Puurakentamisen kiertotalouden ratkaisut -selvityshanke

Raportti 3

Industrial timber construction in marine conditions

Pete Halsall
international_haus limited

Raport 3

Industrial timber construction in marine conditions

Contents

Introduction

This document summarises UK expertise and experience with regard to the construction of residential apartments using CLT (cross laminated timber), taking into consideration the obvious vulnerability of its primary constituent, softwood, to moisture ingress and subsequent damage.

Experience in the UK with CLT goes back almost 20 years with over 600 such buildings now constructed in the UK, a country with a wet, windy and decidedly maritime climate; similar in some respects to that experienced in Jätkäsaari, the old port area of Helsinki

The document has been written with no knowledge of Finnish building regulations, local Helsinki building codes as may apply or any local standards for timber frame or CLT or mass timber construction and these may indeed be superior to UK standards and regulations; in this regard nothing is assumed.

The purpose of this document is three fold:

- To summarise UK practise and approach as regards moisture management risks in UK CLT buildings and also to refer to international expertise and experience
- To enable the designers of the Jätkäsaari City Village housing project to benefit from UK experience by showing how this experience can be applied to the project
- To expand on the approach set out in the *kehittyvä* kerrostalo competition submission of May 2019

It is evident that the moisture risk/water damage risk to CLT has been under estimated by the CLT industry, with notable exceptions, across jurisdictions. Indeed, it is quite right and understandable that Helsinki housing developers are nervous about, and reticent to use, CLT in their projects. UK experience with CLT would appear to have been largely gained through the "hard knocks" route; common sense and deeply embedded knowledge of softwood structural timber across the ages, combined with feedback from where moisture damage has led to CLT building component failure and the need to cut out and replace sometimes entire wall, floor and roof sections. This is partly due to the considerable enthusiasm, proselytising zeal even, for the material and especially given its very wide range of significant benefits to all parties; designers, constructors and building occupants

A level of honesty, openness and transparency about moisture risks and how these can be addressed and suitably mitigated could help to change perceptions positively for those reticent to use CLT. Don't hide it, or deny it; talk about it and sort it out

One cannot ignore in all of this the necessary drivers to address climate change challenges and the exciting role that CLT and other mass timber construction systems can play out in this endeavour. Finland has much to be gained by becoming a powerhouse of CLT and mass timber construction and with all of the notable export opportunities that could inevitably accrue; as well as this being a way to develop a more comfortable and agreeable housing stock for the future which is greener, smarter and better

One thing is certain - Northern European participants exposed to more challenging maritime climates could do a whole lot more on the research side to get a far better understanding and grip on the subject of moisture risk associated with CLT with the research focus at present being limited in the main to the Austrians and Swedes in Europe, and the Canadians and Americans in North America.

If CLT is going to be a viable replacement for concrete and steel then there needs to be far more thought and care given to its long term durability and specifically to its moisture vulnerability.

1. Background to the use of cross laminated timber (CLT) in the UK

The UK has a long tradition in timber frame construction and which goes back into the medieval era; in those days there were plentiful local supplies of timber; oak, sweet chestnut, elm, poplar and various fruit tree timbers such as cherry being predominant. Oak framed buildings are the ones that, typically, have survived; unsurprisingly, oak frames are still produced nowadays for more expensive new home construction. The import of timber from Scandinavia goes back a long way into the 16th.,century. As British naval power became predominant in the 17th century, the construction industry could not compete with naval interests for dwindling supplies of oak and other hardwoods and over time imported softwood; pine, redwood, Douglas fir became habitually used in construction. So there has been a long history of the use of softwood timber structures with the necessary skills set to go alongside.

Whilst housing in England has in recent times been dominated by traditional masonry construction, Scottish housing has for a long time been more dominated by timber frame construction due to both the reduced building season, adverse winters , etc., more akin to a Nordic climate, and also the inherently warmer and better insulated nature of timber framed housing. English housing developers now prefer timber frame for their suburban, low rise, single family housing; given construction speed, reduced cost and sustainability advantages; timber frame is thus now taking significant market share from the traditional construction methods.

There has been a huge growth in urban regeneration projects across the UK in the last 30 years, with London being the centre of this. London construction can be challenging with small, irregular shaped sites in the middle of busy urban areas where the noise, dust and general kerfuffle of construction is most unwelcome; with larger and more modern buildings carefully threaded into medieval and other tight street patterns with little spacing between buildings. So it was inevitable that this urban regeneration market, focussing on housing, schools and offices in the main would meet a form of mass timber based construction - CLT - that was particularly suited to it and which was badly needed.

CLT as an innovative form of construction was initiated by joint industry and academic research in Austria in the early 1990s. It was scaled up to industrial production in the early 2000s with manufacturers based in Switzerland, Austria and Germany. Right from the start of this, an early International adopter of CLT has been the UK with the Austrian company Binderholz targeting the market aggressively and effectively from the early naughties onwards. Stora Enso is also an active player in the UK market. The first CLT apartment building to be constructed here was a 5 storey mixed-use development of commercial and residential units at Waterson Street in London; inevitably a race developed for the biggest and tallest.

CLT has become seen as an acceptable form of construction for apartment and other forms of construction in the UK because of its numerous benefits, widely cited. Thus far, over 600 CLT buildings have been built and which include residential, school, office, institutional, health care, community and leisure buildings. Indeed, the London Borough of Hackney has been actively promoting and supporting mass timber/CLT construction in its jurisdiction and hence there are a cluster of projects there.

Key drivers for the use of CLT include the UK's perennial construction industry skills shortages, in part exacerbated by low levels of technical and craft training, as well as Brexit; the rather ungainly hybrid of craft and industrial systems building approaches which is a legacy of a drastic shift back to craft based building in the late 1970s/early 1980s and away from the hyper mechanisation in residential construction of the 1950s/1960s. This melded approach has low productivity and high cost challenges as well as poor overall sustainability appeal and is seen rightly as compromising climate change ambitions; unnecessary complication and green building practises are not good bed fellows. The latter has meant that CLT has become quite charged politically at times in the context of the 'climate emergency'. However, the extreme level of competitiveness across construction sectors is often a driver in itself; how to be better, faster, cheeper than the rest to secure the construction contract, or indeed the attention of press, media and market.

CLT addresses core challenges with aplomb; it is easier to construct than a conventional building requiring less construction trades; its considerably lighter weight leads to more modest and cheeper to construct foundations; something which is relevant particularly in London with numerous underground obstructions and limitations, and it has been shown to be 'carbon neutral' by virtue of the carbon lock up that is integral to tree growth and the use of timber. Indeed, The UK Timber frame association claims "wood is effectively a carbon-neutral material (even allowing for transport), and timber frame has the lowest CO_2 cost of any commercially available building material. For every cubic metre of wood used instead of other building materials, 0.8 tonne of CO_2 is saved from the atmosphere. Every timber frame home saves about 4 tonnes of CO_2."

The first high rise CLT apartment building in the world, the 9 story 29 apartment Stadhaus in Murray Grove, was constructed in the UK. The project was completed in 2009. The largest CLT apartment building in the world at the time of construction, the 5 to 10 story 121 apartment Dalston Lane project, was also constructed in the UK. The project was completed in 2017. There is evidently a CLT race going on for biggest and best. The Norwegian 18 story Mjøstårnet apartment tower claims to be the tallest CLT building in the world at present. Plans are afoot, apparently, in Stockholm for a development of 31 CLT skyscrapers. The competitive nature of developers will no doubt lead to high rise office developments of similar ambition.

CLT in a sense was fast becoming the blue eyed boy of residential construction, although the party has for the moment been a little curtailed by the Grenfell fire tragedy; it is no longer acceptable to use combustible materials in the external walling of medium and high rise apartment buildings in the UK and so this has put a break on the use of CLT for the present time in such projects. (1) As one can imagine, its major proponents are fighting tooth and nail to get CLT back into vogue, although its use in lower rise buildings of all types, including residential, continues to grow; commercial and educational projects are unaffected.

A key problem in the UK is that the construction industry here, contrary to accepted wisdom, has a legacy of at times excessively innovating, and not at all of being an under innovator. Part of this is likely to be the inventive and restless British spirit for the new, the exciting and the different. Like the car industry before It, constructors can be too quick to promote and sell the new and not so quick to invest in rigorous and where needed, forensic, research and development to ensure that good performance and reliability can be delivered. Indeed, yesterdays blue eyes boys of construction; namely, wood wool slabs, asbestos, high alumina cement etc., are now today's deleterious materials; virtually illegal to be used. In their day they were feted as the answer to almost anything. In each case, their performance in use, or in the case of asbestos their health impacts, were disastrous. In all of this ambition around CLT, what is of some surprise is that the frailty of CLT construction to moisture damage does not appear to be suitably recognised by the CLT industry/supply chain as a whole; with some notable exceptions. Whilst fire issues do present risks, it would seem that moisture issues could be significantly more risky and indeed more difficult to address. The Grenfell Tower was constructed of concrete frame columns and slabs and it was painfully obvious that any form of construction, if poorly designed, built and maintained can lead to such a tragedy.

