterised by a floating transition between inside and outside as well as between the building and the landscape. (holzbau-stiegler 2012)

104
Single-family house, Ennstal, AT (2002) by Koller & Stigler. (Photo: courtesy of KLH, AT)

105
The 'stick' and the 'plate' as a space generating element.

106-107
Holiday cottage in Them, DK (2006) architect Jesper Nielsen. (Photos: Author).

opposed to this, the plate per se gives a sense of space. The space can unfold itself between few or several plates (surfaces) – from the merely defined space to the physical spatial enclosure [ill. 105].

Through time, architects have used plates to create simple and floating structures, e.g. Mies van der Rohe's Barcelona Pavilion (1929), and Rietveld's Schröderhaus (1924). At that time, the used concrete plates were very costly and therefore, the plate did not gain great currency (Affentranger 2005). But now, with prefabricated multi-functional plates like CLT, the plate might face a revival as a generator of form. A single-family house in Haus, Ennstal, Austria, is a significant example of the possibilities that CLT provides in terms of being a space generating element. Here, CLT elements are utilised to create a floating composition of horizontal and vertical plates [ill. 104]. Another example is a holiday cottage in Them, Denmark, where the entire corner is extracted from the otherwise compact body [ill. 106-107]. This feature is possible with traditional timber construction methods, however, it can be achieved much easier with the plate and by use of only few elements.

106

107

3.1.2 Freedom in designing

Due to its large format and cross-laminated structure, only few plates are necessary in order to create a stable construction. Besides, these properties allow for more complex designs and variations in building heights, etc., without the actual construction becoming too complicated [ill. 109-111].

The first thing that caught the attention of the Skagen Nordstrand design team was the incredibly simple structure of the small annexe in Skagen, DK (which is further described and illustrated in appendix 6). This building is structurally cut down to few basic elements; walls, floor, and roof. Due to the format of the plate and its cross-laminated structure, neither ridge beam nor lintels over the large openings are needed. Likewise, in Kingsdale School, Music and Sports Buildings, London, UK, the distinctive structure of the CLT is utilized to cut amorphous holes directly in both wall- and ceiling elements [ill. 108]. Since the plate spans in both directions, holes can be cut out almost at random (of course provided that enough material remains to ensure the stability). Thus, the plate allows for great freedom in designing while at the same time providing a simple building system.

108
Kingsdale School, Music and Sports Buildings, UK (2007) by dRMM Architects. (Photo: courtesy of KLH AT)

109
Assembly of CLT elements. Only few plates are needed for an entire facade. (Photo: courtesy of Miguel Nevado)

110
The large plates allow for a quite complex structure. (Photo: courtesy of Miguel Nevado)

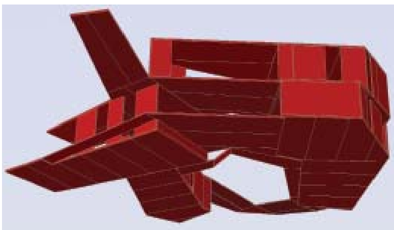
111
3D model of the complex structure. (Photo: courtesy of Miguel Nevado)

108

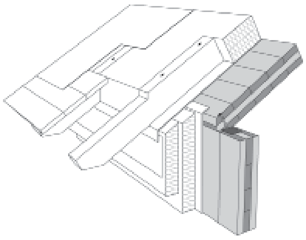
109

110

111

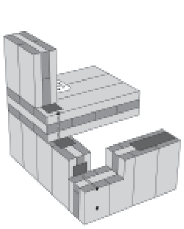


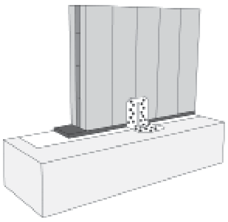
3.2 THE SIMPLE BUILDING SYSTEM



The ‘simple building system’, referred to above, is not alone given by the plate-function of the element. As described in the introduction, the CLT element constitutes a multi-functional plate that, besides being the bearing and stabilising structure, can provide the final interior surfaces. This simplification of the building system is evident, when looking at the material as a building envelope, as well as when it comes to the assembly of elements.

3.2.1 The assembly





112

Due to the fact that the elements can be used for roof, wall and flooring structure, and they can be delivered from factory in sizes up to 2,95m x 16,5m, in regular as well as irregular shapes, with carved openings and a final interior surface, CLT offers a simple and rational building system. By means of simple joints, it is possible to create a structural stable construction that has good qualities for taking up vertical as well as horizontal forces [ill. 112]. Besides, due to its property of being a plate and the fact that wood is easy to work with, the assembling of the CLT elements only necessitate simple tools and screws, other than the cranes needed for lifting the elements on place. Hereby, the type of skilled labour needed for constructing timber buildings has changed – from being based on craftsmanship and specialised wood-joining-techniques, to this contemporary type of timber construction that demands expertise for the assembling of elements, while the actual jointing does not call for particularly skills in carpentry [ill. 113].

113

112
Low-tech assembling details of a CLT building system. (Basic graphics from KLH)

113
The assembly of a house. (Photo: courtesy of Miguel Nevado)


114


115


116


117

118


119


120


121


The simplicity of the building system and joining methods means that the building can be assembled and closed relatively fast [ill. 114-121]. For instance, the design team was informed that it took only one day to erect the 165 m2 CLT for the annexe in Skagen, and thereafter a few days to put in all the screws. Similarly, the *entire* nine storeys apartment building on Murray Grove, London, was completed within 49 weeks (Waughthistleton 2012). By reducing the construction time on site, it means that the building is less dependent on weather conditions.

3.2.2 The simplified building envelope

Another quality when building with CLT, which the design team found especially interesting and unique, is the possibility of creating a house (almost) entirely of wood. The latest years of increasing demands to the energy consumption of building etc., have led to walls consisting of several layers, with each layer being essentially monofunctional (Deplazes 2001). However, with the CLT element, it is possible to leave out the vapour barrier, if the longitudinal joints are sufficiently sealed. This possibility of leaving out the traditional vapour barrier of plastic seemed very appealing to the design team.

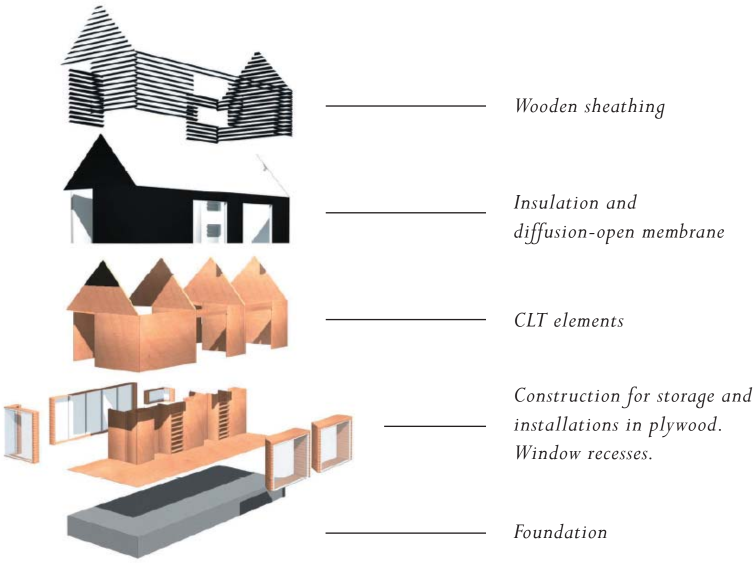
Likewise, as the element functions as bearing and stabilising structure and interior surface simultaneously, the number of layers of the building envelope is reduced significantly. Once the structure of the building is erected and the joints are sealed, it only takes insulation, a diffusion-open membrane, and exterior cladding in order to finish the building envelope [ill. 122-123]. In this way, CLT elements provide a simplified building system in proportion to the make-up of the building envelope, as well as regarding assembly and jointing.

114-121
The large CLT ellemts allow for a fast assembly. Here at a house near Madrid, ES. (Photo: courtesy of alterMATERIA)

122
The different elements of the annexe in Skagen illustrates the simplified building envelope. (Courtesy of Jesper Nielsen).

123
The simplified building envelope. (Photo: courtesy of Miguel Nevado)

122



123

3.3 THE WORKABILITY

As pointed out in the introduction of the thesis, wood has been used for endless purposes and in all scales from time immemorial. For one thing, this is due to the ability of wood to be shaped and processed i.e. its workability. With the characteristic properties of CLT, this workability of wood opens up for even more possibilities within shapes and applications.

3.3.1 The ability to be shaped

The cross-laminated structure of the large massive plate makes the element capable of retaining its structural capacities, even though parts of it are cut out. And due to the ease by which one can work and cut out parts of the wooden element, the CLT element can take various forms, in the overall shape of the element as well as in openings. Deplazes compares this feature with the way one works with 'cardboard models':

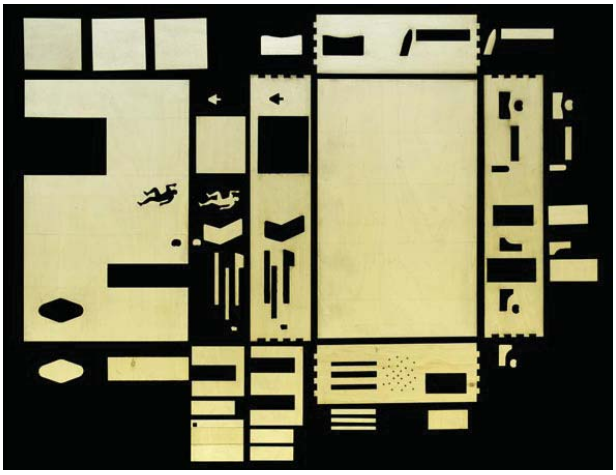
This [the parallel between the cardboard model and the building] *becomes rather more obvious in the treatment of openings: the incredible resistance shown by sheet tectonics in buildings is clear from the way in which openings can be punched into or cut out of the sheets, as if cut out of cardboard.*
(Deplazes 2001)

Thus, together the characteristic structure and workability of the CLT element allow for great freedom in the shaping of the element (as also mentioned in 3.1.2), and even for shapes that one usually would not expect in timber constructions. An illustrative example of this feature is dRMM's experimental project *Naked House* from 2006. This project clearly demonstrates that the shaping of the element and openings is not

124-125
'Naked house' (2006) by dRMM Architects. (dRMM Architects 2012)

126
Interior of the preschool in Langenegg, AT (2004) by Fink &Thurnher Architekten. (Photo: Author)

124

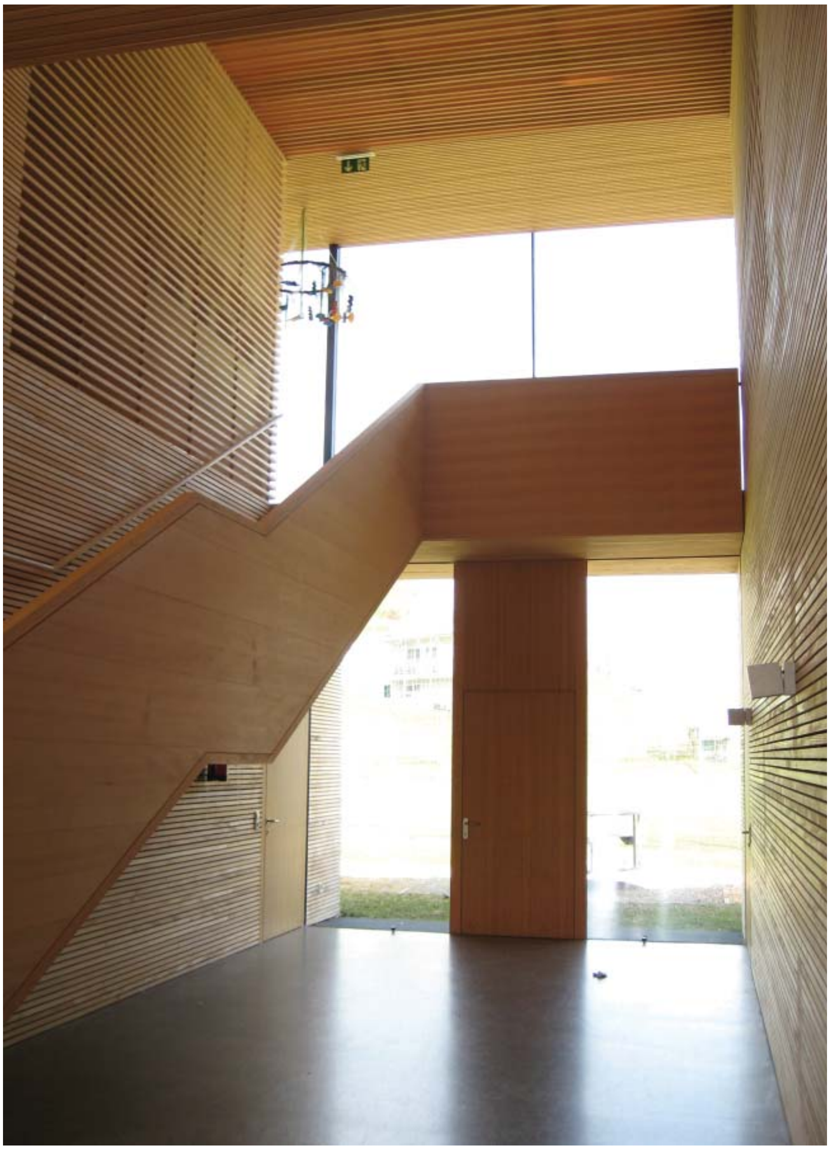


125

given by the structure (which allows for all shapes), but it is determined by the tools available for working and cutting. And by the use of CNC-technology, even the amorphous shape of the human body can frame the view [ill. 124-125].

Another example of the possibilities given by the workability of wood is the preschool in Langenegg, Austria. Here, wood's workability is utilized to create wood in different formats. Although the preschool is not made of CLT, but a thinner yet massive and cross-laminated plate, it illustrates very well how massive timber elements can be used in combination with wood in different shapes and formats to achieve a varied and yet consistent atmosphere by means of one single material [ill. 126].

126



3.3.2 Its countless applications

Due to its great workability and the fact that wood can be used for many different purposes, CLT also opens up for a fusion between plates and functions. Again, the preschool in Langenegg is an illustrative example in its use of massive timber. Here, the entire interior is made of wood, and thanks to its ability to be shaped, it has been possible to make delicate integrations of construction and the interior, e.g. the wall unit [ill. 129]. Large sliding doors made of massive timber, which extend from floor to ceiling, makes it possible to change the openness of the wall unit. When closed, the doors appear as the other walls and hereby bring about a consistency in the unified architectural expression. Similarly, the delicate design of the door [ill. 130] is possible due to the workability of the material, but also due to the high level of detailing in the processing of the elements.

129
In the preschool in Langenegg the wall unit is an integrated part of the interior and the large massive sliding doors extend from floor to ceiling. (Photo: Author)

130
The delicate and precise transition between door and wall. Preschool in Langenegg. (Photo: Author)

129

130

3.4 THE DETAILS

131
The precise transition between walls and ceiling in the annexe in Skagen. (Photo: Author)

132
The large elements are joined by screws. (Photo: courtesy of Miguel Nevado)

131

132

The fourth aspect, that is found particularly essential for CLT's architectural potentials, is the high level of detailing in production as well as final product. This high level of detailing is present within all phases of the building process i.e. from the 3D-object-based designing and the actual cutting of elements during production, to the delicate working of surfaces and the joints between these.

3.4.1 The longitudinal joint

Where the detailing of the wooden skeleton construction traditionally has been focused on the joint of the column and the beam, the detailing, when working with CLT elements, lies especially within the lengthwise jointing between plates, position of openings and surface treatment (Affentranger 2005). When jointing plates, one needs to consider the technical assembling, of course, but for the experience of a room, the meeting of surfaces is of pivotal importance as well. Due to sharpness in cutting from factory, these longitudinal joint can be made with great precision [ill. 131].

Although being a very form-stable plate, in all probability, the single lamellae will decrease a bit over time, and consequently the straight surface will appear less uniform and the single lamellae be more exposed. Therefore, it is important to design with this transformation in mind, e.g. ensure that ends of lamellae meet ends of lamellae when joining plates [ill. 131].

Due to the workability of wood, it is easy to cut, screw and mill in the CLT elements, e.g. for joining partitions [ill. 132], electrical fittings, etc. On the other hand, if the CLT element is to be a visible surface, one cannot simply fill out the holes afterwards. A solution for e.g. the electrical fittings is to have them laid out in a milled track behind the door frame, underneath the flooring, or behind the external walls.

3.4.2 Appearance and tactility

Building with wood is not tantamount to architecture associated with purely bared wooden surfaces. On the contrary, there are a great number of surface treatments which can bring out different qualities of wood. Examples can be painting, oil, stain, varnish or lye. Besides, the surface can be rough and tactile or level and smooth according to the desired expression [ill. 133-135]. Another possibility is to use the CLT in combination with other constructions and surfaces and hereby, create expressive contrasts. This could be heavy materials like concrete [ill. 136] and bricks or light constructions covered with plasterboard, plywood or MDF, etc. [ill. 137].

Although, the CLT elements come as large plane plates, the natural modularity and linearity of wood is still present in form of the lamellae and the structure of wood; the grain pattern. This structure can be used with great effect in the detailing of the surfaces. Inspirations for this can be found in the detailing of a door at the Center of Municipality in Ludesch, Austria. Here, the transition from door to wall is performed with great precision. The width of the door is adjusted to the module of the lamellae, and the lines of lamellae which are very precisely carried on from door to wall [ill. 133].

133
In the community centre of Ludesch, the transition from door to wall is made with great precision and a very smooth surface. (Photo: Author)

134
Another place in community centre, it is the tactile qualities of wood which mark the wall surface. (Photo: Author)

135
In the holiday cottage in Them the surfaces are painted white but the tactile structure of the lamellae is still clear. (Photo: Author)

3.4.3 From design process to finished building

By means of digital 3D-object-based designing, high-technology machinery, CNC-milling etc., working with CLT elements allow for a very detailed and direct process from planning and designing to producing and assembling the building. For example, the small annexe in Skagen was drawn in a 3D-object-based computer program and then send to the producer. This very direct communication of drawings can help prevent misunderstandings, and eventually help ensure a very precise fitting.

133

134

135

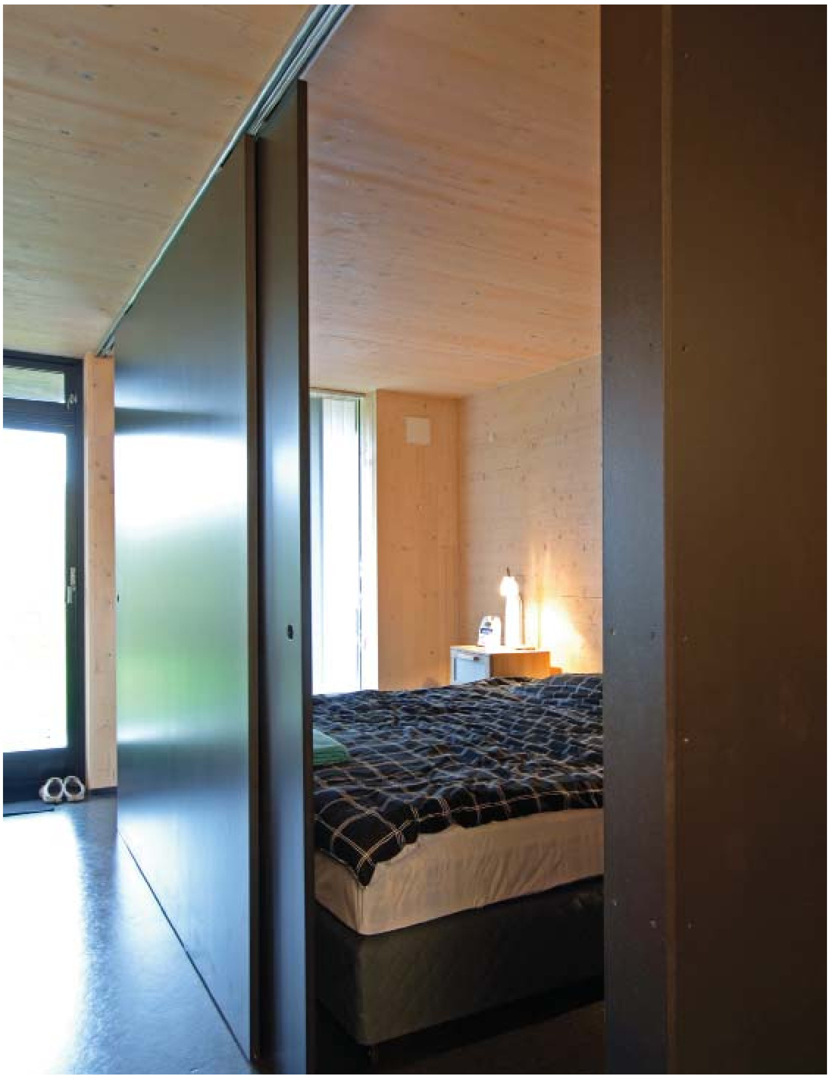
136
The warm CLT elements is in contrast to the cold concrete at the summer cottage in Hurum, NO (2006) architect Knut Hjeltnes. (Photo: Knut Hjeltnes)

137
For the youth housing in Hokksund, NO (2006) by CODE arkitektur AS, the CLT elements are used in combination with a light timber structure that is painted in a dark contrast colour. (Phote: Nils Petter Dale)

The process related to the Skagen Nordstrand project also pointed out, that with the advantage of the multi-functioning plate – being bearing and stabilizing structure, partition and exposed surface – the need for paying attention to details occurs already in the early design process. For example, it has been important for the architect, that the lamellae are horizontally oriented in order to enhance the longitudinal direction of the building. This entails, however, that the number of layers increases from three to five in order to attain sufficient bearing capacity.

Thus, the great finish from factory makes it possible to use the elements directly as exposed surfaces, however, this also entails, that many details are to be determined already in the design process. This concerns e.g. the orientation of lamellae of the exposed surface, the surface quality, appearance and tactility, at which side the fine-graded surface is to face, how electrical fittings are to be laid out, etc. This is of course desirable in most building projects however, when using CLT it is particularly important when the building system per se is to be the final exposed surface.

137



136

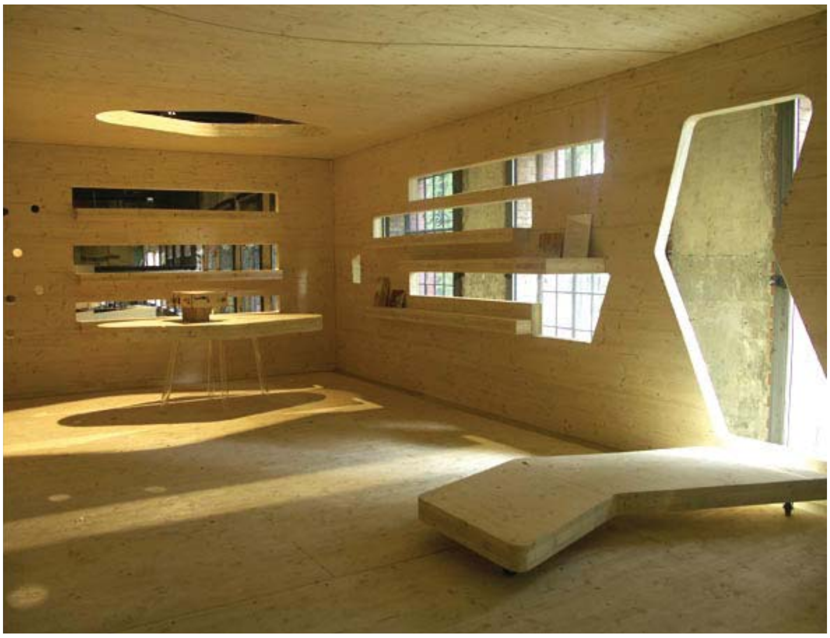
3.5 CONCLUSION

Through these preliminary studies, it has been clarified that CLT possesses many qualities within the technical and aesthetic field together with great applicability. The qualities which have been found particularly interesting, seen from an architectural point of view, are those related to its property of being a plate and provider of a simple building system, as well as to its workability, and high level of detailing in production and appearance.

The inquiry points out a shift in timber architecture from being based on the stick to being based on the plate. This change is of great importance on several levels; regarding the creation of space, the assembly, the freedom in designing, the applicability, etc. By means of its cross-laminated structure, huge format, workability, and multi-functional character, the CLT elements provide a simple building system in regards to assembly and jointing, as well as a simplified building envelope. This also implies a change in the type of skilled labour required for constructing a house of timber – from being based on craftsmanship to being based on skills within assembly. Moreover, with the massive plate, the shaping of the element and holes within it, is not given by the structure, but determined by the tools available for working and cutting, thus providing great freedom in designing. The high level of detailing and the workability of the massive element furthermore, allow for great variability in applications, surface treatments, and combinations with timber in general, as well as other materials. Additionally, by means of digital designing, high-technology machinery, CNC-milling etc., working with CLT elements allow for a

138
The experimental Naked House by dRMM architects is in many ways an exemplification of the 'new ways of thinking, designing and building with wood' facilitated by CLT. (dRMM Architects 2012)

138



very detailed and direct process from planning and designing to production and assembling. The inquiry also points out that with the advantage of the multi-functioning plate, as bearing and stabilising structure, partition and exposed surface, the need for getting into detail already in the design process also occur.

This inquiry has not aimed at reaching a final conclusion on whether CLT has architectural potential or not, but rather to form an introduction of the possibilities this material provides for the designer. However, it is finally stated that CLT does not only provide a very simple building system, but if it is designed based on its property of being a plate with multifunctional qualities, it may generate new ways of thinking, designing and building with wood [ill. 138].