As mentioned above, the use of CLT in medium rise and high rise housing above 11 m is now somewhat in hiatus as a result of deliberations due to the output of the enquiry into the Grenfell tower fire; the use of combustible materials in such external walls are now banned. People in the UK fire service do not accept CLT industry claims as regards the inherent fire safety of CLT due to its mass and charring factors, stating that any form of construction that is combustible will add fuel to the fire and thus increase fire risk. Industry innovators are developing CLT structures that use non combustible forms of external walling whilst the main structural elements remain as CLT; as well as seeking to install sprinkler systems. It is a little early to see how this evolution will pan out in relation to the residential market.

There is no doubt though that in overall terms CLT has a bright future in the UK; a more locally based technical competency has now developed and become embedded. A particularly exciting development is the establishment of a local research based CLT manufacturing facility in Scotland that uses locally grown wood for construction projects and which is based on a Swiss production system. (2) There are a wide range of UK softwoods, and most particularly in Scotland and so this has potential to service at least some niche areas of the CLT market to leave the large and more repetitive projects to the dominant market incumbents.

References:

(1) https://www.clarionsolicitors.com/articles/new-building-regulations-for-external-cladding

(2) https://www.cs-ic.org/media/2312/first-commercial-clt-panels-in-the-uk.pdf

The following documents could also be read in conjunction with this section in order to gain an overview of the different types of CLT buildings in the UK;

Think-Wood-Publications 100 Projects; UK CLT

https://www.thinkwood.com/wp-content/uploads/2019/08/Think-Wood-Publication-100-Projects-UK-CLT.pdf

This is a simple and easy to peruse document that can be quite inspiring as to the type and scale of some of the UK CLT projects. As one can see there are a wide range of design and architectural styles with these buildings spread across the country with a current focus on London. The time horizon for CLT construction in the UK is such that a high level of confidence has now been built for this material albeit with a wariness to the need for careful design, construction management and ongoing maintenance.

2. Background to the vulnerability of CLT to moisture

We start here with the vulnerability of softwood to moisture damage; an age old problem. Whilst the advocates of CLT will cite a wide range of benefits from the use of this material, there would seem to be less thought at times to its obvious drawbacks. It is combustible and it can rot easily. But this is no reason to not use it; it's environmental benefits are unquestionable and it has obvious strategic and economic benefits most especially to timber rich countries such as those in the Nordics.

Timber (like concrete) is essentially hygroscopic; it will easily absorb water; either as water vapour or indeed water in liquid form. Water vapour can easily move through timber if there are differential vapour pressures either side of the timber (e.g., an outside face or an inside face). Timber will most easily pick up moisture at its end grain and so this is its most vulnerable part, although moisture can also be absorbed into any of its surfaces, albeit this happens more slowly across the grain. The movement of heat, water and air through building elements is referred to as a hygrothermal process.

High levels of relative humidity, rain water penetration and in service chronic water leaks are in combination its achilles heal.

For those who are against using CLT - it's vulnerability to moisture is very often cited as a highly significant risk, in counter point to those selling it. Indeed, it was apparent in conversations with developers in Helsinki that moisture vulnerability and potential moisture entrapment is a major concern leading to their not wanting to use the material in spite of the accepted need to address the climate crisis, ease skills challenges and gain potential project-political pay offs (e.g getting allocated a site); as well as to use a locally based and abundant resource.

CLT - Cross Laminated Timber - is made up of thin layers of wood or lamellas which are glued together at alternate orientations to form a laminated structure. CLT is vapour impermeable because of the layers of glue that separate the thin layers of wood.

CLT is best thought of as an engineered and manufactured material which is made by compressing wood and glue together to form a composite of natural and human made materials through an unnatural process.

CLT panels are mainly constructed using softwood. The majority of woods are made up of Tracheids; long, hollow cells (like drinking straws) that constitute approximately 90-95% of the material. This structure gives strength to trees and serve as the primary conduits for water. Moisture binds in the materials inner pores; in both vapour (gaseous) and liquid forms, depending on the porosity of the material.

There are a number of metrics which need to be considered:

- Moisture content (MC); the amount of water in the wood divided by the dry mass of the wood.
- Equilibrium moisture content (EMC); a constant level of moisture content (MC) in the wood that is maintained at a specific temperature and a specific relative humidity.
- Fibre saturation point; a level of MC at which the fibres in the wood are saturated and beyond which the cells then start to full with water. A level of MC above the fibre saturation point over a period of time will lead to fungal decay.

Wood, and thus CLT, is a biodegradable building material, and under specific environmental conditions wood can be a food source for a number of different types of microorganisms. These organisms use oxygen and water to break down the structures and polymers of wood, causing all sorts of problems and damage. These organisms can be categorised into mould fungi, stainers and decay fungi.

Mould fungi create spores so that they can reproduce. These spores get released into the environment by the mould and particular types of them can result in human health risks and problems if they are emitted into living areas. Stainers can cause aesthetic damage by staining the wood. Such moulds and stainers grow on the outer layers of the wood and do not result in any structural damage. When spores growing on a specific wood specimen have access to oxygen and nourishment there is a critical relative humidity for mould growth that is also dependent on temperature.

Decay fungi can be of greatest concern because this can result in rotting of the timber and can thus lead to structural weakening or even, at the extreme, structural failure. Granted that significant amounts of moisture are required for there to be colonisation by fungi and then its proliferation.

It is relevant to say that fungi decay is not associated with human health risks, that mould risk is not associated with structural failure risks; although evidence of mould is likely to indicate that decay fungi may also be present. So, in terms of moisture issues and risks we must be clear as to the different risk factors involved with CLT:

- Human health risk related to the growth of mould on the CLT.

- Structural failure risk related to the growth of fungi in the CLT.

Softwood typically used in the manufacture of CLT is dried in the factory to a moisture content (MC) of around 12% and at this MC level it will not deteriorate. However, once the CLT is exposed to sustained higher levels of MC at over 20-26% then it is likely that it will then start to decay. The conditions for decay will vary and will depend on the temperature and oxygen supply; full decay will require a persistent MC of 40-60%.

It is essential thus to ensure that CLT structures are designed, constructed and maintained in such a way that they minimise any contact with water and that moisture cannot become trapped and be in permanent contact with the material; something which can be much harder to achieve over the life of any building than one may wish. Water can easily get into the CLT through any micro cracks in wall cladding, raising the moisture content in the CLT because, for example, plasterboard with tiling and grouting affixed to it can act to trap the moisture in. If unseen over a period of months or years then this can lead to serious problems if water leaks continue and if the CLT panel is subject to continuous wetting with saturation first occurring and then followed by rotting. In one case where water leaks have been discovered in UK CLT housing, it was because the residents complained of bad smells in the building, resulting in an entire ground floor area of an apartment building having to be reconstructed.

Whilst advocates of CLT cite its strong environmental and sustainability credentials, 'green buildings' with much higher levels of insulation and air tightness can, somewhat ironically, exacerbate the moisture risks of CLT; mould and fungi can grow from interstitial or surface condensation creating persistent high moisture levels within the CLT material. High levels of airtightness allied to poor ventilation can lead to high relatively humidity in places like bathrooms and thus, again, elevated levels of moisture content. With further irony, higher levels of moisture within the CLT structure can compromise heat insulation performance, structural performance, as well as leading to greater maintenance and inspection costs over the life of the building.

In order to address the risks of failures or construction/installation errors, it is essential that the designers, contractors and subcontractors (including follow on, fit out trades) are carefully briefed as regards to the nature and vulnerabilities of CLT. This could be done though pre-site briefing videos and papers, as well as one site briefings and presentations.

The CLT/ground construction detail interface is critically important (as it is with all timber based construction) and one should aim to always maintain the CLT at a minimum height of 150mm off of the ground. If the CLT is designed to be installed directly on the ground then any failure in workmanship or waterproofing (easy in reality for this to occur) could be disastrous. In any event, the connection detail between the CLT and the substructure should be given acute attention to ensure that moisture cannot collect at the exposed end grain base of the CLT where it can most easily absorb water.

It is good practise, and now increasingly common, for the CLT to be installed on a raised, podium level which is constructed in concrete. This is a good way to keep the timber raised off the ground, with the podium acting as a transfer slab in transferring loads across the ground floor where there are likely to be completely different internal layouts between ground floor (commercial, retail, community etc) and first floor (residential).

CLT structures should be designed to be kept warm; so that the insulation is on the outside of the material with the external weather envelope then outside of the insulation. This measure is extremely important as a way of keeping the dew point outside of the CLT structure.

This whole matter of moisture risks and where they might occur can be further addressed using suitable computer software to model the movement of moisture behaviour in CLT buildings. Given the critical nature of moisture vulnerability, it would be prudent for the team to carry out such modelling.

WUFI (for: Wärme Unt Feuchtetransport Instationar (Transient Heat and Moisture Transport)) is a German modelling software system which models hydrothermal transport phenomena and how this can effect building materials, both individually and in combination with other materials (1). Once the simulation is completed the output results are heat flux densities, temperature and relative humidities at specified monitoring positions, the mean moisture content for each layer, or the total moisture content of the complete construction/construction section. This can be modelled on a time dependent basis so that one can see variances of temperature, relative humidity and moisture content at different specified times.

In relation to WUFI modelling at Jätkäsaari it should be noted that the rain load data may need to be gained through specific on site measurement; anecdotally it would seem that the rain loads (wind speed and rain intensity mm/m2 of rain) in this exposed port area is substantially higher than in Helsinki typically because of both rain intensity and also elevated wind speeds.

The risk of mould occurring can be assessed using software add-ons to WUFI such as WUFI Bio and WUFI VTT (2). Mould growth expressed as an index can be assessed at the surface of the CLT material. This surface could be either internal or external. The software essentially outputs the mould risk in specific situations.

It would appear that given the high internal apartment temperatures for Helsinki, combined with the extremely low dew point temperatures, that there may be a likelihood of mould growth in the building cavities which could be transported as spores into the building via nearby mechanical ventilations systems on the facade.

The designers should also carefully consider the moisture risks on different elevations of the building at Jätkäsaari; the West side has a potentially highly shaded elevation behind the very tall parking house with little or no sunshine to assist with drying out; whereas the southern side may be subject to strong wind driven rain but have the benefit of potentially good levels of sunshine to assist drying out. Any analysis must thus be carried out with regard to the different exposure levels of the different building elevations.

References:

(1) https://wufi.de/en/software/what-is-wufi/

(2) https://wufi.de/en/2017/03/31/wufi-mould-index-vtt/

A good insight into the moisture vulnerability of CLT and timber more generally could be gained from this Canadian paper by Wang et al;

DURABILITY OF MASS TIMBER STRUCTURES: A REVIEW OF THE BIOLOGICAL RISKS

https://www.fpl.fs.fed.us/documnts/pdf2018/fpl_2018_wang003.pdf

3. A summary of the weathering challenges to building facades in UK maritime environments and how these are addressed in the UK

There are two issues to be addressed in considering weather conditions; firstly historic weather patterns which are essentially statistically based and then secondly how these patterns may change with climate change; the latter is again a statistical process and one has to consider a range of scenarios from those considered to be more likely to those considered to be less likely but possible. It is still unclear how severe, or not, climate change effects may be because of the superimposition of cycles of natural variability across decades or centuries of weather and climate patterns. Work has been done in the UK over the last 10 years with regard to climate change adaptation and how building design should accommodate these changes. An example of this is that 20 years ago it was suggested that rainwater gutters in London should be made bigger to accommodate heavier summer rainfall peak flows and it is now clear that this was a correct suggestion; gutters now do indeed need to be significantly bigger as was previously suggested because peak summer rainfall is indeed now more intense than it was 20 years ago.

It is advised that the design team undertake to research climate change projections for Helsinki and with regards to the specific site location and following that to make defensible choices from this data as regards design data parameters to be chosen for the project.

Climate change aside, the UK has a particularly challenging climate as regards building materials and their long term sustainability because of its inherent variability; sitting within a location where it can be subject to weather patterns from five different weather systems, buildings in the UK are subjected to considerable thermal stress as a result of sharp temperature changes, and also, between periods of intense rainfall and then sunshine, to intense cycles of wetting and drying.

The Jätkäsaari location in what is a former port area with significant amounts of reclaimed land would seem to be subject to the potentially fluctuating maritime conditions found more typically in the UK; although one would not wish to draw this analogy too closely and weather/climate data for this specific location should be studied by the design team in concert with the Finnish Meteorological Institute.

What is clear is that buildings in UK coastal areas can be difficult to adequately and cost effectively maintain if during the design and construction period adequate measures and judicious building material choices have not been made. In the 2000s green buildings in the UK, for example, followed their continental cousins in having mixes of Swiss German/Austrian through colour render systems i.e. that is without any cavity, as well as timber and metal cladding and brickwork panels. People had had enough of full brickwork facades the use of which was believed to be driven more by tradition than anything else. It turned out, however, that experience was the key driver for choosing brickwork; render, timber and metal cladding systems have sometimes faired badly in aesthetic terms and can look awful on UK buildings and most particularly in coastal areas. Part of the problem is that tried and tested weathering and construction detailing expertise had become lost to the younger generation of designers keen to use more modern materials, believing that the newer and more modern materials had a greater level of invulnerability to the UK's climate than is the case. So; brick is back in the UK and it seems to be fairing significantly better in terms of its appearance than more modern materials; partly because it would seem that the necessary disciplines of weather detailing are inherent to the brick supply chain.

3.1 Brick facades

Brickwork has been used in the UK since the 16th. Century (ignoring its use in antiquity) to create weather resistant walls, although bricks and mortar are not in themselves waterproof. Moisture can easily penetrate brickwork through diffusion into and across invisible microscopic voids and cracks in the material, or indeed through more noticeable cracks. Historically, for areas exposed to more severe weather, typically coastal locations, thicker brick walls were used. With massive increases in housing during industrialisation a smarter approach than simply increasing wall thickness with increasing weather exposure was needed and from this double brick skinned "cavity wall" construction was developed. Interestingly and somewhat inevitably, this practise was started in the highly exposed coastal location of Folkestone in Kent. One cannot think of brickwork as being waterproof, but one should think instead in terms of the resistance of the brickwork to wind-driven rain relative to the likely level of weather exposure. As it is inevitable that some moisture will get into any cavity, the focus of design should also be to divert this moisture so that it can drain out of the cavity and back to the exterior. If this is not done then water will in time penetrate to the inner wall leaf of CLT thus inevitably creating damp conditions within the CLT and also inside the building.

The first task then, and as noted above, is to establish the severity of wind and rain weather exposure that is likely to be experienced at the Jätkäsaari location and to then design and specify brickwork construction which will give, assuming that the workmanship is adequate, an appropriate level of resistance to potential rain penetration. One should start with considering which parts of the building/brickwork are the most exposed parts and to then give specific attention to these areas when making choices as regards design, specification and construction methodology/approach. Good and proper detailing which is translated into the correct built form via workmanship is critical; the nexus of design and workmanship cannot be underestimated. There is not an awareness of Finnish standards here as this document is about what is done in the UK; in this regard consideration could be given to the use of the British Standard Code of practise for assessing the exposure of walls to wind driven rain (BS 8104). The method in this code enables an assessment of the quantity of rain falling on a wall/vertical surface using annual rainfall and average wind speeds recorded by nearby meteorological stations; in this case Helsinki data can be substituted for UK data. BS 8104 enables an adjustment of this average wind speed to location specific features such as topography, the form of the building and the form and spacing of surrounding buildings, landscape features etc. From this work the exposure category can be determined from the four choices of; very severe, severe, moderate and sheltered; using the local spell index. A level of caution should be applied mindful of the vulnerability of the interior CLT structures to moisture; in this case there is potentially far more risk from water ingress into the interior structures. This caution should translate into careful judgment as regards which exposure category the building is considered to be/designed to be in, as well as the chosen weathering/construction details.

Key elements which determine the resistance of the brickwork to wind driven rain and which need careful consideration are; the specification of brick; mortar specification; thickness of the brickwork outer leaf; width of air space within the cavity; mortar joint profile and finish; specification and thickness of insulation in the cavity; architectural and weathering details; likely/realistic level of workmanship quality.

These are issues for the project designer. In terms of what bricks are suitable for the location, it would seem that bricks with low water absorption features should be favoured, as softer bricks with higher water absorption characteristics may get easily water saturated. This former choice would place more importance on the mortar specification; high strength mortars have the lowest permeability and are considered more suitable for low water absorption bricks. The mortar joints are particularly vulnerable to moisture ingress and so must be constructed carefully and well.

For this type of situation in the UK; an exposed coastal location; it would be usual to have a 90 mm outer brick wall and a clear 50 mm cavity; i.e. that is an overall cavity width which is made up of the insulation thickness plus 50 mm; so if the insulation thickness is 100 mm then the overall width of the cavity would be 150 mm. It is emphasised here that no reliance whatsoever should be placed on the CLT structural part of the cavity leaf, i.e. the CLT structure itself, to resist water penetration as it is not sufficiently durable and moisture resistant to do this. This job must be done through judicious choices, good detailing and good workmanship as regards the inner wall face within the cavity, drainage from the cavity and all other details such as cavity trays, brickwork ties, window and door closures. The key element in all of this is the water and moisture protection to the cavity face of the insulation layer which is fixed to the CLT inner wall; this can be achieved through the use a high performance breather membrane which is fixed strictly in accordance with the manufactures instructions and also the Architects detailed drawings.