This inquiry has provided a preliminary insight into the architectural qualities of CLT. However, in order to gain insight into how the engineered CLT element is *perceived* as a material, we first of all need to get an overview of how materials in architecture are perceived in general, what is the role of materials, and what factors impact these perceptions. Therefore, the aim of the following chapter is to inquire into the perception of CLT, i.e. to examine its *materiality*.

4 THE MATERIALITY
OF CROSS LAMINATED TIMBER

The flatness of today's standard construction is strengthened by a weakened sense of materiality. Natural materials – stone, brick and wood – allow our vision to penetrate their surfaces and enable us to become convinced of the veracity of matter. Natural materials express their age and history, as well as the story of their origins and their history of human use. All matter exists in the continuum of time; the patina of wear adds the enriching experience of time to the materials of construction. But the machine-made materials of today – scaleless sheets of glass, enamelled metals and synthetic plastics – tend to present their unyielding surfaces to the eye without conveying their material essence or age. Buildings of this technological age usually deliberately aim at ageless perfection, and they do not incorporate the dimension of time, or the unavoidable and mentally significant processes of aging. This fear of the traces of wear and age is related to our fear of death.
(Pallasmaa 2005, pp. 31-32)

As Pallasmaa describes above, wood is a 'natural material' that 'expresses its age and history, the story of its origins and its history of human use'. But in the quotation, Pallasmaa distinguishes between 'natural materials' and 'machine-made materials', the latter tending to present themselves without conveying – i.e. *expressing* – their material essence. As clarified in chapter 3, the CLT elements possess several features known from wood in its 'natural' form – e.g. its workability and visual and tactile characteristics. These are qualities which 'enable us to become convinced of the veracity of matter.' However, CLT is also the machine-made material that allows for 'scaleless sheets' of wood, and although it does not aim at 'ageless perfection' as the machine-made materials Pallasmaa refers to, CLT illustrates a similar wish to control nature by extending the 'natural' limitations of the raw material.

Pallasmaa's critique of machine-made materials as being without materiality seems to have roots in the theories of John Ruskin (1819-1900) and William Morris (1834-1896), to whom industrial products were 'dead and soulless without any traces of Man', and they called for a reimposition of craftsmanship (Werne 2004, p. 17). This concern about changes in architecture caused by new technologies has been a frequently debated issue over the years, with theorists and architects like Gottfried Semper, Eugène Emmanuel Viollet-le-Duc, John Ruskin, William Morris, Otto Wagner, Adolf Loos, Walter Gropius, Frank Lloyd Wright, Mies van der Rohe, Le Corbusier, Alvar Aalto, Konrad Wachsmann, and contemporary Kenneth Frampton, Finn Werne, Gernot Böhme, and Gerhard Auer, among its main contributors. An example is the article *Inszenierte Materialität* by the German philosopher Gernot Böhme (b. 1937), in which Böhme points out a trend towards a 'systematic construction of materials according to the qualities demanded' (Böhme 1995, p. 38). He calls it the birth of science of materials as engineering technology where materials are produced to fulfil specific - usually structural - functions, and according to Böhme this entails a rift between the inner structure and the outer appearance, i.e. a rift between *material* and *materiality* (Böhme 1995, p. 39). Thus, the question is whether these engineered CLT elements are examples of Böhme's *rift between material and materiality* – have they been reduced to merely serve a technical purpose or have they retained the appealing and poetic qualities of wood?

Besides, in his book *Style: Style in the Technical and Tectonic Arts; Or, Practical Aesthetics*, the German architectural theorist Gottfried Semper (1803-79) describes how the inconveniences and disadvantages of wood's inclination to crack and swell have been reduced and partly eliminated with products which are capable of taking up forces in all directions. These properties are found in ancient lattice work and the early development of thin sheets of wood glued together crosswise, like the arts of inlaid work, intarsia and veneers (Semper 2004, p. 657). Hence, this enhancement of the properties of wood is nothing new. However, Semper strongly incites the importance of staying true to the 'nature' of the material:

Art should confront these disadvantages, exploit them, and make a virtue of necessity. Nothing should be affected or feigned which would contradict the nature of wood.
(Semper 2004, p. 655)

As described in chapter 3, the CLT elements change the way of building with wood – structurally as well as spatially. Likewise, with its large format and cross-laminated structure, the massive plate allows for great freedom in designing in regard to the overall shape as well as the shaping and placement of openings – a processing that is not given by the anisotropic structure of the linear 'stick' but by the (approximately) isotropic 'plate'. Does this mean that CLT contradict the nature of wood? What does it mean to the perception of the material wood, that it – in form of CLT – is processed into a product that (structurally) is beyond its nature? And, after all, what is it in fact that defines the 'nature' of a material? Hence, the aim of this chapter is to inquire into the experience and perception of CLT, i.e. to analyse and evaluate its *materiality*.

In order to enable a discussion of what this new technical variability of timber as a building material means to the experience of timber architecture, it is first of all necessary to clarify how materials can be perceived and interpreted within the field of architecture. In the article *The materiality of novel timber architecture – developing a model for analysing and evaluating materials in architecture* (appendix 1), a model for analysing and discussing the materiality of timber in its contemporary engineered forms is developed. Here, it is suggested that in order to reach a thorough insight into the qualities of a material, one needs to consider three aspects; *technology*, *material* and *materiality*. Additionally, three perspectives; *entity*, *enclosure*, and *transition*, are included in order to tie the perception of the material to the architectural frame. Together these six aspects constitute a model that helps structure the analysis and evaluation of the experience and perception of novel timber construction materials (Bejder et al. 2011). The following is divided into two parts. In part one, the model and its six aspects are further elaborated and illustrated, and its theoretical foundation is briefly outlined. In part two, the model is applied for an analysis and evaluation of the *materiality of CLT*, based on a number of case studies. Finally, the applicability of the model as a tool to analyse and evaluate materials in architecture is discussed.

4 PART 1:
A MODEL FOR ANALYSING MATERIALS IN ARCHITECTURE

Throughout time, several models for structuring an architectural analysis have been proposed. However, where some analytical frameworks focus on the physical elements and composition in architecture (Unwin 1997, Thiis-Evensen 1987), others on colour (Billger 1999), rhythm (Hopsch 2008), spatial experience (Dahlin 2002), the relation between form and experience (Riis 2001), and architecture as space (Bek, Oxvig 1997), no *structured* model seems specifically focused on materials and their role in architecture.

The aesthetic potential of a specific material is the research topic in Gammelgaards PhD dissertation *Materialeæstetik – en undersøgelse af krydsfiners æstetiske potentialer* (Material Aesthetics - an inquiry into the aesthetic potential of plywood) (Gammelgaard 2002). Gammelgaard's methodological approach is based on a line of physical experiments through which he exposes plywood to different kinds of processing, and hereby clarifies its aesthetic potentials. The thesis provides an elaborated vocabulary for the articulation of the aesthetics of materials, and Gammelgaard draws several conclusions which are of great interest for the research theme of this present thesis. However, the dissertation does not provide an explicit model for analysing materials in general, and thus not a sufficient basis for an evaluation of the *materiality of CLT.* Likewise, Finn Werne's (1942) review of aspects related to materials and materiality in architecture (Werne 2004) constitute a good foundation for this inquiry, but does not provide the requested explicit model.

In the book *Basics: Materials*, Hegger et al. present a number of parameters that are essential for the choice and use of materials, including technical properties, material requirements and the perception of materials [ill. 139] (Hegger et al. 2007). However, this book is more general in its approach to materials in architecture, and seems focused on reaching a versatile overview of the properties of materials, whereas this inquiry is specifically focused on reaching insight into aspects related to the *perception* of materials in their architectural context. Thus, nor these books provide an adequate model for structuring the analysis of the *materiality of CLT.*

Besides, within phenomenology, architectural theorists and practicing architects like Steen Eiler Rasmussen (1898-1990), Juhani Pallasmaa (b. 1936) and Peter Zumthor (b. 1943), present an implicit model for understanding materials and their materiality by suggesting that experiencing architecture must be based on multi-sensuous perceptions (Rasmussen 1966, Pallasmaa 2005, Zumthor 2006). This 'model' is, however, intangible and difficult to apply for structuring an architectural analysis.

Materiality is a commonly used and investigated term within other fields, such as archaeology (Hurcombe 2007) and Industrial Design (Adelson 2001). However, in this cases, the focus will first of all be on getting an overview of how materials are used and perceived in architecture.

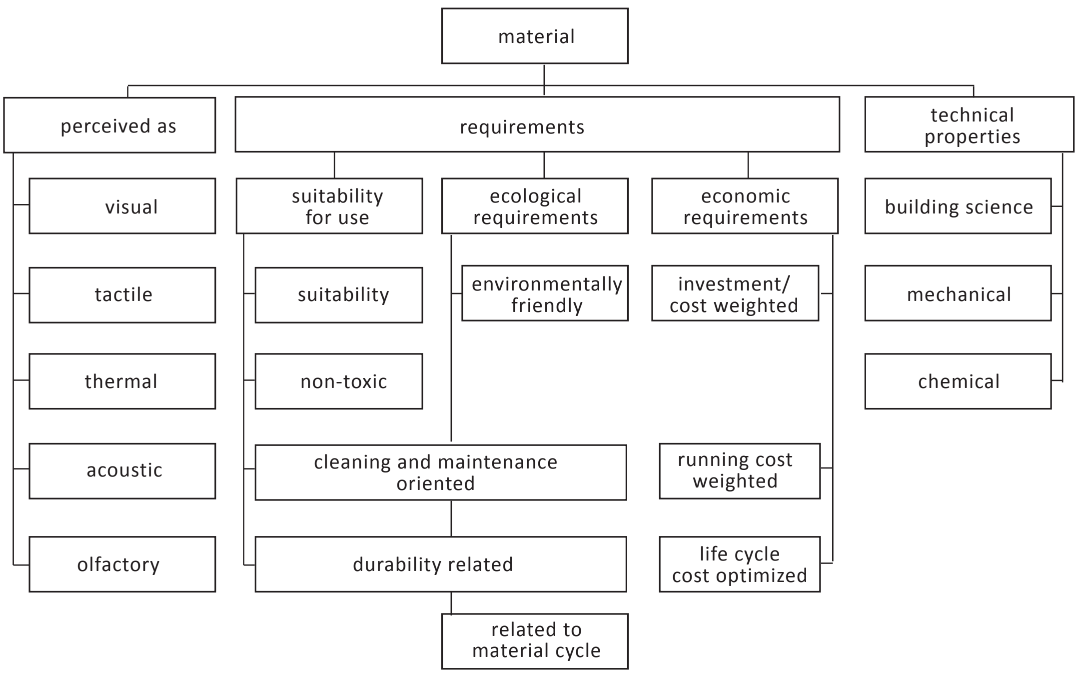
Hence, the first task of this chapter has been to develop an explicit model that includes aspects essential for describing materials and their materiality within an architectural context, and that additionally can help to structure the analysis and evaluation of the *materiality of CLT.* The theoretical foundation is initially focused on materials in general. However, the development of the model is successively directed towards wood specifically, as the qualities exemplified in the model are gradually adjusted in consequence of smaller intuitive and structured analyses of timber architecture (see chapter 2).

139
Properties of materials according to Hegger et al. (Basic graphics from Hegger et al. 2007).

140
Arch: the form of the brick. (Photo: Author)

141
The Lion Gate at Mycenae. Stone construction with clear references to the timber post-and-beam construction. (Weston 2003)

139



4.1 THE THEORETICAL FOUNDATION
– from a pragmatic to an abstract approach

The theoretical foundation of the 'model for analysing novel timber architecture' developed in (Bejder et al. 2011) includes thoughts and theories of Empedocles, Aristotle, Vitruvius, Karl Bötticher, Gottfried Semper, Viollet-le-Duc, John Ruskin, Frank Lloyd Wright, Gerhard Auer, Gernot Böhme, Juhani Pallasmaa, Peter Zumthor, Marco Frascari, and Richard Weston. Together they represent a considerable breadth, i.e. from ancient philosophers to 19th century architectural theorists and contemporary practicing architects. This breadth of the theoretical foundation has been chosen as the aim is not to follow a specific scientific theory, but rather to reach a wide realm of understanding and interpretation of materials and their role in architecture.

In (Bejder et al. 2011), two different ways of approaching materials in architecture are described: the *pragmatic* and the *abstract approach*. This theoretical framework takes its point of departure in the duality of architecture, as exemplified by Bötticher's distinction between *Kerneform* (core-form) and *Kunstform* (art-form), Semper's distinction between the *technical* and *symbolic* aspects of construction, and Frascari's distinction between the actual *construction* and the mental *construing* (Frampton 1995, Frascari 1984).

140

141

Within the *pragmatic approach*, choosing and utilising materials in architecture is either a direct and logical consequence of material properties or it depends on the material's capability to provide a specific form. In these cases, it is the material's intrinsic, tangible properties that qualify the material or not. Quality architecture, in the pragmatic sense, occurs when there is coherence between material properties, the form it provides and the purpose it fulfils. This may manifest itself in a reasonable choice of materials in order to achieve durable building, as argued by Vitruvius, or in the interaction between material, form and function, as seen in the theories of Aristotle (Bejder et al. 2011). This approach is clearly illustrated in Kahn's conversation with the brick: 'When you are designing in brick, you must ask brick what it wants or what it can do. Brick will say, *I like an arch*.' [ill. 140] (excerpt from Wurman 1986, p. 152).

Within the *abstract approach*, we encounter a more complex and context-dependent approach to materials in architecture. Through his 'four elements of building' and his theories about 'material transformation' (*Stoffwechseltheorie*), Semper describes how architectural elements will keep their traditional form, even through a change of material, in order to preserve the element's symbolic value. Semper substantiates his theories by referring to the ancient Greek temple with its post and beam construction in stone and its polychromatic ornaments, which, according to him, is reminiscent of traditional timber framework and its textile covering [ill. 141] (Mallgrave 2004). In this perspective, the product or architectural object is not primarily given by material properties, i.e. how materials are utilised and what form they take mirror the time and place in which they are produced; the social, cultural, environmental, political, religious, etc. circumstances affecting it. (Bejder et al. 2011).

Where Semper brings in the socio-cultural dimension to architecture, Pallasmaa, Zumthor and Böhme represent a phenomenological approach to architecture and its materials. In brief, phenomenology can be described as the understanding of the subjective experiences of the phenomena in the world around us. From this perspective, architecture is a complex, multi-sensory experience that arises when the observer encounters the architectural object. The building becomes active and capable of communicating with its surroundings. Materials may be the basic substance that forms the physical architectural body. However, in interaction with form, spatial arrangements, light, sound, temperature, construction, surroundings, etc., materials also become tools for creating multi-sensuous architecture – tools for creating atmospheres. From a phenomenological point of view, the perception of a material furthermore relies on the observer's personal frame of understanding, which is based on memories and previous experiences (Bejder et al. 2011).

Hereby, Semper, Pallasmaa, Zumthor, and Böhme add another layer to the understanding of materials and their role in the creation and experience of architecture, by bringing in social and cultural aspects, and the human being, i.e. the subject, with its sense organs and distinctive mind with memories and dreams, as the centre of architectural creation. Thus, regarding materials in architecture does not only include knowledge about the materials' intrinsic, technical properties or knowledge about their processing. It also includes insight into the intangible qualities of the material, i.e. qualities that relate to how the materials are *perceived*.

142
Traditional Swiss house. (Photo: Ida Wraber)

143
Japanese house with traditional heavy and rich ornamented roof. (Photo: Ida Wraber)

144
A small gab between the facade and the thin roof plates emphasise the lightness of the roof construction. Community centre in Ludesch. (Photo: Ida Wraber)

145
The light roof construction of the community centre in Ludesch. (Photo: Author)

146
A modern Swiss house. (Photo: Ida Wraber)

142

143

In the theoretical survey, the two approaches are handled in two separate tracks. However, the two approaches are not mutually exclusive; rather they should be regarded as each other's supplement in the aim of reaching a wider understanding of a material and its role in an architectural context. Likewise, architecture rarely expresses one of these approaches exclusively. Taking the roof as an architectural element, for example, this is designed with great difference according to different cultures. Often either the *pragmatic* or the *abstract approach* dominates, but both approaches are present to some extent [ill. 142-146]. The most pragmatic example is the traditional Swiss house where the roof primarily serves to protect the facade and to cover the gallery [ill. 142]. Similarly, the elegant and floating eaves at the Community Center in Ludesch, Austria (2005) by Hermann Kaufmann serves a practical function with its protection of the facades and as part of the external solar screenings. However, they also form symbolic discs that unify the detached buildings constituting the Community Center [ill. 144, 145]. In the Japanese building, the heavy and highly ornamented roof is very symbolic and culturally determined, but it also serves a pragmatic function as canopy for the veranda that encircles the house [ill. 143]. In great contrast to the Japanese roof construction, the symbolic meaning of the modern Swiss house seems be its 'non-existence' [ill. 146].

In (Bejder et al. 2011), this theoretical survey leads to the identification of three main aspects, which are found essential for describing the role of materials within an architectural context. These are termed *technology*, *material* and *materiality*, and are further elaborated and illustrated in the following.

144

145

146

4.2 TECHNOLOGY – the nature of materials

In (Bejder et al. (1) 2011) it is stated, that with the development of tools and technologies and the appurtenant new materials and construction methods, the 'nature' of a material can no longer be defined by the properties of the raw material alone. Qualities related to the processing a material has undergone, become an inevitable part of understanding a given material and its potential.

According to the German architect Gerhard Auer, 'natural' materials are most often defined as naturally occurring materials that grow and decay. However, Auer claims that 'building materials are artificial by nature', since every building material (with the exception of the earliest states of materials utilised, e.g. in the primeval hut) has undergone some kind of processing. Instead, Auer suggests that materials exist in six 'states of nature'. These 'states of nature' range from unprocessed materials to materials formed only mechanically, and further on to materials subjected to a physical transformation by means of e.g. fire. In the fourth, fifth and sixth 'state of nature', the physical transformation increases progressively according to developments in tools and techniques, which facilitate the development of thermodynamic properties, hybrid materials and towards chemical mechanics (Auer (2) 1995). Terry L. Patterson shares this conception about the applied technology being a part of a material's 'nature'. He writes:

Given the inseparable relationship between the nature of the technology and the potential and limitations of the material substance, analyzing the essence of a material must also include consideration of the associated technology.

From this he concludes, that the 'nature' of a material can change over

147
In Eames house the standardized steel elements form the overall expression. (1949) by Charles and Ray Eames. (Photo: Author)

148
The marks of the axe of the roughly hewn beams. (Schindler 2009)

149-150
Salk Institute, La Jolla, California, USA (1959–1965) by Louis I. Kahn. (Photos: Author)

147

148

time according to changes within technologies (Patterson 1994). In this perspective, the *nature* of a material should not be defined solely by the *inherent properties of the raw material*, but also include the *characteristics imparted by tools and technologies applied* [ill. 148]. This is an important aspect to keep in mind when working with or discussing an engineered material like CLT, which can show characteristics quite different from those of wood in its original 'state of nature'.

In Salk Institute, La Jolla, California, USA (1959–1965) by Louis I. Kahn, as well as in Eames House, California, USA (1949) by Charles and Ray Eames, the technology underlying the construction method and materials clearly manifests itself and plays a significant role in the architectural expression. In Eames house, the overall expression is given by the standardised dimensional steel columns and beams. This modularity provides a steady rhythm and controls the formal variations, by which the building become an example of the 'industrialisation' of the house [ill. 147]. For the Salk Institute, the construction of the huge concrete surfaces is clearly evident in the final design [ill. 149-150]. Here, Louis Kahn emphasises the processing the concrete has undergone by letting the formwork of large plywood plates and bolts used for keeping the forms flat while the

149

150

concrete set, become the ornamentation of the surfaces. Weston describes this as a 'constructional ornament' (Weston 2003). In both cases, it is not merely the properties of steel and concrete which provide insight into the materials used. In particular, it is the qualities related to the processing these materials have undergone, which report about their qualities and limitations.

Thus, when a material manifests itself through what is termed *technology*, the material demonstrates in some way the processing it has undergone. One could argue that these qualities lie implicit in *material* and *materiality* and some necessarily do, like enhanced structural capacities, a level and smooth surface, etc. However, qualities like format, level of detailing, standardisation, and flexibility, etc. are examples of qualities directly linked to the process of fabrication and which provide decisive information about both technical and aesthetic qualities and limitations of the material.

4.3 MATERIAL – based on inherent properties

The second aspect that is found essential for gaining a thorough insight into the essence, i.e. the nature, of a material, is termed *material* (Bejder et al. 2011).

With the industrialisation, new materials like iron, concrete and large sheets of glass opened up for new ways of building. These new materials, their properties and architectural potentials was a general subject matter in the nineteenth-century debates about style, where working 'in the nature of materials' was a recurring motif (Weston 2003). The 'nature' referred to here, relates to the properties of the material, i.e. the properties which determine what the material *can do* – to use the wording of Richard Weston (Weston 2003). Some of the most influential debaters within this topic are Semper, Viollet-le-Duc, and Ruskin. In relation to the increasing influence of industry on building materials and thus architecture, the theorists position themselves quite differently.

In the theories of both Ruskin and Viollet-le-Duc, *honesty in the use of materials* is a main issue that is inextricably linked to their encouragement of *utilising the inherent qualities of a material* (Hearn 1990, p. 169). However, where Viollet-le-Duc is very favourably disposed towards new industrially produced materials, Ruskin is more sceptical. This disagreement is particularly evident in their approach to iron as a building material. Ruskin regards historical styles and traditional materials as the *true* architecture, and since the inherent properties of iron do not follow the laws and proportions of traditional (*true*) architecture, Ruskin excludes iron as a building material. Contrary hereto, Viollet-le-Duc sees iron and its distinctive properties as means of innovating architecture and the way out of formal imitation (Ruskin 1988, Hearn 1990).

151-152
This infill project exemplify the difference between the utilisation of brick based on its inherent properties and not. By forming an arch the brick alone can take up the load above the openings. In contrast, the rectangular openings necessitate reinforcement of the brick-beam above. (Photos: Author)

Viollet-le-Duc writes:

And so we hear it maintained in the present day, as it was formerly, that iron cannot be employed in our edifices without dissembling its use, because this material is not suited to monumental forms. It would be more consistent with truth and reason to say that the monumental forms adopted, having resulted from the use of materials possessing qualities other than those of iron, cannot be adapted to this latter material. The logical inference is that we should not continue to employ those forms, but should try to discover others that harmonize with the properties of iron.
(Hearn 1990, p. 170)

According to Viollet-le-Duc, the honest handling of materials furthermore implies that the materials are used in a building in the manner in which they have been worked (Hearn 1990). Instead of adapting new materials to formats given by previous materials, one is to take advantages of the new materials and new formats made possible by developments within tools and technology. Summing up the words of Viollet-le-Duc, Hearn puts it in this way:

The corollary of this principle is that architects, perceiving an advantageous structural formulation for which no manufactured material yet exists, should not hesitate to propose the production of a new format for the material. Without such initiative progress is not likely to occur.
(Hearn 1990, p. 178)

151

152

Viollet-le-Duc's search for new forms giving by new materials becomes a great inspiration to many Modernists, not least to Frank Lloyd Wright who states that 'Every new material means a new form, a new use if used according to its nature' (Devane, Gutheim, Wright 1975). The above-mentioned Eames house exemplifies this with its slender profiles enabled by steel, which give rise to a new modern architectural expression.

In this way, Ruskin and Viollet-le-Duc have the common agenda of *honesty in the use of materials* but part ways when it comes to their architectural position and approach to industrially processed materials. However, they have a shared perception of the *inherent properties* as essential for understanding the essence of a material and its potentials, since these, i.e. the (technical) properties, are to determine the form.

Thus, when a material manifests itself through what is termed *material*, it demonstrates the technical properties of the material, i.e. what the material *can do* [ill. 151-152]. Dealing with these material properties, we face the absolute factors of a material (Werne 2004, Böhme 1995). This could be qualities like workability, breaking strength, elasticity, combustibility, homogeneity, thermal conductivity, etc. These are tangible and absolute qualities, which provide information about the structural and building technical possibilities, the material provides.

4.4 MATERIALITY – perceiving materials

The third main aspect in the model is termed *materiality* (Bejder et al. 2011). Materiality seems to have been a buzzword in the debates on architecture in recent years as a response to an agelong one-sided focus on vision (Böhme 1995, Weston 2003, Pallasmaa 2005, Thomas 2007) and the dematerialisation seen in early Modernism, Deconstructivism and Postmodernism. However, materiality is often used in a quite broad sense. In many cases, it basically indicates that materials have been a determining factor in the creation of a specific building, but it is often unclear whether it expresses *material* or *materiality*. Here, the aspects *technology* and *material* cover the absolute qualities of the material, whereas *materiality* relates to the material's distinctive character as we *perceive* it (Bejder et al. 2011). As the main focus is to inquire into the *materiality of CLT*, this section is given a bit extra space for the elaboration of this aspect. However, this does not mean that *materiality* is superior to *technology* and *material* in the general model.

In order to gain insight into how materials are perceived, (Bejder et al. 2011) take a point of departure in the theories of Böhme. According to him, man establishes three relationships to materials – these are the medial, the working, and the perceptual relationship (Böhme 1995, p. 43)

The medial relationship

The medial relationship is dominant in the early childhood and relates to the child's first unbiased experience of the world. Through the child's intuitive and curious study of the world, it learns that different materials act differently, and each has unique characteristics [ill. 153]. Through its body, the child experience that some materials are cold and hard, others are warm, soft and smooth. Some materials break easily, others are tough or flexible, each having its unique appearance, smell and taste (Böhme 1995, Werne 2004). According to Böhme, Aristotle termed this special perception - which is carried out *on* and *in* the body - as the actual touching (Haphe). Böhme translates this to *sensing* and points at a direct connection between this physical sensing of materials and the sensing of oneself:

The fact that we exist as bodies among other bodies and live physically within different media is the basis of our direct physical experience of materials. We experience softness or hardness, wetness, dryness, coolness, and warmth on, or better, in our own bodies. (...)The sensing of materials is in this way a sensing of oneself. In this physical sensing of ourselves lies the foundation of the later perception of materials as well.
(Böhme 1995, p. 43)

Thus these early childhood experiences, the unbiased, intuitive and curious approach to materials, form the background for future experiences and perceptions of materials. These are the memories that phenomenologists like Zumthor and Pallasmaa, among others, find so essential to the creation as well as perception of architecture (Bejder et al. 2011).

153
The child's intuitive and curious study of the world form the basis for future experiences and perceptions of materials. (Photo: Author)

153

The working relationship

In the working relationship, we are also involved with the material as raw matter. Through working the material, i.e. forming and changing it, we learn about its technical qualities, we experience its ability to bend, melt, break, dissolve, etc. (Böhme 1995, p. 43). As it was the case with the medial relationship, these sensory perceptions have their starting point in the physical sensing of the materials. However, the unbiased approach is soon replaced by knowledge of the material which increases progressively with ones experiences. The Swedish architect Finn Werne (b. 1942) describes a similar relation:

Someone dealing with sheep breeding for wool, or as a tailor with wool fabrics, develops a special feel for the quality of wool. The goldsmith develops a special feel for stones and metals and can readily distinguish one disc which is 0.25 mm from one that is 0.35 mm or 0.15 mm thick. The carpenter knows (or maybe felt) immediately timber's dimensions, moisture content and quality.
(author's translation, Werne 2004, p. 22)

In this way, learning by experience improves one's knowledge about the material. This knowledge is originally based on a physical sensing of the material but with this 'knowledge building', it will increasingly reflect a mental perception as well.

The perceptual relationship

In the perceptual relationship, we are involved with 'the pure form of its appearance'. This is what Böhme terms as the *materiality* of the material. Within the perceptual relationship, Böhme introduces three dimensions in which *materiality* manifest itself. These are its physiognomy, its syn-aesthetic character and its social character.

A material's *physiognomy* covers the material's distinctive characteristics that can be read from its outer appearance. Qualities that are of particular importance to describe the character of a material, Böhme underlines three: irregularity, colouration in all its nuances, and the structure of the surface (haptic qualities) (Böhme 1995, pp. 39-40). Examples within irregularity are texture, grain, marbling, pattern, etc., i.e. qualities which form a materials unique appearance – its *fingerprint*. 'Coloration in all its nuances' refers to the many colour differences which together make up the unified colouration of a material. The structure of the surface can either be rough or level and these haptic qualities are important to the reflection of light, among others. According to Böhme, all three parameters are crucial in order to distinguish between the 'real' material and its imitation.

When materiality manifests itself in its *synaesthetic character*, it relates to the fact that many of the characteristics of the material, i.e. the qualities related to its *physiognomy*, can be perceived through several different senses. In that way, sensory perceptions can generate haptic experiences without the actual touching. Böhme describes this by saying that the qualities are 'atmospherically perceptible' (Böhme 1995, p. 40). We know this from the perception of colours, among others, where blue is perceived as being cold, red as being warm, etc. [ill. 156]. We are also introduced to

154
In the Utzon Centre all three aspects, which Böhme finds particular important for describing the character of a material, are clearly present. Irregularity, colouration in all its nuances, and haptic qualities, characterize the composition of brick, concrete and zinc. (Photo: Author)

155
Hadid's housing project appears as dematerialized white volumes. The surfaces possess no irregularities, colour variations, or haptic qualities to indicate the materials used. Furthermore, knocking on the facade reveals that what is immediately perceived as massive walls, actually appear to be thin plastered surfaces. (Photo: Author)

154

155

this phenomenon in the theories of Zumthor, where he ends his descriptions of *The Temperature of a Space* by saying:

So temperature in this sense is physical, but presumably psychological too. It's in what I see, what I feel, what I touch, even with my feet.
(Zumthor 2006, p. 35)

With the *social character* of a material, Böhme points out that when dealing with materials one must consider that materials in some cases *stand for something*. When materials become carriers of meaning, it can either be caused by the origin or a limited availability of the material, or it can reflect specific trends or ideologies in society (Böhme 1995, Weston 2003). So when concrete is regarded as an exciting and beautiful material with great potential in the first half of the twentieth century and then turns into the opposite, i.e. being held responsible for the inhuman and monotone stereotypes of late Modernism, it actually illustrates a change in the *social character* of concrete (Auer(1) 1995, Weston 2003, Böhme 1995).

In regard to manifesting the *materiality* of the materials of which they are made of, *Utzon Center* (2008) by Jørn og Kim Utzon, Denmark, and Zaha Hadid's *Spittelau Viaducts Housing Project* (2005), Austria, are diametrically opposed [ill. 154-155].

156

156
For the interior of Hamar Bispegaard Museum, NO (1969-73) Sverre Fehn uses the slender glue-laminated timber columns and trusses and thin wooden sheets for seats as a light, soft and warm contrast to the heavy, hard and cols concrete. (Weston 2003)

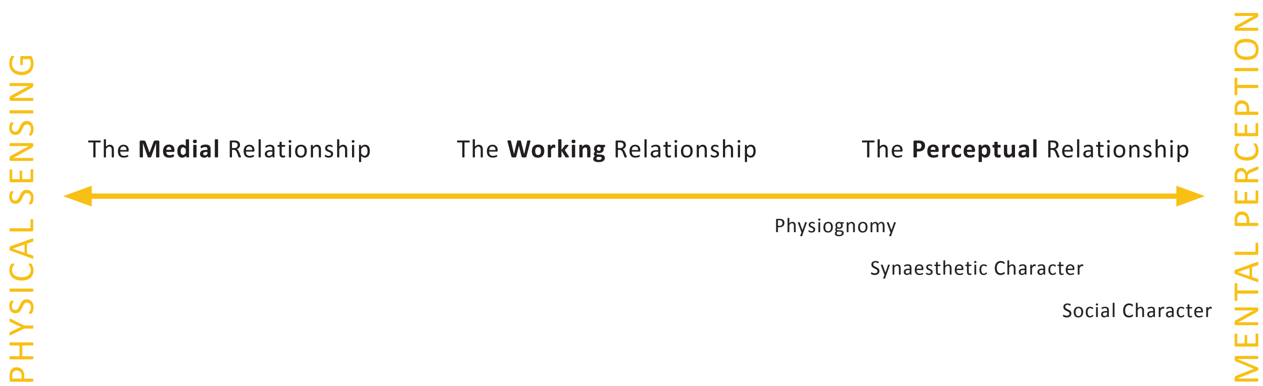
This brief survey of how materials are perceived demonstrates, that materials can be experienced through a physical sensing, i.e. a sensing of its surface character and its technical capacities. However, this physical sensing will be influenced by previous experiences with materials, impacts from society, just as it might give rise to the more incorporeal sensory perceptions e.g. expressed through its *synaesthetic character*. Thus, the sensory perception of materials can range from the *physical sensing* to the *mental perception* [ill. 157].

Hence, *materiality* relates to the sensuous experience of the material. As it has been clarified, experiencing materials is a subjective matter, i.e. marked by the person's cultural and personal background including earlier experiences with materials. Likewise, the architectural object is a product affected by various extrinsic factors, i.e. time and place, traditions, and religious, economic, political, etc. circumstances affecting it. Therefore, it is not possible to make a general description of a material's *materiality*. It is, however, possible to identify qualities that can describe the *character* of a material. These qualities are first of all connected to the material's *physiognomy*, exemplified by irregularity, colourations, patterns, texture, etc. These qualities are physically perceptible through vision and the sense of touch, and form the basis for describing the character of a material. Besides, these sense impressions might also give rise to sensory perceptions on a mental level, through its *synaesthetic* and *social character*. Furthermore, in order to embrace a multi-sensory experience, as expressed by Zumthor and Pallasmaa (Bejder et al. 2011), qualities perceptible to the sense of smell and hearing may be relevant in this level as well.

157
The sensory perception of materials ranges from the physical sensing to the mental perception.

158-160
The architect Anders Gammelgaard Nilesen's experiments in plywood are expressive examples of the interrelation between technology, material and materiality. (Photos: Anders Gammelgaard Nielsen)

157



4.5 THE EMBODIMENT OF MATERIALS

As it is found in the survey, the perception of a material (*materiality*) is based on a preceding insight into the various properties of the material (which is gained through the medial and the working relationship). Similarly, knowledge about the material's technical qualities (what it *can do*) and the processing it has undergone are vital to the unified perception of the material. Hence, these three levels – *technology*, *material* and *materiality* – are not to be regarded as opposites. Rather, together they constitute the *essence* of a material (Bejder et al. 2011). Therefore, when focusing on any of the levels of *technology*, *material* or *materiality*, it is important to consider the interrelation between them. The three levels and their interrelation are clearly expressed in the Gammelgaard's physical experiments with plywood (Gammelgaard Nielsen 2002), in which our perceptions of the material changes significantly with the objects' physical transformation and as the tools applied become increasingly refined [ill. 158-160]. However, Gammelgaard's examples also illustrate that the three levels relate to the form-material relation in general, as in this case, exemplified by a sort of art item. Hence, referring to the aim of the model, *technology*, *material* or *materiality* comprise the aspects essential for describing materials and their materiality, but they do not bring this interpretation of materials into an architectural context and thus, are not capable of structuring the analysis by themselves (Bejder et al. 2011).

Therefore, in order to make the model more focused and tangible within an architectural context, and capable of structuring the architectural analysis, three further aspects are included in the model. These aspects; *entity*, *enclosure*, and *transition*, constitute the architectural object, i.e. building, room, etc., and provide three perspectives through which the above-mentioned material qualities can be analysed and evaluated (Bejder et al. 2011). As it has been the general approach through this thesis, and which characterise the theoretical foundation (4.1), these three perspectives are regarded from a pragmatic as well as an abstract point of view.

158

159

160

4.5.1 Entity

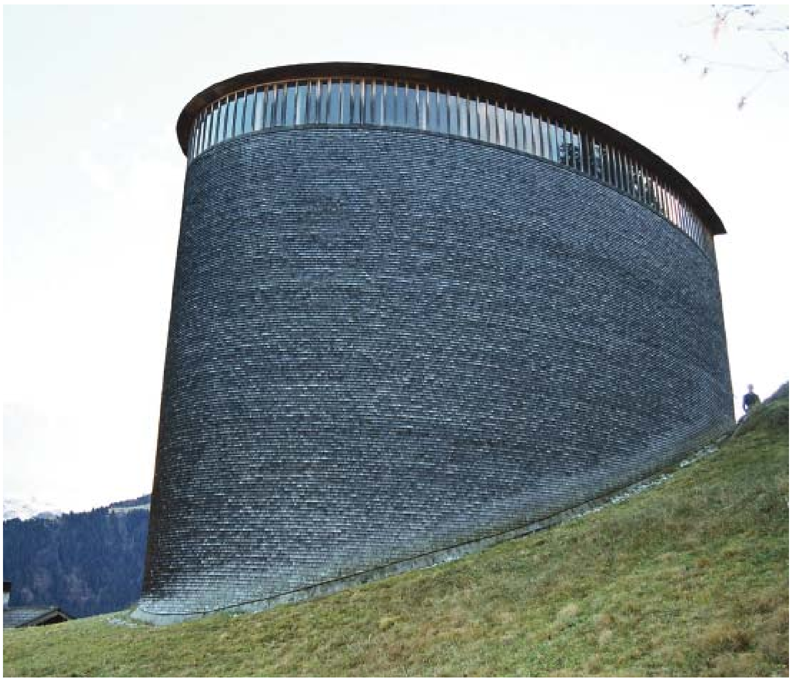
Entity refers to the building as we experience it in its entirety. This perspective has its point of departure in, among others, the 'four elements of building' defined by Semper (Bejder et al. 2011). According to Semper, these four elements, i.e. hearth, mounding, roofing and walling, constitute the fundamental basis of building (Semper 2004). Semper elaborates these elements – or 'motives' as he also calls them – into a more complex or metaphysical interpretation of architecture by drawing parallels between *man* and *building*. This is particularly evident in his extensive descriptions of textiles, where he links *surface* to *skin* and *dressing* (*Bekleidung*) (Semper 2004, volume one). A similar analogy between the building and the human body is propounded by Zumthor. Like man, the building has its structure or *skeleton*, which is covered by a protecting layer, the *skin* (Zumthor 2006). Hence, within this perspective and scale, we deal with the material as a building system, which can be technically as well as symbolically motivated.

Besides, on this scale, materials are experienced in their interaction with the spatial, functional and constructional settings for which reason an important aspect is the material's impact on the perceived atmosphere (Bejder et al. 2011). Within the architectural realm, Böhme's reflections on the phenomena *atmosphere* are interesting as he defines atmosphere to be that in-between subject and object, object being 'environmental qualities'. Being this indefinable matter floating between the perceiver and the perceived, Böhme nevertheless links atmosphere to the object

161-162
Chapel in Sumvitg, CH (1985-88) by Peter Zumthor. (photo: Ida Wraber)

163
For this modern Swiss house the wooden cladding wraps the building as a dark skin, but at the same time it turns into warm spatial enclosures. (Photo: Ida Wraber)

161



162

by suggesting that atmosphere radiates from the object and its physiognomy, this he calls the 'ecstasy of the thing' (Böhme 1993, pp. 120-123). Zumthor follows this line of thought by referring to the 'magic of the real', i.e. the magic of things as opposed to the magic of the thought, and hereby makes the architectural object capable of creating magic, i.e. creating *atmosphere* (Zumthor 2006, pp. 17-19).

Looking at the small chapel in Sumvitg, Switzerland, by Peter Zumthor, one experiences its *entity* in the contrast between the compact, closed and simple exterior and the light at warm interior. Besides, the composition of its slender skeleton that is slightly detached from the smooth massive wall, both along the wall and at the top where the separation between the two 'systems' let the light enter the room, together create an evocative *entity* [ill. 161-162].

4.5.2 Enclosure

Enclosure refers to the *parts* that constitute the body – the elements and surfaces that (figuratively) fill the gap between the knots and the seams (Bejder et al. 2012).

Within Semper's 'four elements of building', walling, i.e. *textile*, cover the materials which in a linear or planimetric (two-dimensional) form, are capable of binding, covering, protecting, and enclosing (Semper 2004). These features characterise the *enclosure* referred to here. Furthermore, as Moravanszky describes the surface of an object, *enclosure* is not merely a boundary that defines where the building ends, but an active interface between 'inside' and 'outside', that regulates the exchange of flows (energy, air, light, information, etc.) (Moravanszky 2000, p. 39). On this scale, we are more physically related to the material. We touch it and look at it from different angles and hereby perceive its tactile, visual, thermal, etc. qualities. Hence, in reference to the above-mentioned analogy between man and building propounded by Semper and Zumthor, and Semper's analogy between *textiles*, *surface*, *skin*, and *dressing*, the *enclosure* can be described as the pragmatic protecting *enclosure*, and at the same time it is the outermost layer through which the building communicates with its surroundings.

163

In this way, *enclosure* refers to the *physical enclosure* that wraps the building or building elements, i.e. a *dressing* [ill. 161, 163], but it also covers a more abstract aspect, namely the *spatial enclosure* that can be more or less physically related to the material as structural element [ill. 163].

4.5.3 Transition

Transition refers to the smallest parts of the building – the points where surfaces, elements, and materials meet (Bejder et al. 2011).

Among others, this emphasis on the joint manifests itself in the significance Semper ascribes to the *transition* from the stereotomic base to the tectonic frame. According to Semper, every work of architecture contains both tectonics and stereotomics; tectonics being the fundamental structure and stereotomics being the heavy construction, and the essence of architecture lies in the *transitions* between these (Frampton 1995). This glorification of the joint is carried on by several architects. The American architect Louis Kahn (1901-79) describes the joint as the 'adornment of the event of two materials coming together' (Wurman 1986, p. 239), and the contemporary architect and architectural theorist Marco Frascari (b. 1945) claims that 'any architectural element defined as detail is always a joint.' Frascari ascribes the details a double articulation, suggesting that details can be *material joints*, as the connection between the column shaft and an architrave, or *formal joints*, as a porch which forms the connection between an interior and an exterior space (Frascari 1984, p. 24). Besides, like Semper, Zumthor draws parallels between music and architecture by describing both as arts of making a meaningful whole out of many parts. The joining of these single parts; the points where surfaces intersect and different materials meet, he describes as the edges and joints (in Semper's words: seam and knot), and according to him the quality of the finished object is very much determined by the quality of these joints. The formal detailing of these *transitions* are – if successful – capable of communicating the entire building; expressing belonging or separation, tension or lightness, friction, solidity, fragility, etc. (Zumthor 1998, pp. 11-16). In this perspective, the transition between materials become more than merely a physical joint, it becomes a piece of poetry.

164
Corner detail, FDF outdoor centre Sletten, DK (2003) by aart architects. With the exposed cross-section of the wooden boards one clearly sense the depth of then exterior surface. (Photo: Ida Wraber)

165
The bevelled boards form a sharp corner. (Photo: Ida Wraber)

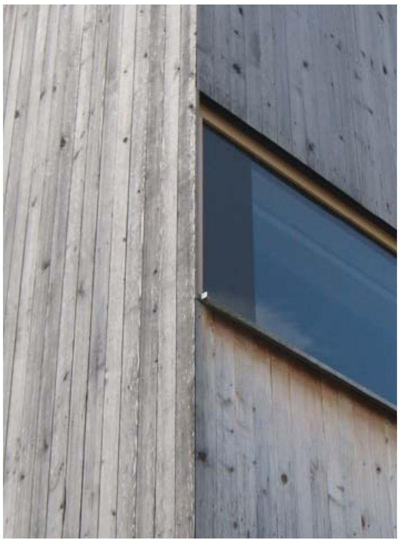
166
At this preschool in Vorarlberg, AT, the window is extended which enhance the perception of the wooden skin as a thin membrane . (Photo: Author)

167-168
Bregenz Museum of Art, AT (1990-97) by Peter Zumthor. (Photo: Author)

164

165

166



Hence, these *transitions* can be both *material joints* and *formal joints*, which are related respectively to the physical material and the spatial experience. Likewise, the *material joint* itself can be both pragmatic and abstract. In its pragmatic form, the *material joint* constitutes the actual connection of two or more materials, while it in its abstract form can – if successful – constitute the entire architectural expression; communicating belonging or separation, tension or lightness, etc. [ill. 164-166] (Bejder et al. 2011).

An example that illustrates both a wrapping *enclosure*, i.e. a *dressing* of the building, and the *transition* between elements and surfaces as the most central part of a building's natural ornamentation, is the art museum in Bregenz (1997) designed by Peter Zumthor. Using a size reasonable for the material, production and erection, Zumthor creates a patchwork of glass sheets that wraps the entire building. The detailing and the expression lie in the *transition* between these sheets, i.e. the seam, and in the conspicuous fixation, which altogether exemplifies the principle, proclaimed by Semper, of 'making a virtue out of necessity' [ill. 167-168] (Semper 2004).

This example also indicates that the three perspectives are not to be regarded as independent features, but rather as interrelated parts of the same unity. The proposed division is solely suggested in order to insure that the material is studied from various perspectives and distances, i.e. from its smallest details to the building in its entirety, thus facilitating a thorough insight into its qualities and limitations (Bejder et al. 2011).

167

168

4.6 A MODEL FOR ANALYSING MATERIALS AND THEIR ROLE IN ARCHITECTURE

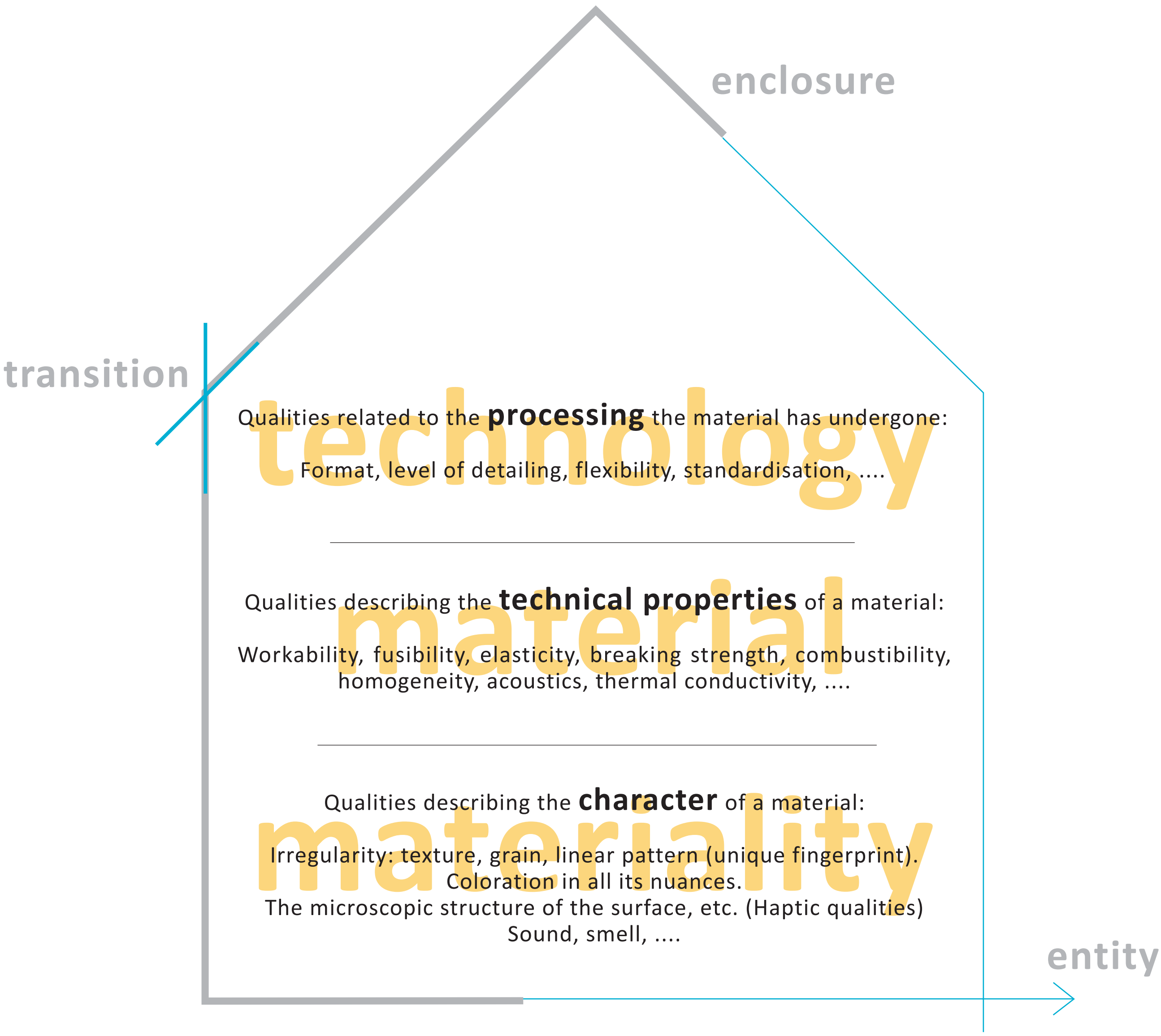
The six aspects outlined above, i.e. *technology*, *material*, *materiality*, *entity*, *enclosure*, and *transition*, constitute the model that is to structure the analysis and evaluation of the perception of CLT [ill. 169]. The model is kept simple in its visual design, and only the most essential keywords are included. Other than the six aspects, only examples of qualities related to *technology*, *material* and *materiality* appear in the model. Likewise, in relation to *materiality*, the qualities exemplified relate to describing the *character* of the material, i.e. its *physiognomy*.

169
The six aspects that constitute the model for analysing and evaluating materials in architecture.

As described above, the perception of these qualities may be influenced by the *synaesthetic* or *social character* of the material. Besides, the experience, perception, and interpretation of the materials and the architectural object will always be marked by the personal background of the perceiver, just as the object will have been influenced by more or less known extrinsic factors, i.e. cultural, political, economic, etc. During the process, different model designs have been developed and discussed. However, a relatively simple design for the model has been chosen, in order to make it more tangible for structuring the architectural analysis. Hence, these latter perspectives are merely implicitly present in the model.

This model forms the basis for the analysis and evaluation of the *materiality of CLT*, of which an excerpt of the findings are presented in the following.

169


enclosure
transition
technology
Qualities related to the **processing** the material has undergone:
Format, level of detailing, flexibility, standardisation, ...
material
Qualities describing the **technical properties** of a material:
Workability, fusibility, elasticity, breaking strength, combustibility, homogeneity, acoustics, thermal conductivity, ...
materiality
Qualities describing the **character** of a material:
Irregularity: texture, grain, linear pattern (unique fingerprint).
Coloration in all its nuances.
The microscopic structure of the surface, etc. (Haptic qualities)
Sound, smell, ...
entity

4 PART 2:
ANALYSING THE MATERIALITY OF CLT

As described briefly in chapter 2, this analysis has evolved through an iterative process including literature reviews, model development, intuitive and structured analyses. The results presented in the article *The materiality of novel timber architecture - based on a case-study analysis of Cross-laminated Timber* (Bejder et al. 2012) (appendix 2), is an excerpt of this process, with particular focus on the aspects relevant for describing and illustrating how CLT is experienced, perceived and interpreted as an architectural material, i.e. illustrating the *materiality* of CLT. In the following part two of this chapter, some of these aspects are presented and, at times, elaborated further through additional projects, photographs and drawings. However, firstly, the five cases are briefly presented.