It is recommended that consideration should be given to a struck weathered mortar joint or a bucket handle joint both of which create a good level of adhesion to the bricks and which also firm up the mortar, reducing its permeability. Recessed mortar joints which the writer has observed in some Helsinki buildings can form ledges which collect water and which can lead to water penetration. Clearly, the project architect will need to use common sense in making sure that in considering all external walling details, consideration should be given as to whether any specific detail will add to wall wetting. This is addressed typically in the UK by seeking to ensure that any relevant details can 'throw' the rainwater through adequate drips, overhangs etc., and the use of sills, copings, string courses and the like. Recessed brickwork features should be strictly avoided.

An additional factor to be considered here is the need for a disciplined and comprehensive approach to quality control and inspection during construction. This should involve specific on site briefings and training on the construction of the outer wall/cavity wall so that the construction trades are made fully aware from the beginning on what is expected. It is common practise in the UK to construct on site an 'example' panel of the external wall, forming part of the permanent works, and which shows clearly all of the construction details for the walling system and how they are to be detailed. This would be typically be one storey height and 5m in width so that window and door opening features can also be included. This helps with both clear communication on what is expected as well as with on site training and guidance; and particularly if there are any changes in on site construction or indeed professional personnel. There should also be an on site quality inspector with specific duties to inspect the work on an on-going basis.

This aspect of the document addresses brickwork exterior wall cladding because it was expressed as a preference for the project. However, there are a number of other possible facade material choices in Jätkäsaari which include metal panels, render systems and indeed combinations of cladding systems. To be really purist about it, one could also consider a truly impermeable facade material for the building outer skin, such as a metal cladding system, where there is a very high level of exposure to rain so that it should be made clear here that a brick facade is not being recommended but simply that, if brick is chosen, then it must be recognised that this is not an impermeable material. If metal cladding is chosen then the same logic as regards ensuring that the metal cladding can easily shed rainwater away from the facade is chosen, in this case, to avoid cosmetic staining etc.

The following document should be read in conjunction with this section:

Brick Development Association document "Resisting Rainwater Penetration"

https://brick.org.uk/admin/resources/resisting-rainwater-penetration.pdf

3.2 Timber cladding

Timber cladding has a good and long track record of performance in maritime climates. It is used throughout the UK with western Scotland being its most testing location. The drained and back ventilated rain screen is the more usual and easier to install system of timber cladding. It operates on a similar basis to brick cavity construction described above; most rain will be deflected by the timber cladding but inevitably some water will get into the cavity and this is fine as long as it can drain away easily. Joints between the timber cladding elements are tightly bound and this will largely obstruct the passage of wind driven rain droplets into the cavity. However, rain can get through due to the combined forces of wind driving which creates pressure differentials between the exterior and the inside of the cavity and gravity effects. Thus during periods of heavy driving rain considerable amounts of water may penetrate the joints between cladding members and run down the back of the boards and into the cavity. As for brickwork and especially with CLT as the interior wall element, it is imperative that this water does not get into the CLT construction; the cavity must act as an effective drain and ventilator. As for the brickwork cavity described above, a key element in all of this is the water and moisture protection to the cavity face of the insulation layer which is fixed to the CLT inner wall; this can be achieved through the use a high performance breather membrane which is fixed strictly in accordance with the manufactures instructions and also the Architects detailed drawings. In the UK it is recommended that for any timbers categorised as being less than moderately durable the timber cladding elements should be preservative treated via pressure impregnation. A very common species of timber used for external cladding in the UK is western red cedar and indeed the attractive weathering effect of this has led to it becoming quite popular, particularly with residential construction. The writer's development in the UK, One Brighton, has successfully used the Finnish heat treated Thermowood cladding system in an extremely exposed coastal location and with no signs after 11 years of installation of any problems; decay, damage, excess weathering etc., at all. In any event, there must be a good and diligent maintenance regime associated with timber cladding systems. Where it is coated, it should be repainted every 5-10 years and boards inspected for rot and replaced where required; although the most important factor above all is to ensure that the cavity remains as an effective drain and ventilator for any water that can get in; thus checks during maintenance of the cavity is very important also with corrective / repair works essential to ensure continued effective working. Again, climate change factors have to be carefully considered with this material. Fungal decay; relevant for average temperatures exceeding 5 degC., may in the next 20-30 years become more prevalent in the Nordics, as may also possible insect attack problems. These factors should be further investigated as regards the choice of building design parameters and also the choice of timber cladding species and specifications.

As with the brickwork cavity, it is strongly recommend that an 'example' panel (as before being part of the permanent works) is constructed for any timber cladding, should it be used, and which is a storey in height and 5m in width so that, as before, door and window openings can be included. It is possible that any timber cladding may require for intumescent fire barriers to be installed within the cavity, and if this is the case, then this detail should also be included in the example panel, and constructed very carefully to ensure that it does not end up becoming a moisture trap.

3.3 Roof coverings

Great care must be taken with the design of the roof structure and roof finishes and most particularly when the roof structure is CLT. Indeed, so much so that consideration could be given to the use of a metal or traditional timber structure in lieu of CLT for this most vulnerable of elements. It is unclear at this stage which approach the Architect is going to take with regard to the choice of design and specification of the roof; choices include pitched roofs, gently sloping roofs or flat roofs. Details in the earlier stages of the document highlight the importance of design details and construction workmanship in getting roof designs right.

There have been problems with roof failures on CLT buildings in London where the waterproof membrane has failed. In one instance the problem, whilst being apparent to tenants and the wider neighbourhood (with scaffolding being erected around the building two years after completion and occupation), was kept strictly confidential by the building owner, Architect and CLT constructor.

In another case, a roof failure of the CLT roof element was reported in the bulletin CROSS (Confidential Reporting on Structural Safety; Newsletter 56 dated October 2019) with the report entitled "Rotting of CLT roof panels" (1). It would appear that the underlying and structural CLT panels as well as the plywood and timber firing pieces had seriously rotted due to the installation of a non breathable (non vapour permeable) single ply roof membrane covering on top of CLT roof panels which had possibly become wet during installation; or had become wet due to a failure of the waterproofing or indeed due to interstitial condensation; all serious risks for CLT structures. Three of the five plies in the CLT element had rotted through both on the roof parapets and also on the roof panels. Much of the roof of the building had to be reconstructed and replaced with the building owner or insurer choosing to use a hybrid steel and timber system in lieu of the originally specified CLT panels. A key observation in this report is the need for 'inspectability' and the need to be able to see if a problem is there. This may have to be done with embedded sensors which form part of the initial installation/roof construction system.

Roof detailing should include similar disciplines than that proposed for the external brickwork walls; there should be great care taken to ensure that any water from the roof is 'thrown' away from the facades with suitable drip detailing; as well as potentially a wide overhanging eave detail, not particularly popular on modern buildings but there is a reason this detail was created in the first place.

However, the largest UK housing warranty provider (NHBC - National House Building Council) has now banned the use of CLT in flat roof constructions. This is clearly as a result of feedback and specifically a history of building failures because that is their business model: i.e NHBC will provide a warranty for specific types of construction and then over time and in the light of experience start to limit the applicability/scope of its use as building defects build up into clear patterns of problem areas; eg flat roofs and CLT.

As regards climate change/climate adaptation issues, thought could be given to the incorporation of living roofs within the overall roof system. This could provide a range of benefits including reduced heat island effect, better thermal insulation performance, enhanced biodiversity reduced peak flow from rainfall into the drainage network.