4.7 PRESENTATION OF CASES

The analysis presented in (Bejder et al. 2012) takes its point of departure in one main case. Along the way, this case is supplemented with qualities clarified through four other cases, in order to substantiate a point or to exemplify other features. Furthermore, a few more projects are included as they illustrate qualities of CLT particular expressively. These are regarded as exemplifications of the given features rather than actual cases, since these have not been analysed thoroughly on the basis of the model developed in (Bejder et al. 2011).

As the aim has been to clarify essential qualities related to the experience of CLT, the focus has been on in-depth analyses of a relatively small amount of cases (see chapter 2). The five cases that constitute the underlying basis of the analysis presented in (Bejder et al. 2012) are chosen on the grounds that they, in the design, take advantage of the specific qualities of CLT (to a varying extent), i.e. CLT is not applied simply as matter to provide a predetermined form. Besides, as the aim is to study how CLT is perceived, a common feature of the cases is that CLT is exposed to some extent. All five cases are located in Western European countries; Denmark, Germany, Switzerland, and Austria. Though, the cases are chosen on the grounds that they exemplify a wide architectural spectrum in their use of CLT. The cases keep within the small scale building. This means that they can be regarded on a similar basis, of course taking into account the differences in legal requirements of the different countries. Nevertheless, as all the cases are detached buildings of maximum two storeys, none of them place severe demands in regard to e.g. fire and sound transmittance, and the cases are considered comparable in regard to the focus of the analysis. The five cases are listed below:

170

1.
The main case is a small annexe to a holiday cottage in Skagen, Denmark [ill. 170]. Behind the project are architect Jesper Nielsen and engineer Henrik Almegaard. The annexe is built in 2005 and consists of 165 m2 cross-laminated timber plates, which provide the spatial enclosure, load-bearing structure and interior finish in one layer. The interior surfaces are exposed untreated CLT elements in combination with white-painted plywood.

171

2.
Single-family house in Haus, Ennstal, Austria (2002), by Ulli Koller and Thomas Stiegler [ill. 171]. A composition of horizontal and vertical CLT elements constitutes the floor and roof construction, bearing walls and partitions. All surfaces are exposed untreated CLT elements.

172

3.
Holiday cottage in Them, Denmark (2006), by architect Jesper Nielsen [ill. 172]. CLT elements are used for the entire construction: bearing walls, partitions, flooring structure, and roof construction. All interior surfaces appear as exposed CLT elements, treated with an all covering white paint.

173

4.
Single-family house in Hamburg (2007), by Kraus Schönberg Architects and Werner Sobek Engineers [ill. 173]. The house is partially sunk into the ground, and its concrete base is in contrast to the exposed and white-painted CLT elements, which constitute the construction raised above ground.

174

5.
Temporary chapel for the deaconesses of the Church of St-Loup, Pompaples, Switzerland (2008) [ill. 174]. A collaboration between bureau d'architecture Danilo Mondada and Shel: Buri & Weinand. CLT elements constitutes in one layer the load-bearing structure, spatial enclosure, and internal finishing of the folded structure of the chapel. Besides, the folded form of construction makes possible a very slender construction, i.e. 60 mm for horizontal and 40 mm for vertical slabs (Schittich 2010).

The data collection for the analysis is photographs and information gained through literature. Additionally, personal visits to Skagen and Them as well as information gained through contact with the architect and engineer behind these two projects (cases 1 and 3 above), have formed the basis of the analysis. A study trip late in the project process has furthermore provided extra documentation in form of photographs, which are used for a further visual elaboration of the qualities of CLT which are related to expressing its *materiality*. In the following, an excerpt of the qualities presented in (Bejder et al. 2012) is provided.

4.8 CASE-STUDY ANALYSIS AND RESULTS

Organised in three sections, an excerpt of the analysis and evaluation of the *materiality of CLT* is presented in the following. The analysis has its basis in questions such as: 'Does the project demonstrate the processing the material has undergone (*technology*), the material's technical capability (*material*), or the material's character (*materiality*)? If so, does this manifest itself in the building in its *entity*, in its *enclosures* or *transitions*? Based on this, the following seeks to clarify how CLT is *perceived* in its *entity*, *enclosures* and *transitions* [ill. 175].

175
Focus of the presented results.

175

	entity	enclosure	transition
technology	format mass customisation level of detailing	format 'state of nature' level of detailing	format level of detailing
material	the plate applicability workability	structure of plate perforation hygroscopic	longitudinal joints assembly workability
materiality	form-material approach skeleton and skin atmosphere	wrapping space or structure plasticity physiognomy	'putting things together' knot and seam articulated or hidden seam

176

177

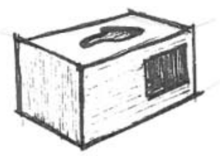
176
Annexe in Skagen, DK. (Photo: Author)

177
House in Haus, Ennstal, AT. (Photo: courtesy of KLH)

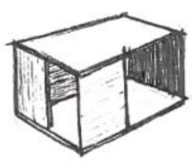
178
Spatial configurations that are based on the properties of the plate: from the enclosed box to the floating structure.

179
The unfinished building of the annexe in Skagen. (Photo: Henrik Almegaard)

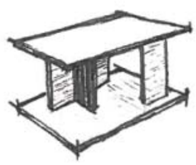
178



a



b



c

4.8.1 The perception of CLT in its *entity*

Experienced from the outside, the small annexe in Skagen and the house in Ennstal express completely different architectural traditions, and offhand, nothing indicates that these are constructed of the same material [ill. 176-177]. However, although it is not equally evident at first glance when experiencing the buildings in their *entity*, both these cases demonstrate what the material *can do*, i.e. reflect the technical properties of CLT. In Ennstal, the large massive plates *form* the entire architectural expression, whereas the external wooden sheathing that wraps the small annexe in Skagen 'covers the sheet tectonics', to use the words of Deplazes (Deplazes 2001). Nevertheless, looking at the unfinished annexe, its compact and closed body appears completely logic to the massive plates which form the simplest yet stable construction – an enclosed box where a small number of elements provide several functions [ill. 179]. Thus, for the annexe, CLT is utilised to carry on a traditional architectural expression, though through a simpler constructional principle. Hence, this case also demonstrates a socio-cultural approach to its use of materials. Contrary hereto, the house in Ennstall finds its form based on the specific properties of CLT, i.e. the plate, as it was suggested to do by Viollet-le-Duc and Frank Lloyd Wright, among others (Bejder et al. 2011).

These cases exemplify three building configurations provided by the massive plates [ill. 178]. These building configurations range from the enclosed box with framed openings somewhat randomly cut in the structural homogeneous plate (a) to an open 'floating' structure (c). In between these, the closed form dissolves and the plate does not only generate the spatial enclosure but also the openings (b). Although it is not equally perceptible in the different building systems, all three configurations utilise the unique properties of CLT, i.e. the large format and multi-functional plate, to obtain simple structures of only few elements (Bejder et al. 2012).

179

These building configurations also express the ambiguity of the laminated timber products regarding the type of construction to which they belong. Although CLT is based on the 'stick', which characterise the filigree constructions, the CLT element in its entirety forms a solid construction, similar to the log constructions, as described in the introduction (1.1.1). On the other hand, due to its structural capacity, the massive plates can be arranged in a floating structure, which has features similar to the filigree constructions, i.e. the not directly defined interior space and the floating transition between inside and outside. This ambiguity of the laminated timber products is also expressively exemplified by the small Finnish pavilion (2006) by TKK Puustudio [ill. 184].

Experiencing CLT as a part of an *entity* also clarifies that the CLT element appears as a fusion between a structure and an enclosure, i.e. a fusion between the *skeleton* and the *skin* if referring to the analogy between man and building propounded by Semper and Zumthor (Bejder et al. 2011). The impression of the spatial enclosure as a continuous skin increases the more closed the building is, as exemplified by the annexe and the houses in Them and Hamburg. In contrast, the perception of the plates as a bearing skeleton increases as the box dissolves, and the spatial enclosure is generated by a composition of separate elements, as exemplified by the house in Ennstal. Here, in-plane joints, exposed cross-sections, and the crude jointing of steel columns directly to the ceiling, clearly express the structural function of the CLT element [ill. 180].

180

180
House in Ennstal. (Holzbau-stiegler 2012)

181-182
Interior, annexe in Skagen. (Photos: Adam Mørk, courtesy of Jesper Nielsen)

181

182

183

Through the analysis in (Bejder et al. 2012), it is exemplified how the same material can lead to completely different atmospheres according to the spatial arrangements, the material combinations they are a part of, and how they are refined and have undergone surface treatments. In the annexe, the CLT in interaction with variations in proportions of the spatial enclosure, contrasts in colours, and between the massive walls and large openings to the outside, lead to great spatial diversity within this enclosed 'box', and create an open yet intimate and cosy atmosphere [ill. 181-182]. A completely different atmosphere characterise the holiday cottage in Them and the house in Hamburg, where the all-covering white painted interior appear more homogeneous and cold [ill. 183]. Referring to a material's *synaesthetic character*, as explained by Böhme (Böhme 1995, pp. 40-41), this effect can be explained by the fact that the white colour is atmospherically perceived as cold, and the yellow/brown wood colour is atmospherically perceived as warm. Compared to these three examples, the atmosphere in the small chapel in St-Loup is more intense, warm and dim with its all covering wooden skin. The atmosphere even appears slightly oppressive from the centre of the building, where the irregular folds seem to pull the walls and ceiling closer inwards, before the room opens upwards as one approaches the altar [ill. 185]. Together these cases clearly clarify that perceiving architecture in its *entity*, i.e. perceiving its *atmosphere*, does not merely involve the materials used, but also their interplay with the spatial arrangement, light, construction, other materials, etc., as Zumthor stated (Bejder et al. 2011).

183
Interior, house in Hamburg. (Photo: courtesy of Kraus Schönberg Architects)

184
Pavilion, TKK Puustudio, FI. (Photo: courtesy of Finnish timber council)

185
Interioe, chapel in St-Loup. (Mondada Architects 2012)

185

184

4.8.2 The perception of CLT in its *enclosures*

Studying CLT as an *enclosure* clarifies that it in fact consists of two surfaces: the *planar* and the *cross-sectional* one [ill. 189 b & c] (Bejder et al. 2012). The *planar surface* is characterised by several wooden lamellae which fit perfectly together. There is no distance between the lamellae, nor are these chamfered to enhance each member. Besides, there are no visible fixations, and the transition from one surface to another in the corner is carried out with great precision: with the lines of lamellae precisely carried on from surface to surface, as if the surface simply bends [ill. 190]. This underpins the perception of the material as a wrapping *enclosure*, a *skin*, as was the experience of the building in its entirety.

In the annexe, the *cross-sectional surface* is characterized by three layers of which the two outer layers show the longitudinal section of the lamellae. In-between these are the cross-sectional surface of the lamellae with their characteristic circular growth rings [ill. 186]. With both surfaces exposed, the CLT is perceived in its entirety for the first time: one perceives its cross-laminated structure, its large format, and its multifunctional character, i.e. being both a load-bearing wall and slab, as well as its interior finish [ill. 187-188].

In this way, the *planar surfaces* alone are purely related to the *spatial enclosure* they create, i.e. figuratively speaking they are *disconnected* from the underlying structure, whereas the two surfaces together form the skin of the plate, i.e. they wrap the structure, not the space [ill. Xx a] (Bejder et al. 2012).

187

188

186

a *b* *c*

189

Another significant difference characterising the surfaces of the CLT element, is the 'state of nature' they represent. The *planar surface* is characterised by the modularity, linearity, and plain flat surface of the lamellae. This standardised form corresponds to the processing at sawmills where a log is cut into several pieces of dimensional lumber. Hence, this surface demonstrates only a part of the technology behind the timber product and, consequentially, also gives associations to other (known) timber products like boards used for non-bearing sheathing or panelling [ill. 190-191]. In the *cross-sectional surface*, on the other hand, the woven structure is visible, and thus, the foundation for creating these massive plates (Bejder et al. 2012). Hence, the *planar surface* merely represents the 'state of nature' of the lamellae, whereas the *cross-sectional* and the *planar surface* together represent the high-technological and composite 'state of nature' of the cross-laminated, large format massive plate.

190

191

186
The cross-sectional surface. Annexe in Skagen. (Photo: Author)

187-188
The planar and the cross-sectional surface. Interior KLH office, AT. (Photo: Author)

189
a The abstract enclosures related to respectively the space and the structure.
b The planar surface
c The cross-sectional surface.

190
Detail annexe in Skagen. (Photo: Author)

191
Traditional panelling at 'A cabin near Vassfaret' (1974) by Wenche Selmer. (Tostrup 2006)

Perforations in the CLT elements are created by either leaving gaps in the structure or *removing* material (Bejder et al. 2012). In the experimental *Naked House* (2006, dRMM architects), the material removed for openings is utilised for furniture. This demonstrates in an expressive manner the otherwise inappropriate waste of material connected to the creation of openings based on removing material [ill. 192]. The Naked House also exemplifies the variety within shapes and sizes of openings, i.e. from large, regular or amorphous holes to smaller perforations, which generate a filtration of light and view [ill. 192 & 195]. The latter is a frequently used feature in timber architecture and is traditionally achieved by *adding* slender wooden 'sticks' to create a grille through which light and view is filtered, e.g. seen in Alvar Aalto's Villa Mairea (1939) and Kengo Kuma's Great (Bamboo) Wall (2002).

This fundamental difference between a massive surface from which material is *removed* and the *addition* of material to become a surface is an essential feature of the perception of CLT [ill. 196]. Perforating the surface in the small scale (also related to the above-mentioned building configuration a), involves *removing* material from the massive. However, in return, the depth of the element provides the possibility to either enhance or minimise the perception of the depth and thus the framing of the perforations [ill. 197], for which one might find inspiration in the works of e.g. James Turrell and Steven Holl [ill. 198]. Creating openings on a larger scale (related to building configuration b and c), on the other hand, involves an *addition* of material. The opportunity also occurs hereby to create a rhythmic expression similar to a filigree construction, although in another form and scale [ill. 193-194].

192

192
Naked House by dRMM architects. (dRMM Architects 2012)

193
Exhibition pavilion in Spain (2008). (Photo: courtesy of alterMATERIA)

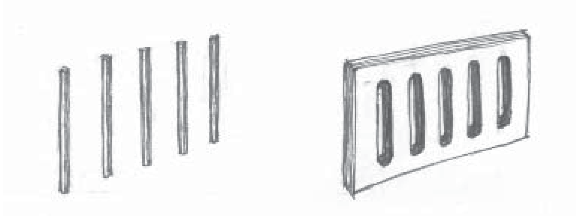
194
For a large enough building even the huge format of the CLT element become a module, which provide a clear rhythm. (Photo: courtesy of Miguel Navado)

195
Naked House by dRMM architects. (dRMM Architects 2012)

193

194

195

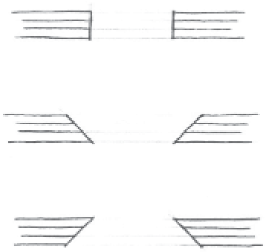


196

196
Filtration of view/light by the 'sitck' vs the 'plate'.

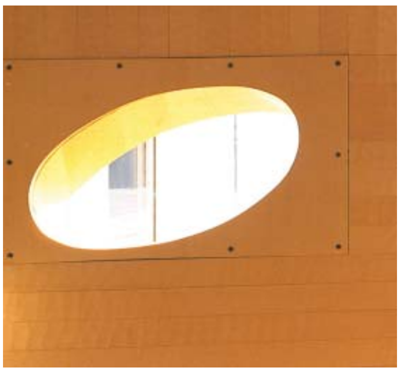
197
By working the framing of the opening the it can be either enhanced or minimised.

198
Detail of the doors, chapel of St. Ignatius, Seattle, USA, by Steven Holl Architects. (Weston 2003)



197

198



In both cases, perforating the surface leads to an exposure of the *cross-sectional surface* and hereby a paradox of the material is revealed: in order to experience the material in its entirety as a plate, one needs to omit or even remove material (Bejder et al. 2012).

The *planar surface* is characterised by the linearity and modularity of the slender lamellae that impart a clear direction and rhythm to the large surfaces. However, in (Bejder et al.2012) it is clarified that despite the immediate dominance of the lamellae, these in fact merely become the ornament of the CLT element. As it was also concluded in chapter 3, the shaping of the element and openings is not given by the structure. Hence, it is technically possible to produce elements and recess perforations of various sizes and shapes. However, the analysis of how this feature is *perceived* raises the question whether there are any 'aesthetic rules' related to this possible detachment between the final shape of the element and its ornamentation (Bejder et al. 2012).

As also described in chapter 3, variations in temperature and moist imply that each lamella will change slightly over time and therefore cracks and smaller variations in height will occur. The linearity and modularity of the lamellae will thereby appear more dominant. This feature is even more evident on white-painted surfaces, as those of the house in Hamburg [ill. 199] where the visual contrast between what is illuminated and what is in shadow is particularly notable. When experienced from a distance, the surfaces here appear as a homogeneous continuous *enclosure* (as described earlier), but when getting close to the surfaces, each lamella stands out as does its grain pattern in both visual and tactile sense. So when Deplazes states that the coloured painted 'thick-laminated sheet' is unable to 'express itself as a material' (Deplazes 2001), he is probably referring to the material as experienced from a distance. At least in the house in Hamburg, where both the *planar* and the *cross-sectional surfaces* of the massive plates are exposed, the material clearly demonstrates what it *can do* as well as what it *is*.

199

4.8.3 The perception of CLT in its *transitions*

Through the analysis of CLT seen through its *transitions*, the conclusion, from a pragmatic point of view, is that two features are particularly striking. These are the simple assembly of the large plates and the longitudinal joint, i.e. the *seam* to use the words of Semper, as the *natural* way to connect the CLT elements (Bejder et al. 2012).

The annexe in Skagen and the house in Hamburg exemplify the simple and relatively low-tech jointing principle, which was described in chapter 3. In Skagen, a detail of the *transition* from roof to wall shows how the pitched roof element is simply bevelled and fastened directly to the wall element with screws [ill. 201]. In Them, two wall elements are screwed together after which the screws are (attempted to be) concealed using filler and paint [ill. 200]. This demonstrates the ease by which one can work, assemble and join this material, but it also reveals a sensitivity of the material (Bejder et al. 2012).

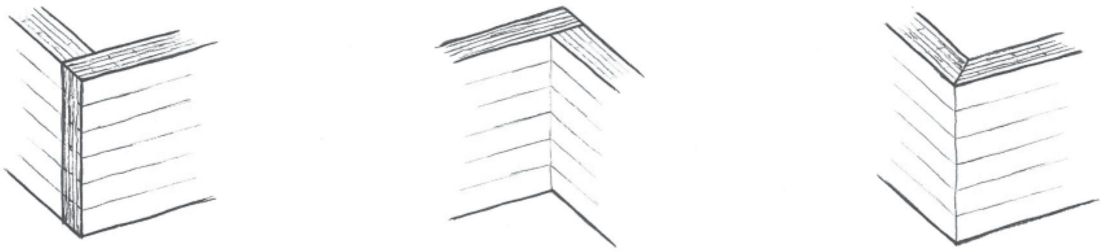
200

201

199
Interior, house in Hamburg. (Photo: courtesy of Kraus Schönberg Architects)

200
Detail, house in Them. (Photo: Author)

201
Detail assembly of the annexe in Skagen. (Photo: Henrik Almegaard)



202 *a* *b* *c*

The analysis furthermore clarifies how the design of these physical connections is of crucial importance to the perception of the *transitions* and the spatial experience in general. Through the analysis, two types of *transitions* are clarified: the *articulated* and *hidden seam* [ill. 202]. The *hidden seam* leaves no sense of the massive character of CLT, but underpins the perception of the material as a skin, i.e. like a tent where the spatial enclosure is created by the pull of the guy ropes and the corners are simply folds in the textile. In this way, the *hidden seams* are rather perceived as *spatial transitions* (formal joint) than actual physical connections (material joint) (Bejder et al 2012). This feature is particularly evident in the chapel in St-Loup, which folded structure is defined by a large number of smaller, irregularly shaped plates unified in alternately concave and convex seams [ill. 204]. This composition furthermore constitutes a unified surface that appears plastic despite its massive body, and a steady rhythm is defined by the long thin seams. This also illustrates how the *transition* between materials and elements can constitute the most conspicuous detailing of a building, as argued by Semper, Zumthor and Frascari (Bejder et al. 2011).

The *articulated seam*, on the other hand, appears three-dimensional and crude with its massive woven structure and low-tech jointing of one plate to another. Besides, with its exposed cross-sectional surface this *transition* entails a hierarchy between the CLT elements, which brings the structure in focus rather than the space [ill. 203].

Common for the *hidden* and the *articulated seams*, is the great accuracy in the *transitions*. This bears witness to the potential of timber, enabled by contemporary tools and technology, just as it expresses the natural workability of wood. This high level of detailing in cuttings, surface processing and assembly, leads to a very smooth and delicate overall appearance. In this way, the *transitions* of the massive CLT plates clearly manifest the style of industrially manufactured timber architecture as being one of continuity, sharpness, and precision (Bejder et al. 2012).

202
a The convex articulated seam.
b A concave seam is always hidden.
c The convex hidden seam (bevelled plates).

203
Articulated seam at the entrance of the office building in Leoben, AT (2009) by Nussmüller Architekten. (Photo: Author)

204
Interioe, chapel in St-Loup. (Mondada Architects 2012)

203

The analysis hereby illustrates how the *transitions* related to the CLT elements become more than merely physical meetings between materials, i.e. they become *spatial transitions* and more or less dominating ornaments, communicators of the material's multi-functionality, workability, and characteristic structure. Likewise, the clean-cut edges and precise *transitions* communicate the processing, which these prefabricated elements have undergone. Hence, referring to the model, the analysis concludes that through its *transitions* this novel timber product expresses all three levels – *technology*, *material* and *materiality* – although in different ways and to varying extent (Bejder et al. 2012).

204

4.9. THE APPLICABILITY OF THE MODEL

The developed model represents one of many possible approaches, and the result naturally reflects the strengths and limitations of this particular model. The aim has been to develop an explicit model that includes aspects essential for clarifying how an engineered material like CLT is experienced and perceived, and that additionally can help structure an analysis. In other words, the model is developed specifically with the aim of structuring the analysis of the *materiality* of CLT.

By clarifying qualities of CLT which relate to *technology*, *material* and *materiality*, and by studying these qualities through the three perspectives, i.e. CLT being a part of the building as an *entity*, an *enclosure* and a *transition*, it has been possible to reach a thorough insight into the perception of CLT as a generator of architecture. By exploring CLT specifically on the basis of the qualities related to the processing the material has undergone (*technology*), its technical properties (*material*), as well as the qualities describing its character (*materiality*), the analysis has led to an enhanced understanding of CLT and its specific means for describing what it *can do*, as well as what it *is* as a material. Besides, the analysis has heightened the awareness of the interrelation between these main aspects. Since the aim specifically is to inquire into the *materiality* of CLT, one may consider if *technology* and *material* are actually needed in the model. However, as described in part one of this chapter, the qualities related to *technology* and *material* are inevitably linked to the overall perception of the material, i.e. its *materiality*. In the analysis, this manifests itself in a direct manner as well as indirectly, e.g. in the way that our previous experiences with timber products have influence on our expectations to new timber products, like CLT. An example is the perception of the *planar surface* of CLT. Exposed alone, i.e. not together with the *cross-sectional surface*, the CLT element is perceived as a non-bearing facing, rather than a massive structural element. This is partly due to the fact that wooden boards are often used as such and partly due to our expectations to the technical properties of these boards – one does not expect these relatively slender boards to be capable of taking up the loads on the wall element. When the *cross-sectional surface* is exposed as well, new qualities related to describing the *character* of CLT are revealed. By sensing the large format of the element and its cross-laminated massive structure, one realises that another technology is behind this product than that of the boards themselves and the laminated massive structure indicates enhanced strength. Hereby the expectations to and thus the overall perception of CLT, i.e. its *materiality*, changes significantly.

Regarding the three perspectives, the analysis demonstrates that in several cases there is agreement between the experiences of the material as being a part of the building in its *entity*, and when zooming in on the material as a creator of *enclosures* and *transitions*. However, at some points, changing perspective entails a significant change in the perception of the material, thus providing insight into material qualities that would not have been uncovered if this specific division in scale/perspective had not been applied.

The perception of CLT described above might have been reached through an intuitive and unstructured analysis of the cases. However, then it would be more random and unclear if all aspects would be uncovered. By applying the proposed structured model and its six aspects, it has been possible to identify essential qualities related to the perception of CLT as well as to clarify the influence of these qualities within the architectural realm, and hereby reach a comprehensive insight into the *materiality of CLT.*

Compared to e.g. the more general overview of material properties included in the model of Hegger et al. (referred to in the introduction of this chapter part one), this model is specifically focused on aspects related to the experience and perception of this particular material, i.e. aspects related to evaluating the *materiality of CLT.* Therefore, aspects related to economy, sustainability, durability, etc. are not included. Such aspects are of course most essential to, and should be included in, the overall judgement when choosing and applying materials for building. Hence, it is important to point out that the model developed here is not to be regarded as an absolute list of aspects that needs to be considered when dealing with materials in architecture. Rather, the model provides an analytical tool for clarifying qualities related to how this specific material is *perceived.* In that way, this model constitutes a supplement to the more general discussion of the material, i.e. a model that can help ensuring that the 'soft' values of CLT are identified and thus can be included in the general reflections on the overall architectural potential of CLT.

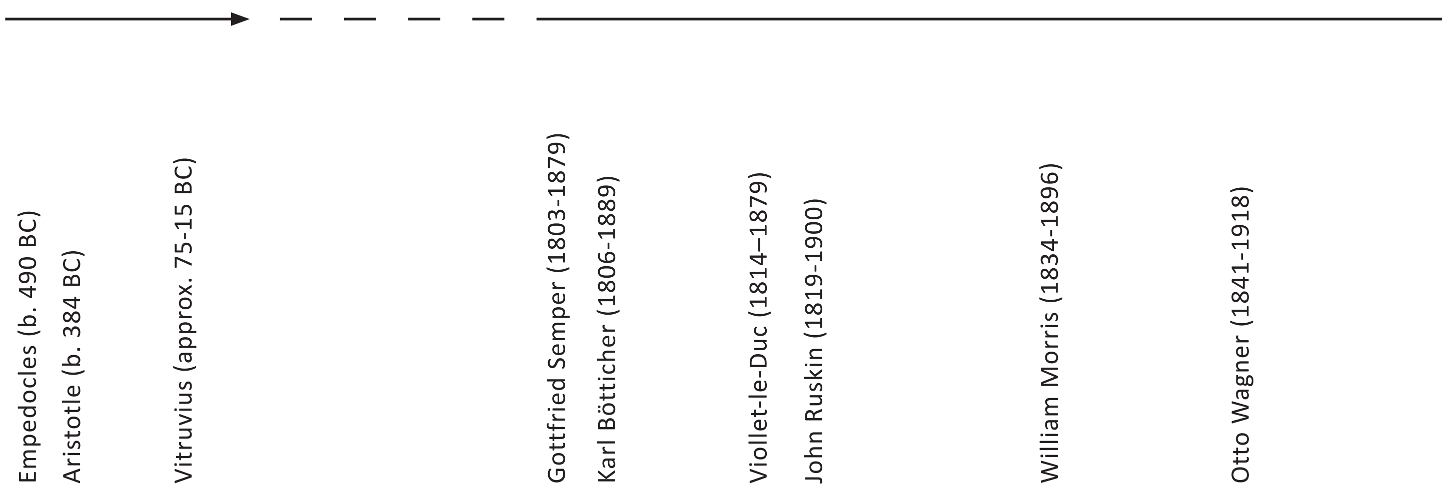
Developing such a model naturally leads to the question about the general applicability of the model, i.e. is the model applicable for analysing other materials than the engineered CLT? As described earlier, the model has been continuously refined through smaller intuitive as well as structured analyses. These 'cases' have been timber architecture in general, different engineered timber products, and CLT in particular. Similar analyses of other materials may uncover other examples of qualities, which would be essential to include in the model, if the materiality of these other materials is to be evaluated. Nevertheless, in its overall form, i.e. the six aspects which stem from the wide theoretical foundation, the model is regarded as a generally applicable foundation for analysing most materials.

A final consideration regarding the applicability of this model is related to its theoretical foundation. Rather than following a specific branch within theory of science, the aim has been to found the model on a wide realm of understanding and interpretation of materials and their role in architecture. However, this also means that the selection of theorists and architects, as well as the parts of their theories that are included, have great impact on the outcome of the model. Therefore, the form and content of the model presented here are also to be regarded as the result of the first iterations of a continuous process. The model can be further refined through additional theoretical insight and case study analyses.

The theorists referred to in this study represent a considerable time wise breadth, i.e. from ancient philosophers, to 19th century architectural theorists, and contemporary practicing architects [ill. 205]. Just like more layers are added to our understanding of materials and thus to the model, the theoretical foundation expresses a progression in knowledge over time. Hence, it spans from Aristotle's early reflections on matter and form to contemporary Peter Zumthor's phenomenological descriptions of materials within the architectural realm. Their theoretical frame of reference, as well as their cultural, technological and architectural context have been completely different. Therefore, these approaches to materials naturally cannot be directly compared; rather they mirror a societal development. Frank Lloyd Wright touches upon this relation in his writings about 'The Art and Craft of the Machine', where he proclaims that the critical approach towards machine-made products propounded by e.g. Ruskin and Morris, is to be seen in the light of the possibilities provided by (or limitations related to) the machine at the time. He writes:

The machine these reformers protested, because the sort of luxury which is born of greed had usurped it and made of it a terrible engine of en-

205



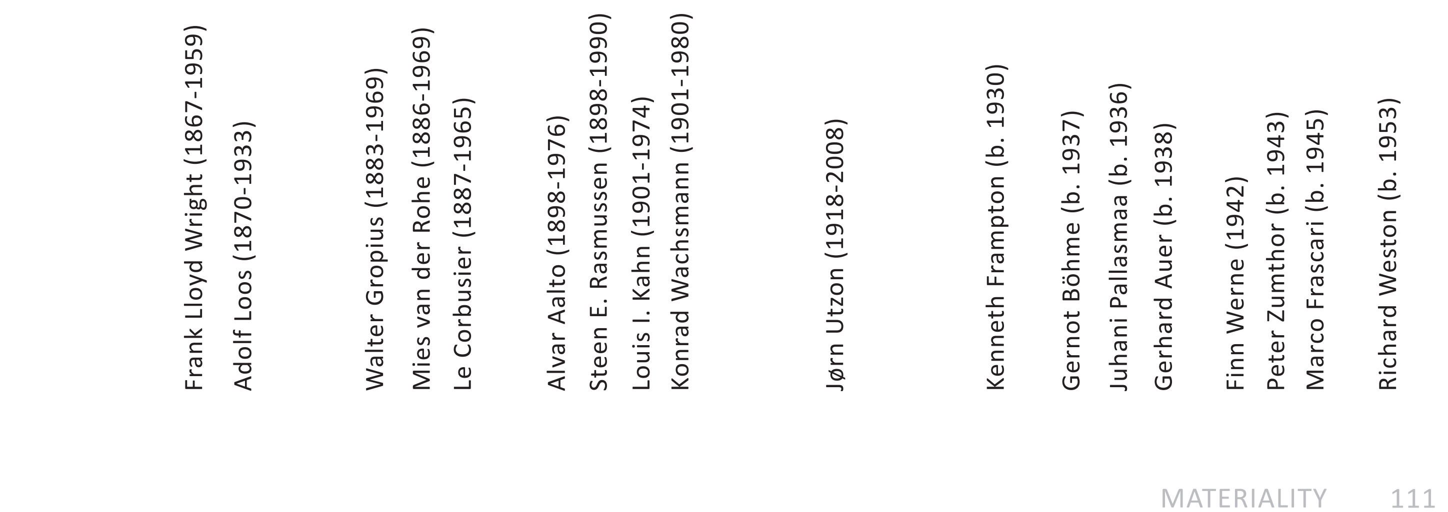
slavement, deluging the civilized world with a murderous ubiquity, which plainly enough was the damnation of their art and craft.

It had not then advanced to the point which now so plainly indicates that it will surely and swiftly, by its own momentum, undo the mischief it has made, and the usurping vulgarians as well.

Nor was it so grown as to become apparent to William Morris, the grand democrat, that the machine was the great forerunner of democracy. (Wright 1901/2007)

Thus, when smaller excerpts of the theories of the selected theorists and architects are included in the theoretical foundation of this model, it is not to indicate that these fragments are all-covering or definitive for the standpoints of the theorists. Nor are the different approaches regarded as mutually exclusive, although they may be presented as opposites. Rather, the specific theories and statements included are excerpts taken out with the special view to clarifying the *materiality of CLT.*

The conclusion of the case study analysis, for which the model forms the basis, is presented in the following section.



4.10 CONCLUSION

The aim of this study has been to inquire into the experience and perception of CLT, in order to clarify whether this engineered timber based product is solely characterised by its technical properties or it has retained the poetic qualities of wood, i.e. to examine if CLT merely is *material* or if it also possesses *materiality*. The methodical approach has included two steps. Firstly, a discursive model that includes aspects essential for analysing and evaluating the materiality of CLT within an architectural context has been developed. This model consists of six aspects, i.e. *technology, material* and *materiality, entity, enclosure,* and *transition*. Secondly, this model has been applied for structuring the analyses of a number of cases constructed of CLT.

By clarifying qualities of CLT related to *technology, material* and *materiality,* and by studying these through the three perspectives, i.e. *entity, enclosure* and *transition,* the analysis clarifies that CLT with its unique massive cross-laminated structure brings a change to timber architecture from being characterized by the 'stick and knot' to being characterized by the 'plate and seam'. This transformation is evident in all three scales and is pivotal to the perception of the material as a part of an *entity*, as an *enclosure*, and in its *transitions*.

Being a fusion between the structural tectonics and the covering textile, CLT possesses a multi-functional character, i.e. being a load-bearing and stabilising element, and at the same time functions as the protecting enclosure. The in-plane joints, exposed cross-sections, and the crude jointing of steel columns directly to the ceiling in the house in Ennstall clearly express this multi-functionality.

Experiencing CLT in its *entity* has led to the conclusion that as a generator of form, the CLT elements provide a number of different building configurations, ranging from the enclosed box to the floating structure. Furthermore, studying the material as an *enclosure* and as a *transition* has clarified that according to the building configuration, CLT is perceived either as a *skin* or a massive *skeleton*. Perceiving the material as an enclosing skin is closely connected to the *planar surface* and the *hidden seam,* whereas perceiving the material as a skeleton is related to the exposed *cross-sectional surface* and the *articulated seam.*

Studying CLT as an *enclosure* has clarified that it in fact consists of two surfaces, the *planar* and the *cross-sectional surface*. The *planar surface* is characterised by the modularity and linearity of the wooden lamellae, their grain pattern, warm colours and tactile structure, and thus pass on the uniqueness of each piece of wood to the surfaces. This is a unique feature for a high-technological product, which in many cases is accused of being too uniform and characterless. Besides, experiencing CLT as an *enclosure* has exemplified that several of these characteristics are apparent even in the painted surface. Hence, this perception of CLT differs significantly from what Deplazes described as 'thick-laminated sheets' (like CLT) that 'can occupy all the tectonic elements of a building structurally without ever being able to express itself as a material', as described in the introduction.

By focusing on the perception of CLT as a *transition*, it has been clarified that the *planar surface* is characterised by thin, clean-cut *seams* which unify the plates. These appear simply as 'folds' in the continuous *enclosure*, or mark a spatial variation or transition. Moreover, the long *hidden seam* is the link that facilitates plasticity within the otherwise stiff massive plates, i.e. the smaller the plates are the more plastic the impression gets. Hereby, the *seams* can also become a most dominant ornamentation of the building, as exemplified in the St Loup chapel.

An essential aspect in the development of the model as well as in the analysis of CLT is that a material is to be studied on the basis of its own 'state of nature', as opposed to the 'nature' of its raw material. Studying CLT as an *enclosure* and as a *transition* has clarified, that the *planar surface* merely represents the 'state of nature' of the lamellae, whereas the *planar* and the *cross-sectional surface* together represent both that of the lamellae and that of the CLT element. Here, we perceive the material in its entirety with the exposed massive structure, and its characteristic, layered shift between circular growth rings and the longitudinal grain pattern. Hence, the *cross-sectional surface* – and thus also the *articulated seam* – becomes communicator of the material's multi-functionality, workability, and characteristic 'woven' structure, i.e. communicator of the 'essence' of CLT.

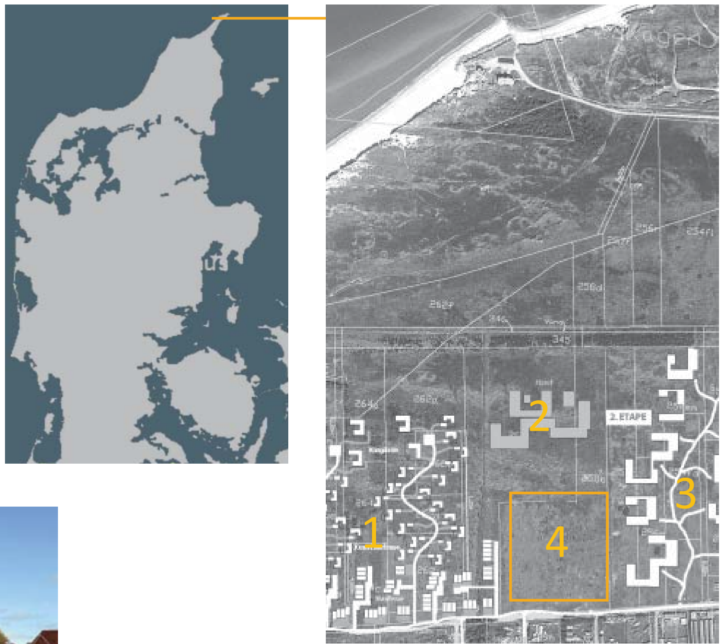
With its massive cross-laminated structure, CLT enables great freedom in the placement of perforations as well as in the possibility to work the framing of these by enhancing or minimising the perception of the depth of the plate. This freedom within placements of perforations as well as in the overall shaping of the plate, also exemplify how the standardized lamellae that constitute the 'building blocks' of the customised elements, during the processing they have undergone, are reduced to being the 'inherent ornament' of the plate. Hence, studying CLT as an *enclosure* has raised the question whether the lamellae merely are the means to reach this flexible product, which can then be adapted randomly, or do the lamellae imply 'limitations' – maybe just aesthetically – to the utilisation and processing of the CLT element?

All things considered, the analysis clearly demonstrates that CLT is not only a material characterised by its transformed properties regarding enhanced strength and stability, its isotropic structure, the size of the plate, etc., i.e. qualities that bring about a simplified building system and assembly as well as various new possibilities within shaping, placement of perforations, etc. Just as much, it is a material characterised by its colouration, tactile and warm surface, its inherent ornament – the grain pattern and growth rings, the linearity and modularity of the lamellae. And it is a material characterised by its high level of detailing in cuttings, surface processing and joints, as exemplified through the long dead straight seams unifying both lamellae and plates. Actually, it is within its *materiality*, i.e. the perception of the qualities describing its *character*, that one first and foremost recognizes the 'wood-spirit' in this material. Just as it is through the perception of the layered structure and the crosswise placement of lamellae in the cross-sectional surface that one fully understands what the material *can do* (*material*), and what processing it has undergone (*technology*). Hence, CLT has not only retained many of the sensuous and poetic qualities of wood, but with its massive multi-functional plate CLT enables new forms, applications, and expressions in timber architecture. CLT tells its own story which is not to be mistaken for that of timber in its traditional form. With is large format, massive 'woven' structure, and clear-cut seams, CLT speaks the language of novel timber architecture – an architecture of continuity, simplicity, and precision.

The inquiry conducted through this chapter has provided 1) insight into the role of materials in architecture, which evolved into an explicit model for structuring an analysis and evaluation of the materiality of novel timber products, and 2) insight into the *materiality of CLT*. Through the case study analysis, it has been demonstrated how applying the model and its six aspects, i.e. *technology, material, materiality, entity, enclosure,* and *transition*, has provided a clear structure to the analysis, and hereby ensured a comprehensive insight into the *materiality of CLT.* Likewise, the case study analysis has clarified that CLT is not merely a pragmatic means for building but, moreover, a material of great *materiality.*

However, how one can ensure that also these 'soft' values (qualitative aspects) are integrated and properly balanced in the decision-making process when materials are to be chosen for a project? The results of a preliminary study dealing with this kind of issue are presented in the following chapter.

206



208

206
The three housing types of area 1:
Klitgården, Kunstnerhuset and Havhuset.

207
View over the North sea.

208
Plan for the site:
1: Residential and commercial
2: Hotel
3: Commercial
4: Residential. Area for test-houses and 40-50 rowhouses.

207

5 DESIGNING WITH CLT

- A CASE STUDY IN PRACTICE

This chapter deals with the practical part of the PhD project, i.e. the cooperation with the estate consortium Skagen Nordstrand K/S (SN) and their design team. As mentioned earlier, this PhD project is partly financed by SN, and this cooperation has had great influence on the development of the PhD project and its focus, especially in the first half of the process. The idea has been to follow the development of a design proposal from the sideline and along the way carry out minor analyses which could contribute to the development of a design proposal as well as to the research project.

In this chapter, the cooperation with SN will be described. The chapter deals with the challenges related to the integrated design process, regarding properly balanced integration of quantitative as well as qualitative aspects, as well as decision-making in an interdisciplinary design team. The reflections related to the design process and decision-making is not specifically focused on CLT but deals with the overall theme of this thesis, namely the duality of architecture, being pragmatic as well as abstract, i.e. quantitative as well as qualitative. Moreover, considerations regarding the design of a housing project constructed of cross laminated timber are outlined and a design proposal is illustrated. Finally follows some considerations on what influence the findings presented in chapter 4 could have had on the design the design proposal. A detailed analysis of the design is not made, as the project was never finished.

5.1 THE SKAGEN NORDSTRAND PROJECT

SN is a real estate company that buy building sites in the scenic landscape of Skagen, Denmark, with the aim of combining the beautiful landscape with high quality housing [ill. 206-207]. Over the past five years, the company has built several houses based on three housing types; Klitgården, Kunstnerhuset and Havhuset [ill.206], which together form a cohesive housing unit. East of this housing area, the company intends to build a larger housing complex of 45-50 row houses [ill. 208]. The plan has been to developed and built 1-3 test-houses as a part of this housing project. These shall be examples of modern low-energy dwellings constructed in wood. Aalborg University, and in particular this PhD project, is a part of the design team that will develop these test-houses. Moreover, the managing director of SN, the Danish architectural firm Cubo A/S, and the Danish engineering firm Carl Bro/Grontmij A/S, is a part of the design team, while the local authority of Skagen will follow the process from the sideline.

5.1.1 Purposes and aims

The aim of this practical project is to design and build a number of full-scale test-houses. These are to exemplify the modern wooden house that:

- Respects and develops the Nordic mode of expression in timber architecture,
- Meets the needs of the individual dwelling with high architectural quality, e.g. regarding functionality, spatial experiences, materials, etc.
- Combines good indoor climate with low energy consumption.

In the first phase, the houses are designed. The above-described goals are to be achieved by combining the practical experience and expertise of the architect, engineer and developer, with the newest research within timber products and construction methods.

In the second phase, the aim is to analyse architectural as well as technical qualities of the erected houses. Among others, the plan is to analyse the aesthetic and spatial qualities related to the chosen timber construction material. Moreover, measuring equipment is installed in order to make different measurements of the indoor climate.

Thus, the overall goal is to develop new knowledge (practical and theoretical) within the area of low-energy and high quality timber architecture. This is to be achieved through design, construction, analysis, and experiments.

5.1.2 Outcome

As it happens sometimes, different external factors become crucial for one's ability to follow a vision through and achieve the established goals. In the case of the SN project, only the first phase has been accomplished. Due to the financial crisis, SN has had to put the project on hold, and the test-houses have not yet been built. Therefore, it has not been possible to conduct phase two, i.e. the planned on-site architectural analyses and measurements of the indoor climate.

The SN project was to have been used for a case study analysis similar to the one presented in chapter 4 part two. Hence the plan was to have full-scale test-houses, based on which partly the *materiality of CLT* and partly the *applicability and qualities of the developed model* could be analysed and evaluated. This change in the plan has not had fatal consequences for the outcome of this PhD, however, it has led to an adjustment regarding the cases for the case study analysis.

In the following two sections, excerpts of the outcome of phase one is presented. Firstly, a preliminary study related to the integrated design process and decision-making is described. Secondly, a short presentation of a design proposal and considerations related to this are presented after which the design proposal is discussed briefly on the basis of the findings presented in chapter 4.

5.2 THE INTEGRATED DESIGN PROCESS AND DECISION-MAKING

As the aim has been to develop buildings of high architectural quality (regarding functionality, spatial and material experiences, etc.), good indoor climate and low energy consumption, many aspects needed to be considered and integrated. The article *MCDM in practice - an architectural point of view* (Bejder et al. 2008) (appendix 7) deals with the complexity of this design process, which is characterised by the importance of integrating both quantitative and qualitative aspects, as well as handling the - often occurring - interconnectedness of these.

Trying to optimize buildings on several levels at the same time, often results in several different – and often conflicting – design parameters. This has caused an extensive need for methods that help structure the complexity of the design process and hereby ensure that all parameters are included and properly balanced in the final project (Bejder et al. 2008). Over the years, several approaches to an integrated design process have been presented, e.g. *Integrated design process in problem-based learning* (Knudstrup 2004), *Integrated Design Process - A guideline for sustainable and solar-optimised building design* (Löhnert et al. 2004) and *Method for Integrated Design* (Petersen and Svendsen 2007). Other approaches focus specifically on the decision-making process within energy-efficient building design, such as ENERGY-10 (Andresen 2000), the Eco-factor (Brohus and Bjørn 2005) and different variations of Multi-Criteria Decision-Making methods (MCDM) (Andresen 2000).

ENERGY-10 and Eco-factor are calculation programs which can provide the decision-makers with some knowledge that may support a decision and guide the project in the right direction. However, by only including the quantitative aspects, none of these methods deal with decision-making from a holistic approach (Bejder et al. 2008). MCDM, on the other hand, is a more general method and is known in many different fields such as policy analysis, social psychology and business management etc.; fields characterised by multi-criteria problems. The general purpose of these methods is to facilitate the decision-making process by identifying a preferred alternative from a set of alternative solutions characterised by multiple, usually conflicting attributes (Andresen 2000). According to (Balcomb and Curtner 2000), the use of MCDM can facilitate the communication of team priorities, the setting of performance goals and the evaluation of different design proposals. Andresen furthermore suggests that a structured approach like MCDM can help clarify as well as uncover important criteria and help ensuring that all criteria are considered when making a decision. Besides, MCDM may facilitate the communication in the design team by providing a common framework that all participants can relate to when evaluating a design proposal (Andresen 2000).

Anyway, while MCDM is a quantitative tool which translates all criteria into a measurable scale, it might be different how useful the method and its results will appear to the different members of the interdisciplinary design team, according to their profession and comprehension of design. Therefore, in the article by (Bejder et al. 2008), the suitability of MCDM is discussed from an architectural point of view in order to discuss which qualities a quantitative decision-making method like MCDM might bring to the creative process.

In order to inquire into this, (Bejder et al. 2008) tries out MCDM in practice by doing an experiment. The experiment is carried out as a thought experiment based on a design process, which has already been accomplished through a traditional way of making decisions. Therefore, the result of the decision-making process will, in all probability, be predictable. However, the aim for this experiment is not to try out the method for the purpose of achieving an optimal design. The aim is simply to discuss whether MCDM can help with structuring the complex design process, including ensure that both quantitative and qualitative aspects are integrated and properly balanced, as well as discuss which qualities the method might bring to the creative process (Bejder et al. 2008).

5.2.1 The experiment

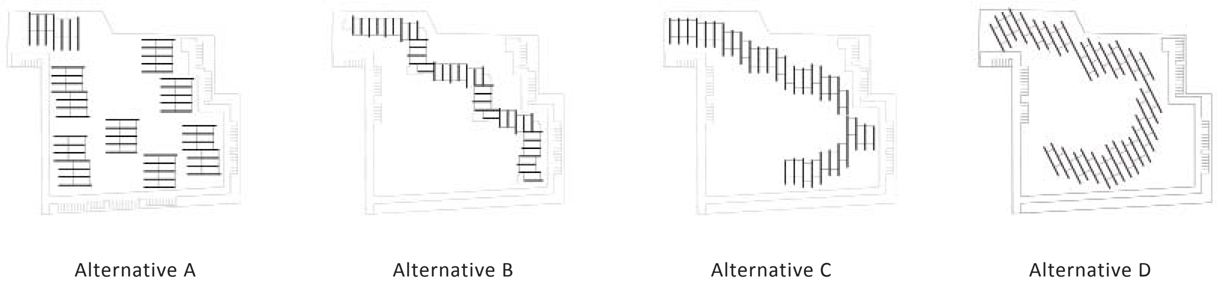
The experiment is an exemplification of the design process and focuses only on the development of the site plan (Bejder et al. 2008). Four alternatives [ill. 209] form the basis of the study, which consists of four steps, i.e. *specification of design criteria, weighting of criteria, ranking the alternatives,* and *identifying the best performing alternative* (Bejder et al. 2008).
In (Bejder et al. 2008) the first step is to specify the visions specifically concerning the site plan, in order to be able to evaluate the proposals in relation to each single criterion. The criteria are listed in [ill. 210, column 1]. Hereafter,

209
The four alternatives which were chosen as objects for the experiment.

210
Ranking of alternatives according to each criterion.

211
Defining the preferred alternative.

209



Alternative A | Alternative B | Alternative C | Alternative D

Design criteria	Weight	1. place	2. place	3. place	4. place
Qualitative					
- Intuitively most appealing architectural concept	1	D	C	B	A
- Orientated towards the view	3	D	B	C	A
- Creates private outdoor space in lee of the strong wind from SW	5	D	C	A	B
- Creates private outdoor space with afternoon sun	6	B	D	C	A
- Promote separation between private and public outdoor spaces	7	D	C	B	A
- Minimizes the need for hard traffic across the site	9	D	C	B	A
- Has its own life (stand out from the building towards west)	10	D	C	B	A
- Come across as a unit without creating a gated community	11	D	C	B	A
Quantitative					
- Daylight	2	D	C	B	A
- Economy	4	B	A	C	D
- Energy consumption	8	D	C	B	A

210

the criteria are weighted. The MCDM method used in the experiment is the *simple ordinal ranking* of alternatives. This method is chosen because the criteria are mainly qualitative and because it seems to be relatively straightforward to use even for those not familiar with applying MCDM (Bejder et al. 2008). Hence, the weighting technique used in the experiment is *ranking*, which means that the criteria are listed in order of importance [ill. 210, column 2]. Using the simple, ordinal ranking method, the four alternatives are then ranked according to how well they performed on each criterion [ill. 210, column 3-6]. This is done in cooperation with the design team architect while it is his experience of the method that is purpose of the experiment. Due to the dominating number of qualitative criteria, the *ranking* is primary based on his expert judgement. Finally, a comparison of how well the four alternatives perform according to the criteria and their respective weight is made [ill. 211].