References:

(1) https://www.istructe.org/journal/volumes/volume-97-(2019)/issue-11/confidential-reporting-on-structural-safety-newsle/

The following documents should be read in conjunction with section 4 overall:

THESE DOCUMENTS INCLUDE ROOF, WALL and FOUNDATION INTERFACE DRAWINGS

Structural Timber Association (STA) Advice Note 14; Robustness of CLT structures Parts 1-3 inclusive

Part 1 - Key principles for moisture durability

https://www.mbmfp.co.uk/media/1093/informationcentre-advice-notes-staadvice-notes14part1-keyprinciplesformoisturedurability010317.pdf

Part 2 - Key principles for CLT wall to foundation interfaces

https://www.mbmfp.co.uk/media/1095/informationcentre-advice-notes-staadvice-note14part2-keyprinciplesforcltwalltofoundationinterfaces010317-1.pdf

Part 3 - Key principles for good practise detailing for the external envelope of CLT

https://www.mbmfp.co.uk/media/1094/informationcentre-advice-notes-staadvice-notes14part3-keyprinciplesforgoodpracticedetailingfortheexternalenvelopeofclt010317-1.pdf

4. Examples of the use of CLT in the UK and measures taken to protect CLT structures from water ingress/weathering.

4.1 Urban environments

In considering CLT in an urban environment one must look at moisture risks that are involved with CLT in an often more sheltered environment. There are a number of areas which should be considered as high risk:

- The external weather envelope
- Airtightness
- Thermal bridging
- Bathrooms and any other MEP intense areas
- Project examples and how moisture risks were considered on these project examples

In terms of the external weather envelope, much is said in earlier parts of the report on this; getting the external weather envelope right so that it can resist driving rain, and if moisture does get into the cavity then making sure that it can easily drain out. This is a common problem in the UK given the climate. Allied to which is the need for good and proper maintenance of buildings. From a conceptual point of view the architect who may not be particularly familiar with CLT, should think in terms of various disciplines of moisture management when designing and detailing the building. This approach will no doubt have an impact on the architectural aesthetic of the building and one hopes that the architect will welcome this potential constraint rather than to fight it. Certainly in the UK architects nowadays often like to use 'flush' and non projecting building elements such as flush window cills, flush roof eaves etc. which, whilst looking attractive and 'slick' to some, can be the source of long term water and moisture damage to buildings. So that one should think in terms of a CLT architecture at the level of building detailing which should inevitably emerge.

Airtightness. This can be missed by some as a CLT moisture risk issue because it is framed as an energy efficiency measure. However, an air leaky facade can allow warm moist air from the building out into the cooler CLT external envelope and insulation where it can condense and thus potentially increase the moisture content of the material. So it is thus imperative from both an energy efficiency/energy saving measure as well as a moisture risk management issue to ensure that the external building envelope is airtight. No doubt local Finnish energy regulations will specify this level of air tightness for both mechanical ventilated apartments and also for naturally ventilated ones, i.e with air ventilators built into the window frames. In the UK it is common now to use mechanical ventilation heat recovery systems (MVHR) in apartments and in the UK one would recommend an air tightness in the exterior building envelope of 3m3/m2 hour @50Pa for such a system. Airtightness of the CLT system can be achieved with air tightness tape and, as before, there must be a diligent QA/QC approach applied to this to ensure that the work is done property and that air tightness details are correctly followed. Certainly an airtightness test should be carried out on some of the apartments to make sure that the airtightness performance is as specified and no doubt this requirement may already be covered in Finnish building standards.

Good levels of ventilation are also critically important with CLT buildings as the moisture content of timber varies according to temperature and relative humidity; MVHR systems are more reliable ventilators of apartments than natural window ventilators and thus reduce the risk of high moisture content levels occurring in the CLT because of inadequate levels of ventilation; specifically in kitchens and bedrooms where bathrooms would be typically ventilated by either extract fans or MVHR units. The risk may be more typically from mould than decay fungi but this is nevertheless a health risk. If, however, there is a ventilation failure as well as a chronic water leak in a bathroom then this could lead to serious decay.

Thermal bridging is likewise important. This is because building elements which are cold, as a result of thermal bridging between the cold exterior and the warmer interior, can lead to condensation on those elements, e.g. CLT panels, which can build up in time to a significant problem. An example would be the fixings for the insulation in the interior cavity of the building which must be thermally broken. Certainly it is not recommend that any external balconies to be constructed using CLT cantilever slabs, but rather with dedicated steel frame structures which may be timber clad, and where all fixings are detailed to minimise thermal bridging as far as practicable.

The above two risks would seem to be especially high in Helsinki due to the very low average dew point temperatures across the winter and mid seasons. It has been recommended earlier in the report that comprehensive WUFI modelling is carried out for the project and these two issues would be addressed as part of that.

The matter of moisture damage risks in areas with high amounts of MEP; bathrooms, kitchens, service cupboards is also addressed elsewhere in the report. However, this is a factor over the long term life of the building and clearly water leaks can easily occur. It is unclear to the writer that this aspect of moisture risk is being taken sufficiently seriously by the CLT industry as a whole; it may appear to be somewhat ephemeral as one cannot say when and where any leaks may happen and to what degree of severity; but at some stage these leaks will occur somewhere. One hopes that people will use their common sense in reporting such problems but one cannot be sure of this; and sometimes this can be especially the case with low cost social housing where people can be distracted by personal issues; most certainly this is an issue sometimes in the UK where housing associations have to be highly diligent as regards potential building defects in order to maintain their housing stock in good condition.

One way of designing out moisture risk in MEP systems is to avoid horizontal pipe runs as far as possible and also to house pipework in dedicated pipe ducts where any water leak can drain out and not into the building structure; as far as practicable that is. These could be at high level in ceilings or in floor voids. Also, a conversation needs to happen with the MEP designer to say that their specification should address the hyper sensitivity of CLT to pipework failures and leaks. If the MEP designer is used to working on pre-cast concrete apartment block projects then they may have no idea that this risk is as significant as it is for mass timber/CLT construction. So again, the issue here is good communication with all of the design team members so that they can all be cognisant of this issue, and so that, again, we don't hear those words; "oh, why did they not tell me that this was a mass timber building and also that it is so very vulnerable to water damage ? ".

Stadhaus, Murray Grove, Hackney, London

This 29 apartment project was constructed on a typically tight London site of 17m*17m with Metropolitan Housing Trust and Telford Homes as the clients and Waugh Thistleton as the Architects. The maximum height of 9 stories (including the ground floor) was set by the constraints of adjacent buildings, the need to avoid over shadowing. Telford Homes required that the apartments were just like conventional London apartments, so that the CLT construction was not apparent within the apartments. CLT panels were constructed by the Austrian company, KLH, using spruce. The external wall panels arrived on site prefabricated and the whole CLT structure was assembled by 4 carpenters in 27 working days (just over 5 working weeks). The overall construction period to complete the project was 49 weeks and which represented a 5 month (20 week) saving on conventional construction. The project Architect claims a saving of 310 tonnes of carbon dioxide emissions from the use of CLT compared with steel reinforced concrete frame construction, which is the norm in London - both at the time of construction and still to this day. This project had a big impact on the construction industry at the time. This was because it was faster than conventional construction, with preliminary cost, ie site running costs savings off setting the increased cost of construction and indeed lending to an earlier occupation of the building by residents than had been planned for. It was also because CLT seemed to offer a pathway to more efficient/more productive construction which was greener, smarter, easier to build and nicer for the neighbours. Building performance is excellent with fire and acoustic standards being met with simple measures; mainly the careful detailing of the building and the use of double layers of plasterboard. The Architect worked collaboratively with the main UK building warranty provider, the NHBC (National House Building Council) and BRE (the Building Research Establishment) to overcome regulatory and perception challenges introduced by the use of CLT for such a large structure during the course of the project.

Dalston Lane, Hackney, London

This is a mixed use building of 121 apartments, offices, restaurants and a gym. The client is Regal Homes and the, again, Architect Waugh Thistleton. These Architects, the UK champions of CLT, here sought to improve on their previous Stadhaus project by reducing the volume of timber per m2 of floor area for this project by 20% compared to Stadhaus. This involved the design of a more efficient external walling system that led to thinner and stronger walls. The architect claims that the use of CLT - with a 30% saving on weight compared to a concrete frame or steel frame building - enabled 15 more homes to be built on the site than would otherwise be the case. Again, this is a very tight London site. CLT reduced the number of deliveries from 900 to just over 100; an important factor for neighbours. In this project the Architect claims to have saved 2,400 tonnes of CO2 emissions. Engineers for this project were Ramboll and the CLT manufacturer was Binderholz with spruce being the main material.

Measures which were taken to mitigate moisture risk on these projects:

- Detailed moisture monitoring of all CLT elements before follow on finishes were applied
- Specification to manufacturers required that vapour open protective coatings were applied in the factory before delivery to site of CLT panels
- Installation of temporary drainage measures to ensure rainwater run off away from CLT
- Pre-manufacturing of completed wall elements to reduce the amount of CLT exposed to rainwater during construction
- Fast construction approach overall which seeks to speed construction in order to reduce weather exposure to CLT panels
- Good brickwork and cladding detailing to reduce the risk of water ingress

The following documents should be read in conjunction with this section:

Structural Timber Association (STA) Advice Note 14; Robustness of CLT structures

Part 4 - Construction process best practise

https://www.architectscertificate.co.uk/wp-content/uploads/2019/02/Construction-process-best-practice.pdf

More information on Stadhaus can be found on this web link:

https://www.trada.co.uk/case-studies/stadthaus-murray-grove-hackney-london/

More information on Dalston Lane can be found on this web link:

https://www.binderholz.com/en-us/mass-timber-solutions/dalston-lane-london-great-britain/

4.2 Maritime environments

Helsinki more widely is in a coastal zone, with potentially elevated wind speeds, air salinity, and humidity levels. The Jätkäsaari site has open water less than 400m away to both the west and the north west of the site with potentially even further elevated wind speeds, air salinity and humidity compared to the rest of the city. From a UK perspective the site would be considered to be within an extreme coastal environment.