As the criteria and the four alternatives are the result of an already conducted, iterative design process, alternative D naturally has a higher total score than alternative A, which was the first rejected design proposal. However, applying the structured method reveals that alternative B actually performs best on some criteria. Hence, even though alternative D performs remarkably better than the other alternatives, the experiment

211

	# 1. places and (weight)	# 2. places and (weight)	# 3. places and (weight)	# 4. places and (weight)	Rank
Alternative A	0	1(4)	1(5)	1(1)+1(2)+1(3)+1(6)+ 1(7)+1(8)+1(9)+1(10)+1(11)	Last
Alternative B	1(6)+1(4)	1(3)	1(1)+1(2)+1(7)+1(8)+1(9) +1(10)+1(11)	1(5)	Third best
Alternative C	0	1(1)+1(2)+1(5)+1(7)+1(8) +1(9)+1(10)+1(11)	1(3)+1(4)+1(6)	0	Second best
Alternative D	1(1)+1(2)+1(3)+1(5)+1(7) +1(8)+1(9)+1(10)+1(11)	1(6)	0	1(4)	Best

clarifies that further work is needed, and that inspiration could profitably be drawn from some of the other alternatives (Bejder et al. 2008). The overall results of the experiment are presented in the following.

5.2.2 Results of the experiment

(Bejder et al. 2008) point out strengths and weaknesses of applying MCDM in the decision-making process in relation to qualitative design parameters based on the experiment, as opposed to decision-making done in the traditional way.

The first step dealing with the specification of criteria was a good exercise as it led to a deeper understanding of which parameters the owner representative considers important. The specification also led to a selection of the most important criteria and in that way the framework of the project got clearer and more defined (Bejder et al. 2008). Actually, in the opinion of the design team architect, this specification of criteria is the most important task when using the MCDM method since the criteria are the foundation of the entire process. Hence, if these are not precise, it may not only be difficult to do the evaluation (step 3) but the result will indeed be misleading (Bejder et al. 2008).

Ranking the criteria according to importance reveals an unexposed hierarchy within the parameters that had not been obvious previously (Bejder et al. 2008). A design process can be full of great visions and preferably implements them all. Nevertheless, a design process is most often full of compromises, and an opaque hierarchy may result in dissatisfaction among the participants. The overall goal must be to ensure that all interested parties are satisfied at the end of the process, and a mutual openness about their priorities is essential in order to ensure that. It is the experience of (Bejder et al. 2008) that MCDM might help facilitate such a transparency. An ascertained downside of the applied weighting method is that *ranking* the criteria indicates that none of them are equally important, which is rarely the reality (Bejder et al. 2008).

While the evaluation is based on a ranking of the alternatives, it is not necessary to transform the qualitative criteria into a measurable scale. That way, using this specific MCDM method, the foundation of the evaluation has clear similarities to the traditional way when making a side-by-side comparison. According to the qualitative criteria, the performance of the alternatives is in both cases based on the architect's expert judgement. But, when making a decision in the traditional way, the alternatives are evaluated according to the overall set of values, whereas, using MCDM, the alternatives are evaluated by one criterion at the time. This may help avoid situations where the design team talk cross-purposes. On the other hand, a downside of this is that the result tells you nothing about the interaction of the criteria.

It is one thing to evaluate alternatives according to each criterion. This might have advantages like ensuring that all criteria are considered and that qualities within even the poorest alternatives are discovered. It is another thing to define a 'best solution' based on a numeration. According to (Bejder et al. 2008), the quantitative evaluation can never include the finer nuances of a design decision, because these are often emotionally defined and rarely possible to describe in words. Hence, when making the final decision, one must always focus on the entirety of the project. At some point, the design team architect actually expresses that to him, the evaluation of alternatives by one criterion at the time can even reduce the appreciation of the entirety of the project (Bejder et al. 2008). An excerpt of the conclusions of the experiment is presented in the following.

5.2.3 Conclusions of the experiment

In (Bejder et al. 2008) the suitability of MCDM is discussed from an architectural point of view. Through the simplified experiment and dialogue with the architect, the qualities which MCDM might bring to the creative process are discussed in the paper.

When using MCDM in a design process, the most important thing to be aware of is that it must not be used inaccurately to make the final decision. In general, methods can be very useful to help structure the design process, but one must never expect them to provide a yes-or-no answer. Evaluating the alternatives by one criterion at the time does not embrace the finer nuances which lie in the interconnectedness of the criteria and which are crucial to the overall experience of the design. The traditional way of making decisions relies on the decision-makers' professional competences. MCDM is not seen as an alternative to the traditional decision-making process, but if used as a supplement to the human judgement it seems to have potential. A quality of the applied method is its ability to provide the design team with a common frame of reference for discussions. Besides, used as a 'checklist' during the evaluation of different alternatives, the method may help ensure that all criteria are considered and qualities of even the poorest alternatives are uncovered. Moreover, the paper concludes that when applying MCDM, it is critical that the criteria are precise. If not, the entire process can be misleading (Bejder et al. 2008).

When facing a complex design with multiple criteria, there is the risk that some parameters are unintentionally neglected. In order to reach low-energy buildings of high aesthetic and functional quality, it is of critical importance to have a well-structured and integrated process. According to (Bejder et al. 2008), applying MCDM could be one way to ensure that the qualitative values are also attached the proper importance as long as the final decisions are made by human judgement.

In the following section, considerations related to the decision of applying CLT for the houses in the SN project are outlined and a design proposal is illustrated.

5.3 THE DESIGN PROPOSAL

This section will give an overall insight into some of the considerations underlying the decision of applying CLT for the test-houses. A design proposal is outlined and the utilisation of CLT is discussed briefly on the basis of the model developed in chapter 4 part one. This will lead to some overall considerations on whether or not a preceding insight into the *materiality of CLT* might have influenced the design.

5.3.1 Choosing CLT

One of the first decisions to be made was on the construction principle for the test-houses. Several principles and timber products were debated, e.g. timber constructions in the form of prefabricated two-dimensional wall panels or three-dimensional volumes, or massive timber elements with boards placed either side-by-side, cross-wise, or as box-elements (see section 1.3.1). The massive timber elements seemed to have many advantages and seemed appealing to the design team first off. However, experiences with this type of construction are rather limited in a Danish context. Therefore, in order to gain more knowledge about these timber products and their architectural and technical qualities as a building system, the design team went on excursions to some of the few Danish buildings where the massive timber elements are utilized technically as well as architecturally, for instance as exposed interior surfaces. Additionally, meetings with producers of single-laminated elements (Lilleheden A/S, Denmark), and cross-laminated elements (KLH Massivholz GmbH, Austria) provided further information about the products.

The overall evaluation of these two timber based products has been similar to what is described in section 1.3.1. Therefore, although the detached dwelling in Ebeltoft made a big impression on the design team with its constructional logic of the interior and many fine details, it was the cross-laminated timber elements and its simplicity that raised most enthusiasm among the design team members [ill. 212-214]. Some of the most determining aspects that underlie the decision of applying CLT for the houses are listed below (several of these are also described in chapter 3):

- The simple structure of the small annexe in Skagen, DK. The building is structurally cut down to few basic elements; walls, ceiling, roof and floor.

- Neither ridge beam nor lintels above openings are necessary due to the cross laminated structure [ill. 214].

- The multi-functional plate: bearing and stabilizing element, partition and interior surface in one.

212
The large CLT elements appear clearly in the design and the lamellae add a tactile structure to the white painted surfaces. Detail, holiday cottage in Them. (Photo: Author)

213
Interior of the holiday cottage in Them. (Photo: Author)

214
The simple structure of the unfinished annexe in Skagen. (Photo: Henrik Almegaard)

- The simple building system: due to the structural properties of the plate and its workability, the plates can be jointed with the use of simple tools and screws.

- By virtue of the building system simplicity, the size of the elements and a brilliant finishing from factory, the construction time can be reduced significantly, thus making the building less dependent on weather conditions, which is often a problem when building with wood in Denmark.

- Since the experiences with CLT elements are lacking in Denmark, the relatively simple assembling of the elements was of great importance to the design team. The idea was to use local labour, who would learn from the construction of the first house (erected by labour with expertise in CLT, related to KLH), and then take over the construction of the following houses.

- The great finish from factory makes it possible to use the elements directly as exposed surfaces. Hereby, the usual large amount of work related to the interior finish can be minimised radically.

- The direct communication of drawings can reduce the risk of misunderstandings between consultants and producer, as well as ensure a very precise fitting.

- The level surfaces which still possess the warmth, soft and visual qualities of wood seemed aesthetically appealing to the design team.

- The possibility of creating a house almost entirely of wood, because the plastic vapour barrier can be left out among other things.

212

213

214

- Offhand, choosing CLT seemed to be an expensive solution compared to a light wooden skeleton construction. However, due to the plate's multi-functionality, its simplicity as a building system, and the fast assembly, the product seemed to be a cost-effective solution anyway.

- From a scientific point of view, this product and building system is interesting for several reasons. It is a material that has gained increased focus during recent years, several buildings have been erected around the world, and several research studies have been conducted. Yet, its aesthetic qualities and 'soft' values are not well studied or described, and full-scale test-houses seemed as a perfect foundation for doing so.

Hence, applying CLT elements for the test-houses seemed interesting from the developers' point of view, as well as in relation to research. How these qualities of CLT was utilised in the design of the houses for SN is illustrated in the following section.

215
Siteplan and the three test-houses.

216
Row-houses, ground floor and first floor.

217
An early model of a one-storey house showing the principle of the transverse stabilising plates. In this case in combination with a core of concrete which runs through the entire house.

218
Cross-section of the three houses.

5.3.2 Designing with CLT

The design proposal presented here is from the late design process. However, further adaption was planned (among others, further material optimisation) when the project was set on hold. Given that the project has never been fully accomplished, it is difficult to draw any final conclusions

216

215

217

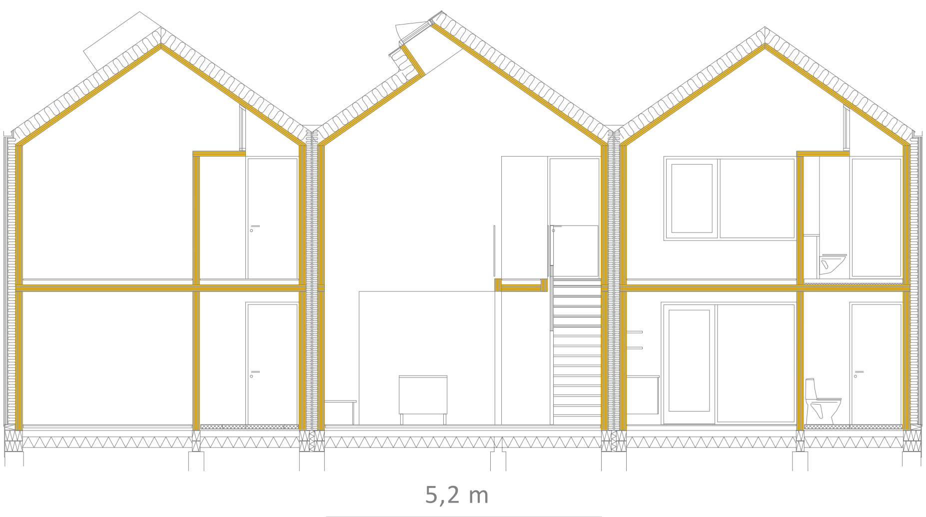
xx

on the perception of CLT in this case. However, based on the preliminary design proposal, some general reflections on how applying CLT has influenced the architecture are presented in the following.

As described earlier, the three test-houses were to be a part of a larger housing project containing 53 row-houses [ill. 215-216]. The project targeted the less deep-pocketed purchaser and the project must therefore be economically rational. This led to the development of two types of buildings: a one-storey house with an inner courtyard and a two-storey house centred around a room of double height. These two types are repeated through the entire complex, and variation in the overall architectural expression is achieved through the overall composition of the 53 houses.

The houses are characterised by their longitudinal, compact and simple bodies. The close contact between the row-houses and risk of fire development means that houses only have openings in the gable as well as a skylight. Using CLT as the building system for the houses has led to a design which is characterised by several transverse plates. The plates function as a supporting structure just like they ensure the stability of the building. At the same time, the repetition of these plates gives the house its spatial character by creating a clear rhythm through the house and a zoning of the open plan [ill. 217 & 219]. Also, the design clearly utilises the ability of CLT to take up forces in both directions. This is illustrated in the sectional drawings where neither ridge beam nor lintels above the large windows and openings through the plan are necessary [ill. 218 & 220].

218



Section A-A

Looking at the design based on the knowledge gained through chapter 4, several qualities related to describing the *character* of CLT (and thus related to its *materiality*) are reflected in the design.

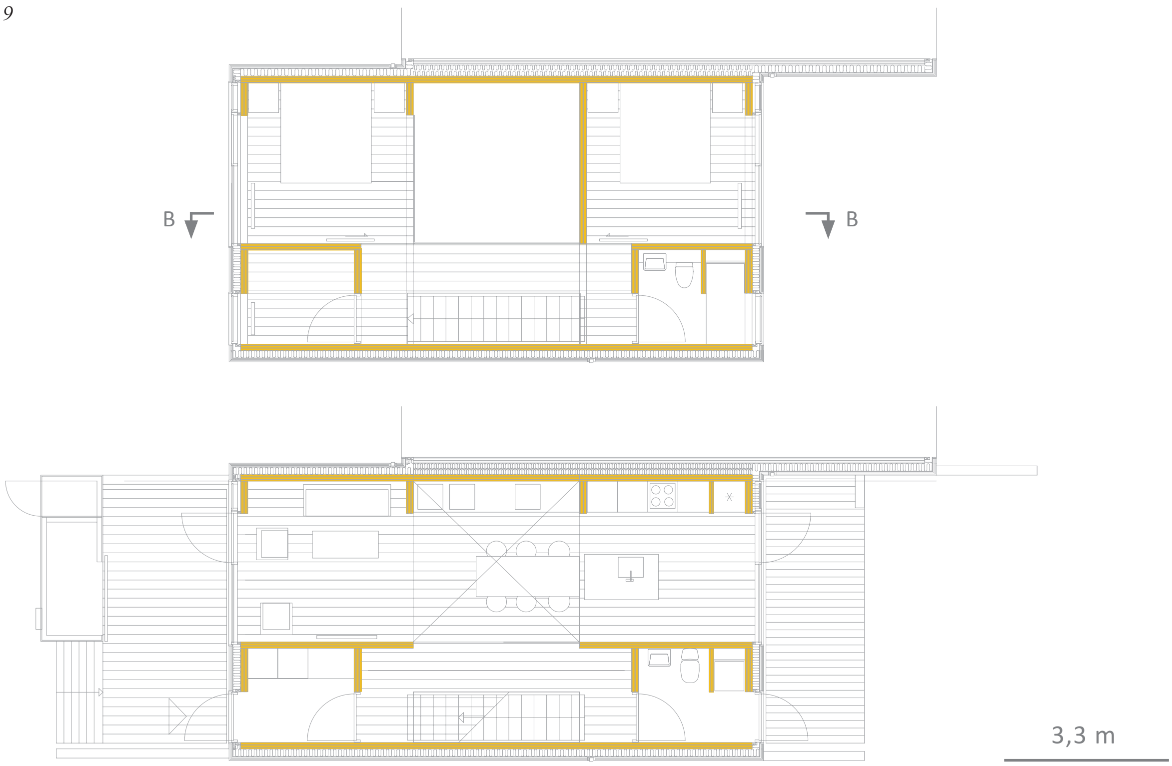
When looking at CLT as part of the building in its *entity*, it is clear that from the outside nothing will indicate that these houses are constructed of CLT. Similar to the annexe in Skagen and the houses in Them and Hamburg, which were described in chapter 4 part two, these houses exemplify the more closed building configurations provided by CLT (see section 4.8.1). From the inside, on the other hand, the distinctive properties of CLT manifest themselves more clearly. This is particularly evident in the large format, transverse plates with large openings cut directly out of the plate without ensuing lintels. And as the CLT elements appear untreated throughout the interior except for the floors, the atmosphere will be characterised by the warm colour of the wood, as well as by the contrast between the massive walls and large openings.

Studying CLT though its *enclosures* and *transitions*, two concepts seem to be present. The outer walls which frame the entire house form a continuous *wrapping enclosure* with its long *hidden seams*. In contrast, one senses CLT as a heavy and massive *wrapped structure* in the transverse plates where both the *planar* and the *cross-sectional surfaces* are exposed. Here, it will be possible to perceive CLT in its entirety; the large format

219
Ground floor and first floor.

220
Longitudinal section of the house.

219

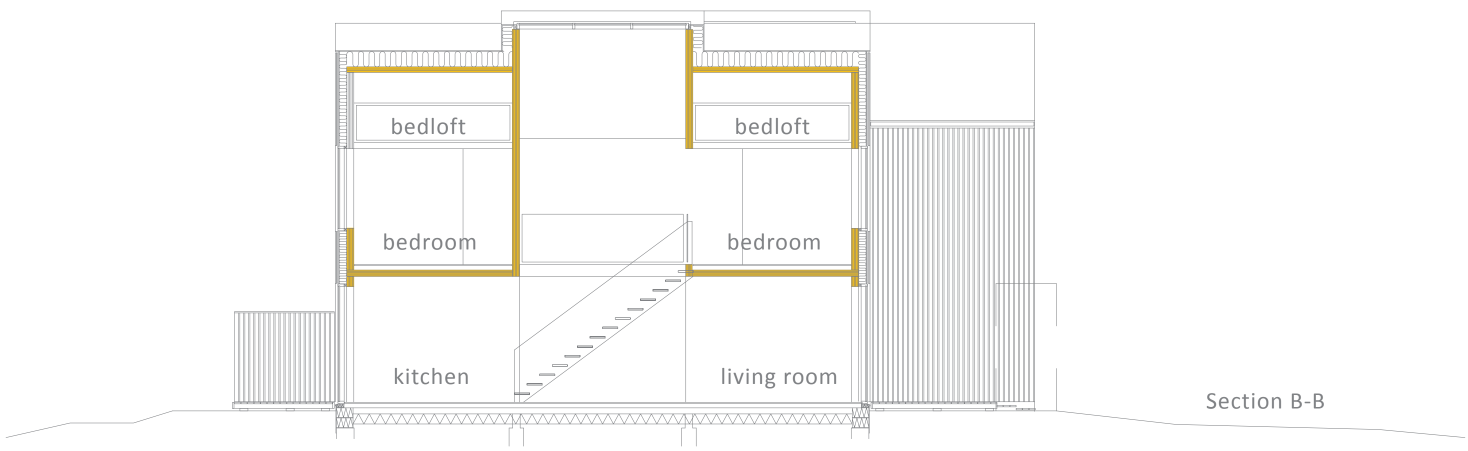


of the plate, the cross-laminated structure, its multi-functional character, its warm colours, the visual and tactile grain pattern, and the lamellae constituting its basis. Hence, in the transverse plates, both the processing the material has undergone (*technology*), its technical properties (*material*), and various qualities which are related to describing its character (*materiality*) is clearly expressed.

However, the utilisation of CLT in the design proposal mainly reflects a pragmatic approach to the material. Although several qualities related to describing the *character* of CLT (and thus related to its *materiality*) are reflected in the design, it seems particularly motivated by the fact that CLT provides a *simple building system*. Generally, the design does not seem to be based specifically on the properties of CLT. It could be constructed in several materials, but is adjusted to this specific material and then 'makes the best out of it' – technically and well as aesthetically. Especially the placement and size of the small transverse wall elements of the small rooms seem to suggest such a relation.

Hence, although the design proposal seems to posses many qualities in relation to a sensuous architectural experience, it would be interesting to see how the design would have developed if the qualities clarified through chapter 4 had been present earlier. If a discussion focused specifically on the *materiality of CLT* had been a part of the early process, the poetic and sensuous qualities of CLT may had been further enhanced in the final design.

220



5.4 CONCLUSION

In this chapter the cooperation with the estate company Skagen Nordstrand K/S has been presented briefly. This has been done in two parts; the first describing a preliminary inquiry into the process of decision-making, the second providing an overall insight into the considerations related to the selection of CLT as building system for the three test-houses, and a short presentation of a preliminary design proposal.

In the first section, trying out MCDM as a method to help structure the decision-making process clarified that the method may provide the design team with a common frame of reference for discussions, and will help ensure that all criteria are considered. However, the study also concluded that one of the strengths of this method, i.e. the evaluation of proposals by one criterion at a time ensuring that qualities of even the poorest alternatives are uncovered, is also the weakness of the method. By focusing on one criterion at a time, the interrelation between several criteria is not included, and the finer nuances in the perception of the design are lost. Hence, the overall conclusion is that the MCDM may provide a valuable tool for *supporting* the decision-making, but the final decision must still be based on human judgement.

In the second section, the presentation of a design proposal and considerations related to this revealed that although the design proposal demonstrated several qualities related to *technology*, *material* as well as *materiality*, the utilisation of CLT appears to be primarily rooted in its property as a rational building system. Based on this it is suggested, that a focused involvement and making visible of the *materiality of CLT*, i.e. the qualities clarified through chapter 4, in the design process, might help ensure a further utilisation of the poetic and sensuous qualities of CLT.

Although the quantitative MCDM methods and the analysis model developed in chapter 4 are in no way directly related, they share a common feature. Both methods provide an explicit model which by 'demolishing' the 'object' (decision-making process or the building material) imply a making visible, i.e. an *articulation*, of its qualities, and hereby provide a more comprehensive appreciation of the 'object's' possibilities.

6 CLOSING

In closing of this thesis, a short summary of the previous five chapters is given. This is followed by the final conclusion, and finally, a short discussion and suggestions for future challenges.

6.1 SUMMARY

In the introductory chapter 1, it is illustrated how wood has been a valued building material throughout history, not least due to its multi-sensuous qualities, great applicability, and workability. Therefore, although losing ground to materials like brick, steel, and concrete, timber architecture has continued to develop up until today. A brief review of the developments within timber architecture has revealed a change from traditional construction principles like log and post-and-beam constructions, which are generally characterized by constructional logic and a clear relation between material, construction, and form, to 'structure-less' constructions, which structural components disappear in the envelope of the wall construction.

How and to which extent wood has been applied in architecture depends on several factors, e.g. societal, political, economical, contextual, as well as availability of resources, interest of the industry, knowledge, experience, prejudice, human perception of the material/product, etc. However, one factor that has had particularly significant importance as to *how* timber architecture has developed is the development within tools and technology, which has led to innovation within applications, form, and material expressions. This does not only concern timber as a structural material, but also in regard to the perception of the material. This duality of materials being the concrete, pragmatic, tangible, quantitative but also the symbolic, abstract, intangible, qualitative has become a recurring theme throughout the thesis.

Prevailing encouragement from society and the wood industry has led to a general, increased interest in wood as a building material, and in parallel, new production methods and further refined timber products have been developed, among others CLT. Through a literature review and state-of-the-art, it has been illustrated that CLT possesses several qualities within the engineering field, and most research within CLT has been related to this field. The architectural and aesthetic qualities of CLT, on the other hand, are not well clarified or articulated.

By means of high-technology development within compound materials, production and processing, CLT has gained technical properties beyond those of unrefined timber. However, with this follow the questions: 1) is this at the expense of wood's sensuous and poetic qualities and 2) what does it means to the experience and perception of this material as a creator of space and as a surface, that it is processed into products which (structurally) are beyond wood's nature?

This led to the overall theme of this thesis to inquire into the understanding of the role of materials in architecture and, with a point of departure in this, be able to clarify and articulate the architectural and aesthetic qualities of CLT. Moreover, in the light of the primary focus on the technical properties of CLT, it has been an aim to reach a suggestion for how to ensure that these aesthetic qualities of CLT are integrated in the design process.

These issues have been examined through 7 papers (appendix 1-7) and an excerpt of these have been presented and, in some cases, further elaborated in chapter 3, 4 and 5.

In chapter 2 the methodical approach is outlined. Besides the experiment related to the testing of MCDM which was conducted in cooperation with Skagen Nordstrand, it has primarily been literature surveys, model development, and case study analyses, which have constituted the methodical approach. These have been chosen due to the wish of gaining a heightened insight into the theoretical background of the subject of materials and their role in architecture. Hence, the findings presented in the chapters 3, 4 and 5, are based on these particular methods and the delimitation related to them.

Chapter 3 provides an introduction to the architectural qualities of CLT, i.e. the possibilities this material provides for the designer. The qualities and challenges of CLT outlined in this chapter have been based on knowledge gained during discussions in the interdisciplinary design team connected to the Skagen Nordstrand project (where CLT was chosen as building system), as well as through literature surveys and study trips.

The qualities which have been found particularly interesting, seen from an architectural point of view, are those related to its property of being a *plate* and provider of a *simple building system* as well as to its *workability* and high level of *detailing* in production and appearance. The chapter finally states that CLT does not only provide a simple building system, but if the design is based on its property of being a plate with multifunctional qualities, it may generate new ways of thinking, designing and building with wood. Hence, this inquiry has clarified that CLT possesses several architectural qualities, and in order to explore its aesthetic qualities further, the following inquiry went into depth with CLT by inquiring into how it is perceived, i.e. its *materiality*.

In chapter 4, the primary research of this PhD is presented; the inquiry into the *materiality of CLT*. The proposed method to deal with this has contained two steps. Firstly, based on a theoretical review, a discursive model that includes aspects essential for analysing and evaluating the *materiality of CLT* within an architectural context has been developed. This model consists of six aspects, i.e. *technology, material and materiality, entity, enclosure,* and *transition.* Secondly, this model has been applied for structuring the analyses of a number of cases constructed of CLT.

By clarifying qualities of CLT related to *technology, material* and *materiality*, and by studying these through the three perspectives, i.e. *entity*, *enclosure* and *transition*, the analysis has clarified a number of features which in different ways express the *character* of CLT, and thus are essential for describing its *materiality*. Among these features are: its general character being based on the *plate and seam*, the *planar surface* and the *cross-sectional surface* which are related respectively to the perception of CLT as a *wrapping enclosure* or a *wrapped structure.* Other characteristic features are: the long, dead straight *seams*, the *articulated seam,* the *hidden seam,* its distinctive *'state of nature'* which can be more or less perceptible depending on the surfaces exposed, as well as its *colouration, tactile* and *warm surface*, its inherent ornament, which is characterised by the *grain pattern* and *growth rings* in addition to the *linearity* and *modularity* of the lamellae.

Other than making visible these features related to the perception of CLT, the analysis of the projects constructed of CLT has also functioned as a test of the analysis model itself. The overall conclusions of this inquiry are: 1) with the case study analysis, it has been demonstrated how applying the model and its six aspects, i.e. *technology, material, materiality, entity, enclosure,* and *transition,* has provided a clear structure to the analysis, and hereby ensured a comprehensive insight into the *materiality of CLT,* and 2) the case study analysis has clarified that CLT is not merely a pragmatic means for building but, moreover, a material of great *materiality.*

Chapter 5 provides an introduction to the cooperation with Skagen Nordstrand (SN), including a preliminary inquiry into the decision-making process, and a short presentation of a design proposal which led to some overall considerations on whether a preceding insight into the *materiality of CLT* could have influenced the design.

The general conclusion of the first inquiry is that the tested MCDM method may provide a valuable tool for *supporting* the decision-making process, partly because it leads to an articulation of the most important criteria and their mutual prioritisation. However, in order to perceive the finer nuances of a design, it has been found crucial that the final decision is still based on human judgement.

The illustration and discussion of a design proposal of the SN project led to the conclusion that although the design proposal demonstrated several qualities related to *technology, material* as well as *materiality,* the utilisation of CLT appeared to be primarily rooted in its properties as a *rational building system.* Therefore, it was suggested that a focused involvement and articulation of the *materiality of CLT* in the design process might be a way to ensure further utilisation of the poetic and sensuous qualities of CLT.

Hence, the overall conclusion of this chapter is that by applying an explicit model which imply a making visible, i.e. an *articulation*, of the various qualities of the 'object' (e.g. decision-making process or the building material), a more comprehensive appreciation of its qualitative qualities may be provided, and this may lead to architecture where also the aesthetics and 'soft values' are properly utilised.

Altogether, this leads to the final conclusion which is presented in the following.

6.2 CONCLUSION

This thesis has its point of departure in the great importance wood has had as a building material throughout history as a naturally occurring, strong, light and workable construction material with various multi-sensuous qualities and great applicability. With the development within tools and technology, many of these qualities have changed over time, and many of todays' timber-based products show enhanced technical properties and changed visual and tactile qualities, which have influenced the way we design and build timber architecture. The thesis specifically focuses on the engineered timber-based product 'Cross-laminated Timber', which is primarily known and acknowledged by its technical properties. It is the hypothesis of the thesis that CLT possesses an undefined aesthetic potential that may innovate how we construct and perceive timber architecture. The overall aim of the thesis has, therefore, been to inquire into the architectural and aesthetic qualities of CLT.

Based on the findings presented in chapter 3, 4 and 5, CLT is found to be not only a material characterised by its transformed properties regarding enhanced strength and stability, its isotropic structure, the large format of the plate, etc., i.e. qualities that bring about a simplified building system and assembly as well as various new possibilities within shaping, placement of perforations, etc. Just as much, it is also a material characterised by its colouration, tactile and warm surface, its inherent ornament, i.e. the grain pattern and growth rings in addition to the linearity and modularity of the lamellae. Actually, it is within its *materiality,* i.e. the perception of the qualities describing its *character* that one first and foremost recognizes the 'wood-spirit' in this material. It is also through the perception of the layered structure and the crosswise placement of lamellae in the cross-sectional surface that one fully understands what the material *can do* (*material*), and what processing it has undergone (*technology*). Hence, CLT has not only retained many of the sensuous and poetic qualities of wood, but it is through these qualities describing its character that the 'essence' of CLT is perceived to a great extent.

Furthermore, the general architectural expression of CLT range from the closed building configuration where openings are cut out more or less 'randomly' (as exemplified by *Naked House*), to the open and floating building configuration (as exemplified by the house in Ennstal). In these cases, CLT is perceived either as a light *wrapping enclosure* or a massive *wrapped structure,* which again is linked to the features: the *planar* and *cross-sectional surface,* the *hidden* and *articulated seam.* Common for these features is the accurate and delicate processing in all levels when experiencing CLT in its *transitions, enclosures,* and in its *entity.*

An important aspect in these findings is the conclusion related to the 'nature' of CLT. Throughout the thesis it has been stated that the processing a material undergoes is an inevitable part of understanding a given material and its potential. Therefore, one must study materials, including the engineered CLT, on the basis of its own 'state of nature'. Studying CLT as an *enclosure* and as a *transition* has clarified that CLT expresses two 'state of nature'. The *planar surface* merely represents the 'state of nature' of the lamellae, whereas the *planar* and the *cross-sectional surface* together express both that of the lamellae and that of the CLT element. Here, we perceive the material in its entirety with the exposed massive structure, and its characteristic, layered shift between circular growth rings and the longitudinal grain pattern. Hence, CLT tells its own story which is not to be mistaken for that of timber in its traditional form. With is large format, massive 'woven' structure, and clear-cut seams, CLT may not express the 'intimacy of the craft' which Affentranger refers to in the introduction, instead it speaks the language of the technological 'state' of which it is a part, i.e. a (high-technological) timber architecture characterised by continuity, simplicity, and precision.

Furthermore, by applying an explicit model and analysing the cases on the basis of its six aspects; *technology, material, materiality, entity, enclosure,* and *transition,* it has been possible to reach a thorough insight into CLT, and by this be able to clarify and articulate qualities essential for describing its *materiality.* Finally, based on this conclusion and combined with the minor studies related to the MCDM methods and discussion of the design proposal in the Skagen Nordstrand project, it is finally concluded that an explicit model which imply a making visible, i.e. an *articulation,* of the various qualities of the 'object' (e.g. decision-making process or the building material), can be a help to ensure that the qualitative aspects and 'soft' values are also integrated and properly balanced in a design.

Based on the research conducted through this thesis, it is the author's belief that it is possible to go beyond the utilisation of the material as a mere technical product or a simple building system, and by this achieve a pragmatic yet poetic and sensuous future timber architecture by engaging into the deeper layers of a material, and by clarifying and articulating its qualities that are related to the perception of the material, i.e. its *materiality.*

6.3 DISCUSSION AND FUTURE CHALLENGES

The common thread through this thesis has been the aim of bringing the aesthetic, poetic and sensuous qualities of materials into focus. This is done with the belief that materials are more than merely the means of construction, i.e. more than a building system.

As the presentation and discussion of the design proposal related to the Skagen Nordtrand project showed, the proposal seemed to have, if erected, several qualities related to the *materiality* of CLT. This is despite the fact that the general basis for the utilisation of CLT seems to have been its quality as a rational (multi-functional and simple) building system. First of all, it would have been interesting to see how the project would have developed if the findings presented in chapter 4 had been present in the early design process. Secondly, the reason why these qualities are utilised in the design, may be the result of an architect with appreciation of the aesthetic and spatial qualities of CLT.

Basically, the projects presented in this thesis have been chosen on the basis that they, in one way or another, express aesthetic qualities of CLT. Common to the (most) projects is also that an architect or a person with experience and expertise within materials is involved in the designing. However, the fact is that many buildings, especially detached houses, are designed and constructed without the involvement of an architect. In this perspective, the great potential which lies in the simplicity of this building system might end up being its disadvantage as well. Building in wood may be possible for 'anyone' – with the risk of losing the spatial and aesthetic qualities of the material. Hence, the need for a clarification and articulation of the aesthetic qualities of CLT may be particularly great within this field. Likewise, the model developed in chapter 4 (or similar models pointed at other materials) as a means of analysing and evaluating the aesthetics of a material may be of relevance to students of architecture or other educations with interest in the field. The content of this thesis has not been specifically targeted these groups. However, an interesting task for future work could be to look into how the *aesthetic qualities of CLT* is communicated and presented for non-professionals and students.

Sustainability is a frequently used term today, and there are many different interpretations and definitions of what that term actually covers. In this case, *sustainability* is regarded as covering three subgroups: *environmental sustainability, financial sustainability,* and *social sustainability.* The research conducted with this PhD is positioned within *social sustainability*; dealing with the mental and physical wellbeing of people. However, in order to reach a comprehensive insight into the full potential of CLT and its future role in architecture, its *financial* and *environmental* profile are of great importance as well and could be interesting topics for future studies.

BIBLIOGRAPHY

Affentranger, C. 2005, "Building simply with wood", in DETAIL: Building simply, pp. 27-35.

Affentranger, C. 2002, ""Building with Wood: Between Sense and Sensitivity"Tendencies in Modern Building Methods", Architecture and Urbanism No. 381, vol. 06, pp. 78-84.

Affentranger, C. 1997, New Wood Architecture in Scandinavia, Birkhäuser Verlag, Basel, Switzerland.

Andersen, H. 2005, Videnskabsteori & Metodelære, Forlaget Samfundslitteratur, KBH.

Andresen, I. 2000, A Multi-Criteria Decision-Making Method for Solar Building Design, PhD-dissertation, the Norwegian University of Science and Technology.

Auer, G. 1995 (2), "Baustoffe sind von Natur aus künstlich / Building Materials are Artificial by Nature", Daidalos, vol. 56, pp. 20-35.

Auer, G. 1995 (1), "Editorial", Daidalos, vol. 56, pp. 19.

Bejder, A. 2006, Arkitektonisk kvalitet i industrialiseret boligbyggeri, Master of Science in Architecture and Design edn, Architecture and Design, Aalborg University, Aalborg.

Bejder et al. 2008, 'MCDM in Practice: An Architectural Point of View', in Passiv House Norden 2008 Conference Proceedings: The first Nordic Conference on passive houses. SINTEF, 2008. s. 134-143.

Bejder, A.K., Kirkegaard, P.H., Wraber, I.K. & Falk, A. Submitted October 2011, 'The materiality of novel timber architecture - based on a case study analysis of Cross-Laminated Timber', ARQ: Architectural Research Quarterly,.

Bejder, A.K., Kirkegaard, P.H., Wraber, I.K. & Falk, A. submitted January 2012, "The materiality of novel timber architecture - developing a model for analysing and evaluating materials in architecture", Architectural and Planning Research.

Bejder, A.K., Kirkegaard, P.H. & Fisker, A.M. 2010, "On the architectural qualities of cross laminated timber.", , ed. P.J.S. Cruz, Taylor & Francis

Group, London, pp. 119-121.

Bejtka, I. & Lam, F. 2008, "Cross laminated timber as innovative building material", Annual Conference of the Canadian Society for Civil Engineering 2008 - "Partnership for Innovation", 10 June 2008 through 13 June 2008, pp. 1090.

Bek, L. & Oxvig, H. 1997, Rumanalyser, Fonden til Udgivelse af Arkitekturtidsskrift B, Århus.

Bell, V.B. 2006, Materials for Architectural Design, Laurence King, England.

Billger, M. 1999, Colour in Enclosed Space Observation of Colour Phenomena and Development of Methods for Identification of Colour Appearance in Rooms, Chalmers University of Technology.

Blaser, W. 1985, Holz-Haus, Maisons de bois, Wood Houses, Wepf & Co. AG, Verlag, Basel.

Blaser, W. 1992, Joint and connection: ideas in furniture design and their background, Birkhäuser Verlag, Basel.

Blaser, W. 1994, Tomsk: Texture in wood, Birkhäuser Verlag, Basel.

Bogensperger et al. 2010, 'Investigation of vibration behaviour of floors made of Cross Laminated Timber (CLT)' in BAUINGENIEUR Volume 85, pp. 45-52.

Brandner, R. & Schickhofer, G. 2008, Glued laminated timber in bending: new aspects concerning modelling.

Brodersen, L. 2007, Geokommunikation, Forlaget Tankegang A/S, Frederikshavn.

Brohus, H. & Bjørn, E. 2005, 'An iterative assessment concept for building design based on the Eco-factor', in Journal of civil engineering and management, Vol XII, no. 1, pp. 51-56.

Böhme, G. 1995, "Inszenierte Materialität / Staged Materiality", Daidalos, vol. 56, pp. 36-43.

Böhme, G. 1993, "Atmosphere as the Fundamental Concept of a New Aesthetics", Thesis Eleven, vol. 36, pp. 113-126.

Buri, H. & Weinand, Y. 2008, 'Die provisorische Kapelle von St. Loup' in Schweizerische Arbeitsgemeinschaft für Holzforschung SAH, Nr. 2, pp. 16-20.

Dahlin, Å. 2002, On architecture, aesthetic experience and the embodied mind: seven essays, School of Architecture, Royal Instutute of Technology, Stockholm.

Deplazes, A. 2001, "Wood: indifferent, synthetic, abstract - man-made", Werk, Bauen + Wohnen, vol. 88, pp. 78-81.

Deplazes, A. 2005, Constructing architecture: Materials Processes Structures - a handbook, Birkhäuser, Basel.

Devane, A., Gutheim, F. & Wright, F.L. 1975, In the cause of architecture: With a symposium on architecture with and without Wright by eight who knew him, Architectural record, New York.

Dragheim, A. & Kreiner-Møller, J. 1999, Etagehuse af træ i Europa: en eksempelsamling, By- og Boligministeriet, Kbh.

Espansiva-Byg A/S. 1971, ESPANSIVA - Et Jørn Utzon byggesystem, Espansiva-Byg A/S, Roskilde.

Falk, A. 2005, Architectural Aspects of Massive Timber - Structural Form and Systems, PhD dissertation, Luleå University of technology.

Falk, R. 2010, 'Wood as a Sustainable Building Material' in Wood Handbook, Chapter 01, General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 1-1 - 1-6.

Falk, A. 2011, "Cross-laminated timber plate tensegrity and folded roofs.", Wood for Good - innovation in timber design and research., ed. Larsen, Olga Popovic and Lee, Daniel Sang-Hoon, The Royal Danish Academy of Fine Arts, , pp. 91-107.

Falk, A. & Buelow, P.V. 2011, 'Form Exploration of Folded Plate Timber Structures based on Performance Criteria', Taller, Longer, Lighter: meeting growing demand with limited resources : IABSE-IASS 2011Hemming Group Ltd., London, pp. 467.

Follesa, M. et al. 2010, Mechanical in-plane joints between cross laminated timber panels, WCTE World Conference on Timber Engineering.

Frampton, K. & Cava, J. 1995, Studies in tectonic culture: the poetics of construction in nineteenth and twentieth century architecture, Graham Foundation for Advanced Studies in the Fine Arts, Chicago, Ill.

Frangi, A., Fontana, M., Hugi, E. & Jübstl, R. 2009, "Experimental analysis of cross-laminated timber panels in fire", Fire Safety Journal, vol. 44, no. 8, pp. 1078-1087.

Frascari, M. 1984, "the tell-the-tale detail", VIA 7: The Building of Architecture, , pp. 23-37.

Gammelgaard Nielsen, A. 2002, Materialeæstetik: en undersøgelse af krydsfiners æstetiske potentiale, PhD afhandling, Arkitektskolen i Århus, Århus.

Gold, S. & Rubik, F. 2009, 'Consumer attitudes towards timber as a construction material and towards timber frame houses – selected findings of a representative survey among the German population', Journal of Cleaner Production, 17, pp. 303-309.

Groat, L. & Wang, D. 2002, Architectural Research Methods, John Wiley & Sons, Inc., New York.

Hansen, J. 2001, Massivtræ i byggeriet, Træbranchens Oplysningsråd, DK.

Hearn, M. F. 1990, The Architectural Theory of Viollet-Le-Duc: Readings and Commentary, MIT Press., Cambridge.

Hegger et al. 2007, Basics: Materials, Birkhäuser, Basel.

Heikkinen, M. & Zumthor, P. 2007, Zumthor: spirit of nature wood architecture award 2006, Rakennustieto Oy, Helsinki.

Herzog, T. 2004, Timber construction manual, Birkhäuser, Basel.

Hopsch, L. 2008, Rytmens estetik, formens kraft, Chalmers tekniska högskola, Göteborg.

Hvass, S.M. 2007, Hanne Kjærholm Houses, Living Architecture Publishing, Copenhagen.

Jensen 2007: Jensen, Thomas Bo. Miraklet i Vorarlberg, in Arkitekten 7.
Kruft, H. 1994, A history of architectural theory: from Vitruvius to the present, Zwemmer, London.

Liu, C.A. 2011, "Wood in Architecture: Rediscover the Material of Our Time", Green Building Technologies and Materials, vol. 224, pp. 94-98.

Löhnert G. et al. 2004, Integrated Design Process - A guideline for sustainable and solar-optimised building design, International Energy Agency (IEA) Task 23 Optimization of Solar Energy Use in Large Buildings, subtask B.

Mallgrave, H.F. 2004, "Introduction" in Style: Style in the technical and tectonic arts; or, practical aesthetics, ed. Semper, G., Mallgrave, H.F. & Robinson, M., Getty Publications, Los Angeles, pp. 1-67.

Massivträ: Håndbogen, 2002, Trätek, Industrikonsortiet Massivträ, SE.

Massivträ: Håndbogen, 2006, Trätek, Industrikonsortiet Massivträ, SE.

Mo, L. 2003, Philosophy of science for architects, Kolofon, Trondheim.

Musso, F. 2005, 'Simply good' in DETAIL Building Simply, Schittich (ed.).

Norberg-Schulz, C., Fehn, S. & Postiglione, G. 1997, Sverre Fehn works, projects, writings, 1949-1996, The Monaccelli Press, New York.

Norberg-Schulz, C. & Postiglione, G. 1997, Sverre Fehn samlede arbeider, Orfeus, Oslo.

Pallasmaa et al. 1987, The language of wood : wood in Finnish sculpture, design and architecture.

Pallasmaa, J. 2005, The eyes of the skin: architecture and the senses, Wiley-Academy, Chichester, West Sussex.

Pallasmaa, J. & Sato, T. 2007, Alvar Aalto: through the eyes of Shigeru Ban, Black Dog Publishing.

Patterson, T.L. 1994, Frank Lloyd Wright and the meaning of materials, Van Nostrand Reinhold, London.

Petersen, S. & Svendsen, S. 2007, Method for integrated design, BYG. DTU, Denmark.

Rasmussen, S.E. 1957, Om at opleve arkitektur, Fotografisk optryk edn, Gad.

Riis, V. 2001, "Analyse og vurdering af design" in Design gennem 200 år, ed. I. Engholm, Gyldendal Uddannelse, Nordisk Forlag A.S., Copenhagen, pp. 176-216.

Ritter, E. & Dauksta, D. 2011, New Perspectives on People and Forests, Springer Publisher.

Roos, A., Woxblom, L. & McCluskey, D. 2010, "The Influence of Architects and Structural Engineers on Timber in Construction - Perceptions and Roles", Silva Fennica, vol. 44, no. 5, pp. 871-884.

Ruskin, J. 1988, The seven lamps of architecture, Century, London.
Santos, S. C. 2008, 'Timber: a changing material and its effect on the architectural form', WIT Transactions on Ecology and the Environment, Vol. 113, pp. 201-208.

Schickhofer, G.e.a. 2006, 5. Grazer Holzbau-Fachtagung, Tagungsband, Brettsperrholz - Ein Blick auf Forschung und Entwicklung. TU Graz; Institut für Holzbau und Holztechnologie., Graz.

Schindler, C. 2009, Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am Beispiel des Holzbaus, PhD dissertation, ETH Zürich.

Schittich, C. 2005, In Detail: Building simply, Birkhauser Verlag AG, Basel.

Schittich, C. 2010, 'St Loup Chapel in Pompaples', in Detail – Review of Architecture and Construction Details, Timber Construction, Vol. 6, 2010.

Schweitzer 2004: in Herzog et al. 2004: Timber construction manual.

Semper, G. 1989, The four elements of architecture and other writings, Cambridge University Press, Cambridge.

Semper, G. et al. 2004, Style: Style in the technical and tectonic arts; or, practical aesthetics, Getty Publications, Los Angeles.

Slavid, R. 2005, Wood Architecture, Laurence King Publishing, UK.

Slavid, R. 2006, Wood Houses, Laurence King Publishing, UK.

Steurer, A. 2006, Developments in Timber Engineering: The Swiss Contribution, Birkhäuser Verlag, Basel.

Storvang, P. 2000, "Træhuse som boliger i Danmark", Nordic Journal of Architectural Research, vol. 13, no. 4.

Stuerzenbecher, R. et al. 2010, "Structural design of Cross Laminated Timber (CLT) by advanced plate theories", Composites Science and Technology, vol. 70, no. 9, pp. 1368-1379.

Thelandersson, S. 1997, Flervånings trähus, Träinformation, Stockholm.

Thiis-Evensen, T. 1987, Archetypes in architecture, Repr. edn, Oxford University Press, Oxford.

Tostrup, E. 2006, Princeton Architectural Press, New York.

Tykkä, S. et al. 2010, 'Development of timber framed firms in the construction sector - Is EU policy one source of their innovation?' Forest Policy and Economics 12, pp. 199–206

Unwin, S. 2009, Analysing architecture, 3. ed., rev. and enlarged edn, *Routledge, London.*

Vessby, J. Et al. 2009, Experimental study of cross-laminated timber wall panels.

Wachsmann, K. 1995, Building the wooden house: technique and design, Birkhäuser, Basel.

Wachsmann, K. 1959, Wendepunkt im Bauen, Krausskopf, Wiesbaden.

Werne, F. 2004, "Material och Materialitet" in Material och materialitet, ed. C. Engfors, Arkitekturmuseet, Stockholm.

Werner, Richter 2007: Wooden Building Products in Comparative LCA,

Wester, T. 1984, Structural order in space: the plate-lattice dualism, Royal Academy of Arts, København.

Wright, F.L. et al. 1975, In the Cause of Architecture: With a Symposium on Architecture with and without Wright byEight Who Knew Him, Architectural record, New York.

Weston, R. 2003, Materials, form and architecture, Laurence King Publishing, London.

Wurman, R.S. 1986, What will be has always been: the words of Louis I. Kahn, Rizzoli, New York.

Yin, R.K. 2003, Case study research – design and methods, Third edn, Sage Publications, Inc., London.

Zumthor, P. 2006, Atmospheres: architectural environments, surrounding objects, Birkhäuser Verlag AG, Basel.

Zumthor, P. 1998, Thinking architecture, Lars Müller Publishers, Baden.

Webpages:

(Arkitrae 2011) [Homepage of Arkitrae], [Online]. Available: http://www.arkitrae.dk/ [2011, 25/10].

(Dezeen 2011)[Homepage], [Online]. Available: http://www.dezeen.com/2008/04/03/esherick-house-by-louis-kahn/ [2011, 01/11].

(dRMM Architects 2012) [Homepage of dRMM Architects], [Online]. Available: http://drmm.co.uk/projects/ [2012, 01/30].

(Grindley 2012) [Homepage of Grindley Architects], [Online]. Available: http://www.davidgrindleyarchitects.co.uk/projects_view.php?content_id=52&parent_id=5 [2012, 29/01].

(holzbau-stiegler 2012)[Homepage of Holzbau Stiegler], [Online]. Available:http://www.holzbau-stiegler.at/content/architekturgalerie.php [2012, 29/01].

(KLH 2012) [Homepage of KLH, Austria], [Online]. Available: http://www.klhuk.com/portfolio/education/kingsdale-school.aspx# [2012, 29/01].

(KLH UK 2012) [Homepage of KLH, UK], [Online]. Available: http://www.klhuk.com/home.aspx [2012, 29/01].
(Mattarnold 2011)[Homepage], [Online]. Available: http://mattarnold.wordpress.com/2008/06/13/detail-lous-kahn/ [2011, 01/11].

(Mondada Architects 2012) [Homepage of Mondada Architects], [Online]. Available: http://www.mondada-arch.ch/realisations/2009_chapelle_z.php [2012, 29/01].

(Norwegian Wood (1) 2011) [Homepage], [Online]. Available: http://www.arkitektur.no/?nid=216853 [2011, 25/10].

(Panoramio 2012) [Homepage], [Online]. Available: http://www.panoramio.com/photo/4263335 [2012, 29/01].

(proHolz 2011) [Homepage], [Online]. Available: http://www.proholz.at/ [2011, 25/10].

(PUUinfo 2011) [Homepage], [Online]. Available: http://www.puuinfo.fi/ [2011, 25/10].

(Ronacher 2012) [Homepage], [Online]. Available: http://www.architekten-ronacher.at/en/projects/richter-sauna-house [2012, 29/01].