What is the difference between what could be a more sheltered environment on one hand, and a more exposed maritime environment on the other ? The difference is not that the more salty environment of the seaside is more damaging or corrosive potentially to the wood than a less salty environment, but rather that;

- The wind speeds and volume of rain falling on the building surfaces, vertical as well as horizontal, are likely to be greater with more moisture stress placed on the overall external weather envelope vis a vis its ability to resist the passage of driven rain water deep into the structure and thus into the CLT. Anecdotally, the Jätkäsaari area has a reputation for being very windy at times and significantly more so than the adjacent urban areas of the city. This risk places a greater onus on the roof, wall and window/door elements of the construction referred to earlier; the risk could be mitigated by implementing the measures set out in 4.1-4.3 inclusive with attention to design detail and rigorous QA/QC in construction as suggested.

- There is a greater chance of the failure of parts of the external weather envelope due to the more saline, and thus more corrosive environment, and this could lead to a failure of the CLT system if elements of the CLT can become moisture laden as a result. These failures could occur due to the corrosion of brick cavity ties, any metal cavity trays, any flashings around windows and external doors, any metal roof sheeting or wall cladding that may be used. Most critically the numerous steelwork connections which fix CLT panels together could be subject to higher levels of corrosion and thus over time the structural integrity of the building, and/or it's critical elements, could be compromised.

In the UK a fully CLT-framed retirement living project of 34 apartments has been built 30 meters away from the beach in Falmouth, Cornwall (1). Given the winter storms that are experienced in this location, this puts the building in the critical sea-spray zone where corrosion factors are very high. CLT was chosen nevertheless because of its wide array of benefits compared to conventional steel framed construction; warmer and more comfortable to live in; quicker and safer to construct; greener and more environmentally friendly; lighter weight giving cost savings on foundations. Bedrooms and living rooms have a sea view with a large balcony in front of them and which faces the sea. The roof overhangs are very large at 2m to provide a more sheltered and also more sun shaded environment for both the residents but also for the building facade. Given the particularly exposed nature of this location, the exterior wall finish was chosen to be a render finish. The engineers specified stainless steel connectors for all of the CLT connection details. This is because not only is the apartment building in the coastal zone, but that it is within the sea-spray zone thus subject to potentially very high levels of salinity and corrosion. Whilst CLT has moisture vulnerabilities the specific location where a light steel frame structure would often be used for an apartment block would also be subject to potential corrosion and thus weather exposure challenges. Part of what worked well for the project was the development of a highly integrated and motivated team who worked to maximise the benefits of CLT in this location whilst minimising its disadvantages. However, whilst the CLT structure has fared well, there has been some water Ingress to the sides of the larger windows and which has necessitated their replacement. This latter issue is a reminder that any approach must be fully holistic and whilst it would seem considerable attention has been given to CLT construction and detailing, the team has been let down by inadequate detailing to the window reveals.

It is for the structural engineer for the Jätkäsaari project to determine with regard to local Finnish regulations what level of corrosion protection is required for the CLT connector steelwork. However, mindful of the critical nature of the steelwork connections, from a UK regulatory perspective and specifically with regard to the application of the relevant standard BS EN ISO 12944-2; the following standards of corrosion protection could apply to the project: C4 corrosion category HIGH (2). Connections for the project could be effectively corrosion protected by being in galvanised or even stainless steel; the latter quite possibly excessive given that the building is not located in the sea-spray zone. Consideration should be given to local application of timber preservatives surrounding any connections, the oversizing of connections to allow for some loss of area arising as a result of corrosion as well as greasing of any such joints or connections. In any event, local specialist steelwork companies or specialist applicators will be able to advise on the best corrosion protection approach if the project engineer agrees to the applicability of this category.

A further factor to consider given the greater risk of failure of the external weather envelope is the vulnerability of the CLT to sustained moisture damage. One way of addressing this heightened risk is to consider how the CLT material itself can be made to be more durable and less vulnerable to moisture damage. There are a number of ways of addressing this:

- Selection of softwood species for the CLT which are most durable.
- Heat or chemical modifying of the softwood.
- Chemical preservative treatment of the softwood.

In terms of softwoods, Douglas fir is considered to be more durable than Pine; in the UK there are supplies of Larch which are considered to be more durable than Douglas fir. This is an area that should be addressed with the chosen CLT manufacturer/tenderers mindful of what is available in Finland.

There have been some studies related to the heat treatment of softwood timber elements but these do not appear to have been translated into the market as yet in terms of specific product offers (3). However, if there is an ambition to take a significant market share in CLT then local Finnish suppliers could benefit from exploring this avenue of enhanced timber durability.

The Thermowood product already mentioned is a heat treated timber that would appear to have been successful as an external cladding material; this technology could be considered with regard to the softwood used in CLT construction. It is accepted, however, that heat treatment of softwood can reduce its structural strength and thus the structural performance of CLT panels.

Another material which is afforded significant levels of durability is Accoya; some investigations could be carried out to see if it is technically and cost viable to use this chemical change process for the softwood constituent of CLT. Accoya is manufactured from Pine which is harvested at the 30 year mark; the Pine is subjected to a process of acetylation, akin to pickling wood in vinegar. This essentially gives the softwood in its modified form the qualities of a hardwood; highly moisture and thus rot resistant; www.accoya.com

Piveteaubois, a French CLT manufacturer who are active in the UK, has developed a CLT product known as HEXAPLI CLT which has an enhanced durability as a result of pressure treated chemical protection. This product uses Douglas fir; the preservative treatment is to BS 8417 (Preservation of Wood Code of Practice). BS 8417 combines a number of European standards under BSEN350. UK home building warranty providers NHBC (National House Builder Council) and LABC (Local Authority Building Control) requires all structural timber used in home construction and which includes for external walls and roof elements, to be treated to BS 8417 use class 2; except in the case of CLT structures where this is not required; the latter an apparent anomaly which is likely to be corrected in due course.

It would seem prudent to explore with Piveteaubois the potential to use this material at the Jätkäsaari site; indeed, introducing this product into the development project could incentivise local CLT manufactures to take the moisture risk more seriously. This would be to the obvious benefit of the CLT industry in Finland overall as this more rigorous approach would then address one of the key concerns that others, and most specifically Helsinki housing developers, have about the vulnerability of CLT to moisture risk. Their web site may be consulted for further details; www.piveteaubois.com

References

(1) https://www.bkstructures.co.uk/case-studies/cliff-road

(2) https://www.steelconstruction.info/Standard_corrosion_protection_systems_for_buildings

(3) https://portal.nifa.usda.gov/web/crisprojectpages/1011392-next-generation-clt-combining-thermal-modification-and-carbon-based-nanomaterials.html

4.3 International perspective on the use of CLT in maritime environments

CLT is being increasingly used internationally; indeed it now has an established global footprint in terms of awareness and also enthusiasm to use it. In France there are government policy drivers for the use of mass timber (or other natural materials) in publicly procured construction will which no doubt have effect in relatively short time across the wider EU (1); it is as a silver bullet for achieving net zero in construction. Coastal regions and nations where CLT is becoming increasingly used and where the latest research into moisture vulnerability is focused, are Oregon (western USA), British Columbia (western Canada) and Sweden. In New Zealand there has been a combined focus on both moisture vulnerability and earthquake design from which expertise in more flexible mass timber/CLT structures is going to emerge; albeit with more focus on earthquake design. The original research in the early days of CLT development happened in dryer, more continental regions such as Switzerland, Germany and Austria, the latter from where CLT originally emerged; although the German speaking region would seem to be catching up in this area of moisture risk, no doubt in light of some bad experiences. This could be the reason for there being a lower risk factor than one might expect to moisture damage than has been typically attributed to CLT; early UK users may somewhat innocently have been sold a material that in a more maritime and challenging climate was not going to fare as well as one might have hoped. Clearly, as the material is now becoming increasingly prevalent in more maritime climates one must expect to see greater levels of moisture failure and thus more focus on moisture risk and vulnerability and how this can be mitigated and managed. The UK approach is more empirical and with over 600 CLT buildings here failures have happened (albeit some of which would appear to have been concealed under the radar) and from those failures the UK CLT industry continues to learn and improve. There is in the UK a necessary attention to detail and diligence around the construction of good and effective weather envelopes and this will reduce the risks of moisture ingress through these elements.

The most ambitious work in this field has thus far been carried out at the TallWood Institute in Oregon and more information is provided about this in the next section; this work has included the creation of the Smart-CLT programme (Structural health Monitoring And post occupancy perfoRmance of mass Timber structures (2)) which aims to bring together the research work on moisture vulnerability in mass timber and CLT. There is the possibility for the Jätkäsaari project to joint into a partnership group with TallWood as regards sharing of moisture data across a number of such projects and if a research project is undertaken as part of the overall development project then this could add expertise to that endeavour.