(Træinfo 2011) [Homepage], [Online]. Available: http://www.traeinfo.dk/ [2011, 25/10].

(Trefokus 2011) [Homepage], [Online]. Available: http://www.trefokus.no/fullstory.aspx?m=521 [2011, 25/10].

(Trästad2012 2011) [Homepage], [Online]. Available: http://www.trastad2012.se/web/Hem.aspx [2011, 25/10].

(Waughthistleton 2012)[Homepage], [Online]. Available: http://www.waughthistleton.com/project.php?name=murray&img=1 [2012, 19/01].

(Seier + seier 2011) http://www.flickr.com/photos/seier/528613634/ [2011, 03/11]

APPENDIX

APPENDIX 1

The materiality of novel timber architecture - developing a model for analysing and evaluating materials in architecture.

Submitted to: international journal: Architectural and Planning Research, January 2012.

APPENDIX 2

The materiality of novel timber architecture - based on a case study analysis of Cross-Laminated Timber.

Submitted to: international journal: ARQ: Architectural Research Quarterly, October 2011.

APPENDIX 3-5

3: Arkitektur i massivtræ
4: Krydslimede massivtræ elementer i byggeriet
5: Massivtræs æstetiske kvaliteter

Published in Danish journal: Arkitekten no. 12, 2008, pp. 68-71, 74-77, 80-83.

APPENDIX 6

On the Architectural Qualities of Cross Laminated Timber

Published in *Structures and Architecture: proceedings of the first international conference on structures and architecture,* ICSA 2010, Guimarães, Portugal, 21-23 July 2010. red. / Paulo J. S. Cruz. London: C R C Press LLC, 2010. s. 410-417.

APPENDIX 7

MCDM in Practice: An Architectural Point of View

Published in *Passiv House Norden 2008 Conference Proceedings: The first Nordic Conference on passive houses.* SINTEF, 2008. s. 134-143.

APPENDIX 8

Structured analysis of the *materiality of CLT,* based on the analysis model presented in chapter 4.

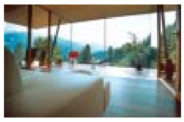
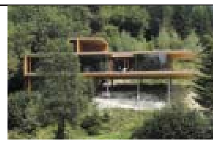
The materiality of Cross Laminated Timber

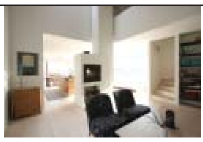
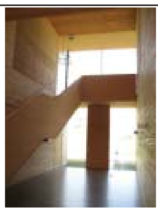
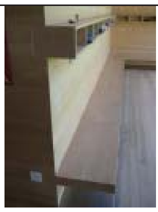
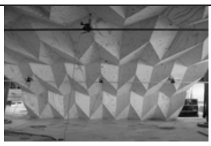
Entity, Surface, Joints – Technology, Material, Materiality

Technology; Format, Level of detailing, Standardisation/flexibility, ….

Material; Technical properties, workability, strength, applicability, ….

Materiality; Character, colours, tactility, structure,

	Annexe for a summer house in Skagen, Denmark **2005** **Architect: Jesper Nielsen, Engineer: Henrik Almegaard.**	**House in Haus, Ennstal, Austria** **2002** **Architect: DI Ulli Koller, Engineer: Thomas Stiegler.**
	 	 
Entity Something in-between and at the same time including both structure and space!		
Technology		
Format Generally, these elements show two "states of technology"; that of the plates (= the technology providing the lamination technique, the huge formats, the plate-function, etc.) and that of the boards (= the technology providing the long, flat, slender boards, and) In this scale, as we experience the material at a distance, it is particularly the "states of technology" of the large	Each part of the building; roof, walls, ceiling, stay within the max **formats** that can be provided from the producer. However, keeping within this format also means that **the large format of the elements is actually invisible** = only visible in the unfinished building. *(The wooden external sheathing "covers the sheet tectonics" as Deplazes expresses it.)*	The large **formats** are visible in the final building design; more than one element is needed for the large horizontal "decks" = joints (seams) within the same plane occur.

Sommer house in Them, Denmark **2006** **Architect: Jesper Nielsen**	**Kindergarten in Langenegg, Austria** **2004** **Architect: Fink & Thurner, Engineer: ????.**	**Folded structures (Origami)** **2008** **Danilo Monada architects & Shel.**
 	  This is a special case –NOT CLT but Solid Wood Panels. Included anyway because there a many similarities between these two materials/products; the cross laminated element. However difference in size and thus function. SWP: 3-5 layer, max 60 mm, for planking large areas external and internal. However, NOT bearing but function as surface and stabilising plate.	 
The large format of the elements is not clear from outside or from inside. Probably due to white paint = homogeneous interior, just at the wooden external sheathing "covers the sheet tectonics".	*(The wooden sheathing outside "covers the sheet tectonics".)* Inside: the large format is clear in the massive railing at the stairs and on the 1. floor and in the massive yet slender vertical element with door. For the interior and furnishing in the nursery the large continuous surfaces with only few in-plane joints demonstrate the large formats provided. At one door; the limitations of element size (format) seems to be "respected" and even enhanced by continuing the	Utilises the large format of the plates to upscale the principles of origami.

homogeneous plates we encounter.		
Standardisation vs. adaptability (flexibility) (An example of mass customization?)	The cross-sectional partitions are from factory given the characteristic shape that lets it continue above the hallway. All the elements were prefabricated with the right dimensions – no adaption on site - and with holes for windows. Clear in the carcass, not in the final building.	Of course each element in this case is also made specifically, however, the consequent use of plates = when massive in stark contrast to glass = when open, generally the plate is not perforated or cut in special shapes; its quality is to be a plate! The ability to customise each element is most clear at the large hole above the “internal” terrace.
Level of detailing	From design process/drawing to built/erected house is extremely clear: (**Level of detailing**): Straight line from design phase (3D computer model) to production and finished element (CNC-filling, etc.).	Composition of a few large sharp cut and precise elements.
Material		
The Plate (bearing and stabilising)	Construction method is not clear. The form is characterised by mass vs. opening; an expression that within timber architecture is seen in log houses and in the light weight timber frame constructions like balloon- and platform framing. However, knowing the material this simple form seems logical to the material properties – an example of the simplest yet stable construction. From inside: construction method is only readable at few points; the end-surface of the elements, which is exposed at the bed loft. Large opening in the corridor: no lintel/beam is needed above. This expresses the plate-function of the element – the ceiling/roof plates are bearing in both directions! However, clear in carcass, not in final building.	The plate-function (shear wall) facilitates the very simple composition of vertical and horizontal plates. Combined with (diagonal) steel columns to obtain great transparency between inside and outside. The plates ***form*** the building = clear demonstration of what the material can *do.*
Applicability	Wood used for all functions; external sheathing, structure, walls, ceilings, floors, window frames, furniture, etc.	
Workability To demonstrate workability in entity the PUU pavilion can be	Pictures from construction process and the carcass clearly demonstrate the workability of the material; partly due to	The hole above the “internal” terrace.

	"door", thus separating the large walls (could be an example of Semper's: "making a virtue out of necessity" and see (here it is important to consider this material based on its own "state of technology" which is not the same as that of wood in Semper's time!!!!)	
Customised elements prefabricated holes for windows/doors. Like case 1: special cross-sectional partitions. Besides, special shaped/formed elements to provide the differentiated ceiling height.	Particularly evident in the large irregular massive railing for the stairs.	Large, irregular formats.
House in Them: Great precision in the straight, relatively thin partition at the stair and as railing. "Lines as straight as an arrow". House in Hamburg: Great precision in the straight, relatively thin partition. "Lines as straight as an arrow".	All elements seem to fit hand in glove. Sharp corners, the precise and narrow gap between walls and floor, walls and doors. = clear demonstration of the precision provided by tools and technologies applied for processing.	Even and uniform elements joined in sharp lines.
"The missing corner" is that expressing the material properties? Yes and no! It would be a very unusual feature in traditional timber building (however, known within the American balloon-framing) and it would require a cantilevering beam of considerable dimension.	(In this case we do not have the bearing and stabilising plate since SWP, not CLT!)	The homogeneous structure of the plates is the foundation of this *entity.* The paper origami; the thin paper gets its strength from being folded. Here we already have the massive and strong timber plates. Se også Detail, English edition, vol. 2010 - 6, pp. 600.
Wood used for all functions; external sheathing, structure, walls, ceilings, floors, window frames, furniture, etc.	Wood used for all functions; external sheathing, structure, walls, ceilings, floors, window frames, furniture, etc.	Wood is used for all functions.
	The fact that the building is "entirely" of wood also demonstrates wood's great workability.	

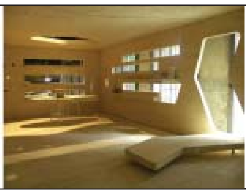
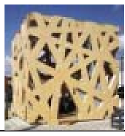
used. 	“wood en general, as raw material”, partly due to the homogeneous structure.	
Thermal conductivity (in regard to thermal bridges)		The low thermal conductivity of wood makes it possible to continue the interior ceiling outside.
Durability		
Other		
Materiality		
Form-material: pragmatic or abstract approach	The pitched roof and the simple body reflect a traditional way of building and traditional materials, and besides it is climate related, being placed in the rainy Denmark. This refers to both the pragmatic and abstract approach to materials in architecture; durability (Vitruvius) and the socio-cultural theories of Semper. The simple and “basic” form also corresponds to the function of the building – being an annexe the main function of the building is to provide extra bedrooms and besides, the large opening with the folding door provides an additional “room” for the terrace in lee of the wind. = Form is based on the function.	Modern interpretation of the wooden house. Breaks with the traditional Austrian timber building tradition…. Based on the “new” material properties; the plate. Characterised by great contrast between the dense, massive timber plates and the large window openings.
Structure or surface (skeleton or skin)	The continuous surface; the wrapping enclosure = in this case we experience the material as a *SKIN*, not a bearing structure.	In this case we experience the material as a *STRUCTURE;* the space emerges from a composition of separate structural elements. Each of these has their own skin. The space is not wrapped but constructed.
Material combinations	CLT, painted plywood (Exterior: wooden sheathing (boards), thatched roof)	CLT, glass, steel columns
Atmosphere	Large defined openings create a contrast to the massive/dense wooden surfaces = differentiate between the elements. To avoid the massive wood to become too dense:	Great contrast between the massive; the structure and openings; floor to ceiling windows and the horizontal plates = a floating space (facilitated by the steel columns as well). The openings are not framed but floats

		“The irregular folds also enhance the acoustics and the incidence of light” (Detail, English edition, vol. 2010 - 6, pp. 599)
General character; particularly clear in Hamburg: ??????		This case is based on an architectural idea inspired by the art of origami. But the plate facilitates this special form naturally. The form/space is based on the function (see DETAIL vol. 6 2010) So the idea (origami) as an architectural and technical …. Is adapted to the function (which must be culturally and indeed influenced by religious traditions).
A combination. Used structurally (e.g. At the stairs and for the railing on 1. Floor) and as a continuous surface/skin at wall meet wall meet ceiling. However at this scale, the white colour entails that the surface – and the unified special experience - appears more homogeneous. No differentiation between wall and ceiling. Conclusion = overall impression: a wrapping enclosure; a *SKIN.*	Used as a wrapping enclosure, a *SKIN,* however, that is also the main function of this product; the Solid Wood Panel which is NOT a structural material!	A skin. The structural system is not clear. Imitate a structure known from completely different material; thin paper. Clearly a wrapping enclosure, a *SKIN.* (Purely materiality, not material?)
Painted CLT (Exterior: wooden sheathing (boards), thatched roof) Hamburg: Painted CLT, concrete for basement, glass. (Exterior: wooden sheathing (boards), concrete basement)	?, STP, wooden battens, glass, …. (Exterior: wooden sheathing (boards))	CLT
The white colour and the diversity in ceiling heights = light atmosphere (this goes for both Them and Hamburg). Contrast between massive and open. Large windows – much light – the light is	Here we have a good example of the well composed interaction between light, materials, form?, …. Refer to Zumthor and see what aspects he uses to describe atmosphere. In this project the architects have succeeded in creating a room entirely out of wood	In general, a more intense, closed, dim (?) atmosphere. However, the “box” is dissolve by the many crooked angles = creates an irregular rhythm and diversity in the spatial experience ….

	- Corridor; white painted surfaces creates a contrast to the warm, intense wood colour - Rooms; ceiling to ridge = less heavy = proportions. Placement of openings, e.g. windows in the rooms are placed so that from the corridor you look outside through the room = not the feeling of a closed “cigar box”.	between ceiling and floor = floating transition between indoors and outdoors.
Enclosure		
Technology		
Format Generally, these elements contain two “states of technology”; that of the plates (= the technology providing the lamination technique, the huge formats, the plate-function, etc.) and that of the boards (= the technology providing the long, flat, slender boards). In this scale, as we get closer to the material, it is particularly the “states of technology” of the boards we encounter.	Almost exclusively we see the large plane surface of the elements = a surface made of boards! With the exception of: at the bed loft: cross-sectional surface of the elements is exposed = the “state of technology” of the element; the lamination of boards placed crosswise in several layers!	(Mangler detaljebilleder for at kunne se, om elementerne stå “rå” som skillevægge).
Level of detailing	Level, smooth and continuous surfaces.	Level, smooth and continuous surfaces.
Material		
The Plate (bearing and stabilising = homogeneous structure, e.g. when cutting a hole in the surface).	The homogeneous structure is not obvious looking at the plane surface where we only see a surface of boards – what is underneath is unclear. Exposed cross-sectional surface of the loft bed: here we not only see the homogeneous structure (the boards placed crosswise in layers), we are also told the story, that the plane surface is a part of the structural system.	

reflected on the white painted surfaces.	without ending up with the "sauna"/"cigar box"; Material combination, dense > < open (spatiality), shift in direction of battens (Bejder et al. 2010) Det skal skal refereres til Portugal artiklen er måske netop det med skift I retning og brug af flere formatter. Det som til føjes i denne artikel er så, at det ikke er de eneste parametre. Lyset, kontrasten mellem massiv og åben, etc. er også væsentlige parametre!!!!	Ceiling become quite heavy as you stand at the one end looking through the building …. Smaller slanting, irregular spatialities along the building. (The intense atmosphere might be the wanted for this function!).
The format of the boards is particularly evident where one sees both the exposed cross-sectional surfaces and the large surface of the element (e.g. Them: "staircase" and railing 1. Floor, Hamburg: partitions).	The format of each board is less dominant – the used wood species is uniform in appearance. The cross-sectional surfaces on the railings are covered with a massive timber batten.	Offhand, no exposed cross-sectional surface = within each element we solely see the plane surface of the elements = the long slender boards. How there are joined to a surface is not obvious; could be glued, tongue and groove, or ….??
Level, smooth and continuous surfaces.	Level, smooth and continuous surfaces. (The precision and sharpness of the slender wooden battens)	Level, smooth and continuous surfaces.
Them: "staircase" and railing, Hamburg: Partitions; exposed cross-sectional surfaces: here we not only see the homogeneous structure (the boards placed crosswise in layers), we are also told the story, that the plane surface is a part of the structural system. Both cases: holes cut directly in the element = we can see the homogeneous structure from the fact that no lintel above the hole is needed. We can see this demonstrated in dRMM's Naked House and PUU pavilion.		

Workability	-	-
Hygroscopic (Due to its hygroscopic nature wood absorbs water and releases it again, depending on ambient humidity → swelling and shrinkage).	This property of wood is evident in the surface e.g. in the corridor; a crack between the boards in the ceiling element. This tells us that, despite the high-technological procedures and the attempt to control the material, we are still dealing with a living material.	-
Materiality		
Surfaces: **1:** The plane surface; the boards side by side. **2:** The cross-sectional surface; the crosswise placement of lamellae in several layers. **3:** The surface as the protecting cover; the wrapping enclosure - SKIN.		
Visual & tactile qualities: - Linear grain pattern - Modularity - Colours (-variations) - Texture - Knots - Growth rings (These qualities can be visually as well as tactically sensed (=a physical sensing). However, these sensory perceptions will (generally) be marked by earlier experiences with materials as well (experienced gained through the medial and working relationship - refer to Böhme) just as the experience of the material might be affected by social circumstances; e.g. the	Clear linear grain pattern. Give the plane surfaces life, structure, direction, tactility. Pass on the uniqueness of each piece of wood to the surfaces. Important/unique factor for a high-technological, designed/engineered product which in many cases are accuse of being too uniform and characterless (Refer to the critique stated by Deplazes 2001) Evt. refer to Wright's use of shifting orientation in board-cladding. The lines of the boards (and the cracks described above) enhance this linearity of the grain pattern The modularity of the boards is very clear and creates a clear and continuous rhythm in the large surface. The original form/appearance of wood; the "stick" is a part of the surface (skin). This rhythm	The linearity of the grain pattern and the boards enhance the length of the long building!

 		
The possibility to easily cut holes in the surface. Not particularly evident in this case; however, the various shapes of holes (e.g. dRMMs Naked house and System 3 by Kaufmann & Ruf) can be made mechanically using simple tools like saw and drill.	The possibility to cut wood in various shapes and sizes. The possibility to merge elements; e.g. the fusion of wall and furniture; they become interrelated – a part of each other's surface and structural system.	
This property of wood is evident in the surfaces e.g. Them: the small height difference between the boards = "movement" in the living material. Hamburg: small cracks/gaps between boards in the partition and the small height difference between the boards in general.		
The painted surface – generally these surfaces appear homogeneous and "uniform". However (at this scale) – as the surface is illuminated the small cracks and tiny difference in height are actually clearer in this painted surface as the illumination cause a notable contrast between light and shadow. At the cross-sectional surface: curved lines of the growth ring mixed with linear grain pattern.	The used wood species = uniform surface (few knots and only little colour contrast) = Linearity, grain pattern and modularity of the boards in the massive elements is not dominant. Warm but not "heavy" colour.	(Contrary to paper origami) these timber elements have an ornamented surface (CLT=the boards, the linearity, modularity, grain pattern in its surface). The elements for each fold seem to be cut without consideration to this "ornamentation" of the plates. Leads to following questions/possible problems: how will the ornamentation "meet" at the seam? It might be technically possible to cut various shape and join these in a simple way (ref. to Deplazes' cardboard model) but are there any aesthetic "rules"? (Same question could be asked to hole of various and amorphous shapes in dRMMs Naked House and Kingsdale Music and Sports….). Se "samlet afhandling" med ref. til Gammelgaards formundersøgelser.

material "stand for something". (social character) …. E.g. the "cigar box", the "sauna" or wood as being a material for temporary and primitive buildings; barracks, shed, etc. Likewise we encounter the synaesthetic character of the material when we experience the colours as being warm or cold, etc., e.g. the warm atmosphere of Langenegg and Skagen vs. Them and Hamburg.)	exists on a visual as well as tactile level. Relatively many knots and colour variation = gaudy ornamentation (in contrast to the white painted surfaces).	
Plasticity (workability)	Plastic? Not in the same way as Wright and Siza have exercised. The surface seems quite "locked" to its "straightness". This is also due to the use of a small number of large elements. (Contrary to the folded structures/origami).	Do not appear plastic – the building (from entity to detail) is characterised by its straight lines and "stiff plates"!
Filtration (light, view, etc.)	No filtering: instead massive > < open.	No filtering: instead massive > < open, however, the hole above the "internal" terrace demonstrate the "filtering" in principle (in large scale though!)
Transition		
Technology		
Format	The large format provided by this specific material manifest itself in the length of the joints. Small scale of the house + the large	= FEW but LONG joints.

The all-covering white paint of all surfaces - except the floor – makes the surfaces in unity appear quite plastic. Especially since the white cover becomes a common feature in all the surfaces; e.g. in both plane and cross-sectional surface; the white colour unify these different surfaces and reduce/erase the hierarchy.	The uniform surface (described above) and the bevelled corners entails that the massive plates in this case seem more plastic than e.g. in the annexe in Skagen.	In contrast to the other projects where the plates are utilised as large straight walls these “folded structures” (origami) (IBOIS institute) are created by many smaller elements. These constitute a unified surface that appears plastic despite its heavy character.
No filtering: instead massive > < open.	A frequently used feature within timber building design is utilization of wooden battens or lamellas as “sticks” to create a grille effect, i.e. filtering light, view, etc. This effect is noticeable in Aalto’s Villa Mairea and in Kuma’s Ginzan Onsen Fujiya where the slender bamboo sticks creates a floating transition between building and landscape. Good examples of perforations within massive, ‘homogeneous’ timber plates: dRMMs Naked House: demonstrate from large holes to perforation as a filtering of light/view. System 3: Perforated massive plates at sleeping area. PUU pavilion: a skeleton appears from removing material – a perforation of various shaped holes. General: perforation within traditional timber design arises from adding material; filtration within homogeneous timber plates arises from removing material.	No filtering: instead massive > < open.
= FEW but LONG joints.	= FEW but LONG joints.	The medium length longitudinal joints (seams) define the irregular formats.

	format of CLT elements → only few elements for the entire house. **No element is jointed to another element in its "own" plane.** E.g. roof = two full-size elements + two triangular elements for gables = very **few joints in the entire construction.** **= FEW but LONG joints.**	
Level of detailing	High level of detailing in the joints, precise cutting (CNC), Compared to traditional,	
Material		
Plate (homogeneous structure)	The longitudinal joints actually express the homogeneous structure of the plate – in Semper's words: á la: *"the seam is the joint of homogeneous surfaces".* However, at the bevelled corners we get no reference to its depth or function as bearing element.	The longitudinal joints actually express the homogeneous structure of the plate – in Semper's words: á la: *"the seam is the joint of homogeneous surfaces".* This is particularly evident in this case, where the plate-function forms the entire formal expression!
Workability	In this project workability in relation to joints is particular clear in the assembling of elements. (picture: detail - assembling) - Carcass: The roof elements are bevelled, placed directly on top of the walls and fastened with screws = demonstrate the ease by which one can work, assemble and join the material.	The workability in the joining - not clearly demonstrated in this project. Rather it seems like the plates are simply put on top of each other – how they are jointed together is not clear. (Perhaps also this: the steel column is fastened directly to the plate (surface); this tells us 1. That the surface is a part of the structural system, and 2. That the steel can be jointed to the elements directly and in a simple low-tech way; using screws (or the like!!!!).
Materiality		
The knot and the seam	**SEAM** – longitudinal joints jointing homogeneous surfaces.	Expression: "Elements are just lying on top of each other" – like glued together

	Sharp and in the merging of wall and furniture.	Sharpness in the seams; sharp bevelled cuts.
In both Them and Hamburg – clear examples of the exposed cross-sectional surfaces → Two levels of jointing; - the jointing of several boards (to become one element) - the jointing of one element to another element The jointing of boards by fastening them together in crosswise layers = clearly express the material properties; the homogeneous structure, but also demonstrate that all boards are a part of the structural, system and the thickness of the element demonstrate that we are facing the bearing element. The longitudinal jointing of element to element also express the homogeneous structure of the plate – in Semper's words: á la: *"the seam is the joint of homogeneous surfaces".*	….	The longitudinal joints actually express the homogeneous structure of the plate – in Semper's words: á la: *"the seam is the joint of homogeneous surfaces".* However, at the bevelled corners we get no reference to its depth or function as bearing element.
  Here we see how the primitive and low-tech jointing of one element to another. The elements are simple screwed together (after which the screw is attempted to be conceal using filler and paint) = demonstrate the ease by which one can join this material.	The fusion of wall and furniture = gives the impression that this material can be worked and jointed together in various ways and relatively easily.	?
	In general longitudinal joints – **SEAM.** Even the sticks meet as a "surface" =	**SEAM:** Longitudinal,

		– not locked structurally to each other!!!!!	
The articulated and the hidden (the joint as an ornament) (Concave or convex)	Mainly concave hidden joints → enhance the impression of the surfaces as a continuous ***SKIN*** (like **a tent which corners are created by the pull of the guy ropes)**. The corner is just a fold in a blanket!		

	with a seam. However, where wall and furniture fusion another type of joint appears. Here the elements become interrelated; a part of each other, as we know it from a traditional way of joining where the different parts "lock" each other and obviate the need for binding material (e.g. corners of traditional log houses) This joint expresses a great plasticity in the material due to the great workability of wood and the fusion between surfaces and functions. (Refer to Patterson's: *"Expressed workability is always in at least partial conflict with primary form but can combine with form to express the nature of the material more intensely than can either property alone."* (Patterson 1994, pp. 27))	Another example: Puu pavilion where the skeleton structure emerges from a perforation of the massive (Bejder et al. 2010). Especially the corner joint is unusual. Most often the corners in timber building design are emphasised and …., which define the body and "keep the building/body on ground". Especially the log houses whose characteristic corner joints constitute the ornamentation of the overall building design. In the pavilion the corner is partly broken down and the diagonal skeleton that continues around the corners give associations to a ball of yarn; a continuous textile that wraps the entire building and dissolves the static and earthbound cube. 
The joints almost disappear in this case – no "life of their own" only the transition from one surface to another.	The bevelled convex corner (e.g. at the alcove) – surfaces meet in a perfect line; a **hidden** joint. This way of joining is very different from the traditional exposed/articulated corners known fra e.g. log houses. Shifting direction of battens = each surface is defined as independent and so is the longitudinal hidden joint. (Compare this to the other cases and	The bevelled, **hidden** joints = a part of the surface; a "surface-character" more than an independent and characteristic feature (as joints often has been in traditionally timber building design). The joints are relatively short and alternately concave and convex → - plastic effect - a steady rhythm - the longitudinal joints become the most conspicuous ornamentation "of the surface" (the lines of the joints are more dominant than the lines of boards and grain pattern)