One of the issues arising out of the work of TallWood and is that unless the building can be constructed in good, summer weather with low levels of rainfall (something which of course cannot be mandated), then CLT construction should be carried out within a temporary weather envelope; an approach which is now more common in Sweden and which seems to have been mandated in Finland for affordable housing projects funded by ARA (Finnish Housing Corporation). This measure addresses many of the concerns and problems which are evident in terms of the moisture risk factors associated with the transportation, on site storage and construction stages, but it cannot address the long term risk factors around failure of the weather envelope and chronic leaks into concealed spaces from areas such as bathrooms, service cupboard, laundry rooms etc; in many ways these two key risk areas are potentially the most challenging. Who is going to look ? Who will know, long after the design and construction team have departed the scene, what to look for snd where ?

There is wide acknowledgement amongst researchers that wet and maritime conditions present particular risks to CLT construction, however. The approach of the Finns and the Swedes is thus to be applauded and is in contrast to the Norwegians who appear to be insisting that temporary weather envelopes are unnecessary; indeed in both the UK and US it is unlikely as well that such an expensive measure would be or could (given cost pressures) be taken. Cost pressures by developers upon building contractors are such that it is almost certain that in the vast majority of cases there would not be sufficient weather protection during construction.

If cost pressures do emerge on the Jätkäsaari project; so for instance if a volumetric prefabricated form of CLT is chosen and it is considered that this form of construction is so fast that a temporary weather envelope is not necessary by the client/contractor then it would be prudent to carefully plan the construction in a summer period with least likely exposure to rain; careful and early construction programme planning is crucial in this regard. A maxim could be that if there is the risk of rainfall exceeding 10-20 mm during the construction period (before the CLT is fully weather protected) then arrangements on site should be made to ensure that rainfall can be diverted to drain and away from the structure. If the likely level of rainfall is over 40 mm or if the construction programme time exceeds 2 weeks then a temporary roof covering should at least be considered as well as ensuring that rainfall is diverted as well.

What is clear is that the CLT market could now really take off internationally and most especially with the intense drivers apparent towards net zero carbon emissions, and that there is a low likelihood that moisture risks would act to curtail this enthusiastic market growth. It is thus entirely up to the international community of moisture risk researchers and CLT practitioners to come together and put their case for this to be taken seriously as quickly and effectively as they can.

References:

(1) https://www.dezeen.com/2020/02/12/france-public-buildings-sustainability-law-50-per-cent-wood/

(2) http://tallwoodinstitute.org/guides/submitted-projects/structural-health-monitoring-and-post-occupancy-performance-mass-timber

5. Summary of experiences of International stakeholders on the maritime environment challenges in their areas and how these have been overcome

Andrew Waugh, Waugh Thistleton - UK

Waugh Thistleton in the UK are preeminent as CLT Architects. With over 30 completed CLT buildings under their belt, in the UK, and over 40 projects in numerous countries where they have acted as CLT technical consultants, including in Norway and Sweden, the firm is well placed as an expert in this field. The two projects featured earlier in this report were both designed by this practise. Waugh Thistleton has over 15 years of experience with CLT making them one of the most experienced firms globally outside of the German speaking region. This experience is primarily in the maritime climate of the UK and not in the more climatically stable and drier climate of the European continent. Their observations are that CLT clearly is vulnerable to moisture and that it can, in the right conditions, rot. At the same time, it has to be understood that the CLT structure is encased in the warm and dry conditions of the inner building envelope once construction is complete and the building handed over to the occupiers. The practise focusses on getting the construction detailing right, and this includes both an aversion to moisture traps and also detailing the weather envelope so that it can easily shed rain water and thus shield the CLT structure; the Structural Timber Association (STA) CLT construction details are recommended in this regard. The firm reminds us that the slab thickness, for example, of CLT floors is driven more by acoustic and fire protection measures than it is driven by structural criteria; if the latter were solely to prevail then a 175mm floor could in some circumstances be designed instead to, say, 100mm. The point being that there is considerable structural redundancy as regards any moisture damage that may occur. Whilst the firm has, over a 15 year period, not had any reported instances of moisture damage to any of their buildings, they have consulted on a project where a smaller and less experienced architect made some detailing mistakes and as a result of which this led to moisture damage to CLT panels in a bathroom and kitchen for a single family dwelling. This damage became obvious early on due to the plasterboard finish cracking and floor tiles lifting; the finishes were removed, the damaged areas of CLT cut out and replaced with scarfed in moisture resistant plywood to which new vapour permeable wall and floor finishes were then applied. The firm considers CLT risk holistically and considers that there are three key risk areas:

1 - Bathrooms: There are inevitably going to be some leakage risks with bathrooms. Waugh Thistleton does not now use CLT structural panels for bathroom floors, but rather creates a vertical shaft dedicated to bathrooms (akin to a lift shaft) and into which it details the bathroom floors as traditional timber joists with moisture resistant plywood on top and plasterboard to the underside for fire protection. This substantially mitigates moisture risk because there is much less mass of timber to get wet, and much more surface area of timber which can dry more readily if there are water leaks.

2 - Flat roofs: Again, this is an obvious risk area. The approach here is not to detail the flat roof so that it connects into the side of the parapet, but rather that it is placed on top of the parapet and thus drains out to an external gutter and not into an internal flat roof gutter. A minimum of 5 degree roof pitch is always applied, and, again CLT is avoided in the construction of the roof with plywood and glum beams being used instead of CLT panels.

In both these case one can see a simple and pragmatic approach - CLT is a great material to create wall and floor elements, but in areas of high moisture risk one can design it out and use more conventional timber construction. CLT construction should perhaps be evolved towards a more CLT-timber hybrid form.

3 - Fixing of water resistant membranes. The approach of the practise working with CLT manufacturers is to insist that water resistant membranes/coatings are applied to the CLT panels in the factory and not on site; follow on finishes/membranes are only applied once the moisture content is at or below 16% and all membranes are specified to be vapour open. In any event, all CLT surfaces are still checked for moisture content on site at 1m square centres to give adequate coverage and, again, follow on finishes are only applied when the moisture content is at 16% or below.

In a recent presentation to the insurance industry, they were advised by insurers that their main concern with CLT is not fire risk, but rather moisture risk. So the insurance industry in the UK is wise to this risk.

Evan L. Schmidt with Mariapaola Riggio, Oregon State University / TallWood Institute

Evan and Mariapaola have carried out seminal research work into the moisture vulnerability of Douglas fir CLT in Oregon; the latter having a maritime climate not dissimilar to that of the UK. This work has involved the insertion of moisture sensors into a new CLT building on Oregon State University campus; The Forest Science Complex; as it was being constructed. It is acknowledged in this work that the level of understanding of the hydrothermal performance of CLT; and in this case specifically Douglas fir CLT; is not well understood and hence the research. The work is very useful in two regards; firstly it highlights aspects of hydrothermal behaviour which appear somewhat counter intuitive with regard to current industry assumptions, and secondly there is much learning and experience with regard to the science and practise of moisture monitoring which is in itself a challenging area where expertise is particularly incipient. The latter will not be addressed in this commentary. However, with regards to getting a better understanding of hydrothermal behaviour of CLT panels.

- As is generally understood, CLT panels during the construction process will go through cycles of wetting and drying, and that provided there is no long term chronic wetting or barriers to drying out, they will dry out to acceptable levels of moisture content once the building is occupied for a period of time.
- However, CLT can be subject to slow drying and moisture pooling in parts of the upper plies of the CLT and CLT can be permanently damaged with high levels of checking at exposed, i.e wetted, edges of the panels (checking refers to cracks in the wood which separate the wood fibres); these wetting/drying induced defects may have some long term structural performance implications.

Whilst the overall hydrothermal performance; ie the tendency for the CLT to essentially recover or dry out from short term wetting was shown to be good, there are nevertheless specific areas of the construction which are probe to persistent high levels of moisture content and thus vulnerability.

An area which is highlighted in Schmidt's work is the ability of mass timber CLT to store large quantities of water within itself; something which is not an issue with more traditional timber frame construction. This presents its own problems in terms of the ability of CLT to dry out; certainly in the short term. There is a " tendency of moisture concentrations to diffuse in all (drier) directions (including further into the panel), despite external conditions themselves being conducive to drying.." So that may include water from the outer part of the CLT moving into and wetting the previously dry or dryer inner core of the CLT. Where impermeable building materials or membranes are thus added to such material the moisture levels at the core may remain wet with higher level of moisture content than one may realise or wish.

It is also evident from this and previous research work that; "horizontally oriented mass timber elements are dangerously susceptible to moisture exposure, and that a non-porous, vapour impermeable coating was one of the only coatings that effectively prevented moisture ingress."

The application of concrete screeds on top of horizontal CLT panels that have not dried out; ie to a moisture content preferably less than 16%, can lead to persistently high moisture content levels in the CLT for an extended period of time; indeed the concrete screed itself in drying out can contribute moisture into the CLT.

A further aspect pointed out here is that CLT can be quite varied in terms of its performance; no surprise when one considers the natural variability of wood from which it is largely manufactured. The result of this is that moisture vulnerability can be sometimes greater or lesser than one might expect. It is suggested that, in light of laboratory tests of CLT responses to wetting/drying cycles that the manufacturing quality and consistency of CLT could be improved. Clearly this is in relation to US manufactured material but it would be surprising if the same principle did not apply in Europe. In any event it is made clear that the CLT end grain is the highly vulnerable part vis a vis moisture up take and thus essential that this end grain is suitably protected with effective and vapour permeable sealant.

In terms of the moisture readings at another study (Brock Commons); 192 MC sensors were installed throughout all 18 floors of the building. In the majority of floor locations MC readings were still between 16-20% MC a year after construction commenced. The majority of these locations appeared to dry out by circa 4% during second year, so that in the majority of cases were around 16% two years after occupation of the building: However, some locations continued to show very high moisture contents at this time.

Given the potential for higher moisture levels at the core, it is recommended that any moisture monitoring should be done at both the surface of the panel as well as in its core. This is particularly applicable to CLT connections where there may be some compromising of structural integrity if at these locations there are high levels of moisture content.

The moisture readings from the Forest Science Complex building highlights different performance and vulnerabilities with different building elevations; drying rates will vary depending on sun exposure.

It should be made clear that both of the buildings referred to were constructed without any weather protection and that as a result defects did occur in both instances including incidents of mould, staining damage and damage to CLT lamina; as well as intense wetting to sensitive structural connections

A clear intimation from this all of this is that, subject to cost benefit analysis, CLT buildings should be constructed within weather protected envelopes, although, as previous addressed UK, US and Norwegian practise is largely anathema to this approach; there is in reality a potentially toxic combination of client cost pressures meeting wishful thinking. “Don’t worry it will be fine.”

In any event, and as referred to earlier, it is critically important when detailing a CLT building to be mindful of the need to make sure that moisture is considered. This includes construction detailing, construction material choices and also the sequence of construction.

In summary then the lessons learnt here are:

- One should never forget the essential hygroscopic nature of softwood; it will easily attract moisture and given the large mass of CLT there is potential for significant amounts of water to be retained and stored by it with potential structural integrity and thermal performance implications.
- Timber that gets very wet can easily dry out; but one must not underestimate the damage that long term wetting can do nevertheless to the fabric even if it does then dry out.
- A tent or canopy is essential to avoid potential moisture damage during construction.
- Construction sequencing is important to make sure that if any CLT does get wet, then later applied finishes are specified as vapour permeable to ensure that no moisture is trapped.

- A greater level of focus could be made by the CLT manufacturers in achieving consistent and better quality of the product.
- CLT connection details are very important in terms of both not becoming moisture traps but also in terms of the potential for any rotting of timber in this area to compromise structural integrity.
- The integration of moisture sensors could assist in terms of long term monitoring of the building elements and their moisture content.

More information on this research can be found on the following links:

- https://www.scanntronik.de/Publikationen/Materialfeuchte%20Gigamodul%20-%20Datenlogger%20-%20Publikation%2063100.pdf
- https://www.researchgate.net/publication/333786017_Monitoring_Moisture_Performance_of_Cross-Laminated_Timber_Building_Elements_during_Construction
- https://www.frontiersin.org/articles/10.3389/fbuil.2019.00098/full

6. Suggested guidelines for the design of CLT structures in Jätkäsaari, Helsinki

DESIGN FOR THE FUTURE CLIMATE - 2062

If the building is constructed ready for occupation in 2022 then with an 80 year building life (so end of building life 2102) it would be prudent to develop project design weather parameters based on mid-case climatic projections out to, say 2062, and to use these as the basis for the construction and systems design. It is recommended that the following metrics/data set are considered during the design period and over the design life of the building; range of summer maximum temperatures; range of summer humidity levels; winter and summer rainfall patterns; wind speed and rain amount. Clearly, minimum winter temperatures and dew point for the current climate could be assumed. In any event, there are overheating problems in a number of Helsinki and Jätkäsaari apartment blocks and so this approach will act to hopefully circumvent potential problems with the project in question; as well as anticipating more stormy conditions which could compromise the protective weather envelope. In this regard three issues could be thought about; extended eaves details would provide for more rain and weather protection to the facade as well as acting to provide more shading from summer sunshine (heat gains); balcony designs could be thought about as shading devices for high summer sun (but not low winter and mid season sun); rainwater gutters sized for greater levels of rainfall than current.

CARRY OUT DETAILED MOISTURE MODELLING USING WUFI ANALYSIS

It would be prudent to carry out detailed moisture modelling for the building so that moisture, mould and fungi damage risks could be established and assessed; this is especially so given the high levels of thermal performance of the buildings to meet energy standards and the greater potential for condensation within the construction and upon surfaces. The vapour permeability of the CLT panels should be carefully checked; if the permeability is in reality lower than the manufacturer's data suggests than condensation could occur in the panels; to avoid this a vapour membrane would then be required on the inner face of the CLT. An experienced WUFI modeller should be sought with at least 10 years of experience.

CONSTRUCT THE CLT/COMPLETED WEATHER ENVELOPE IN A WEATHER PROTECTED TENT STRUCTURE

It is understood that ARA requires any CLT apartment buildings to be built in a weather protected environment, and this approach accords with current practise in Sweden and is also recommended by TallWood Institute in the US. Should the developer choose to use CLT prefabricated volumetric construction then the same risks of moisture will still apply both during construction-assuming that the final weather envelope will still need to be constructed; clearly there is potential for the moisture risks to be lower given the much shorter programme period but this does depend on what time of year the building would be constructed.

CAREFULLY CONSIDER THE KEY MOISTURE RISK AREAS and HOW TO MITIGATE THESE RISKS

It is clear from international experience and associated commentary that risks are most acute in wet rooms; bathrooms, laundries, saunas, service cupboards (leaks) and flat roof areas; for bathrooms the logic of carefully thought about pipe layout designs and suitable specifications (including for workmanship) to reduce water leakage risks needs to be considered in conjunction with the MEP designer. The external walling and roof details that are typically used in the UK and referred to in the accompanying STA papers would appear to be suitable and appropriate for Helsinki; although no doubt existing standards and approaches are already in place for these elements.

CAREFULLY CONSIDER CONNECTION DETAILS FOR THE CLT PANELS AND THE CORROSION RESISTANCE OF ANY STEELWORK

Local Finnish codes and requirements in this respect are not known. However, it is clear that the greater saline environment at Jätkäsaari could create conditions for steelwork corrosion and this could be especially significant in terms of the steelwork connections between CLT panels and any other structural elements. Connections could be protected by being in galvanised or even stainless steel; the latter quite possibly excessive given that the building is not located in the beach spray zone. Consideration should be given to local application of timber preservatives surrounding any connections, the oversizing of connections to allow for some loss of area arising as a result of corrosion as well as greasing of any such joints or connections.

ADOPT A RIGOROUS APPROACH TO CONSTRUCTION QUALITY INSPECTION AND ASSURANCE (QA/QC)

This is increasingly a problem for European construction. Standards and sustainability levels continued to rise in the context of a growing skills problem and thus 'performance gaps' are opening up between the intended performance of buildings and their actual performance in reality. Whilst this performance gap can be disappointing in terms of energy performance, it can be disastrous in terms of moisture performance. A detailed QA/QC plan around the construction is necessary and particularly with regard to the levels of moisture risks and the measures required to suitably mitigate these risks.

SEE THIS AS A RESEARCH PROJECT AS WELL AS A DEVELOPMENT AND CONSTRUCTION PROJECT

CLT use in Finnish residential construction is still incipient and there are strong concerns about its appropriateness of use by the great majority of local housing developers. Indeed, the City of Helsinki officials were themselves concerned about CLT for the Jätkäsaari location and thus the *kehittyvä* kerrostalo proposal addressing their concerns about moisture risks. A focus could be on the embedding of moisture sensors within the CLT to monitor moisture levels throughout the building structure during construction and also occupation. In any event at the very least a survey could be done on all CLT apartments in Helsinki to learn from any mistakes or problems which have been observed on those developments.

MAINTENANCE AND MANAGEMENT PRINCIPLES

The UK approach to maintenance and management of apartment buildings is disciplined. Part of this rigour is the development of a detailed maintenance manual for the building and which, in this context, would translate into the need to highlight areas of moisture risk in the building; this could include photos of what to expect if there is any water damage. These areas should be distinguished between external building risks; main external walls, external roof, building services risers in the corridor areas; which should be covered by the building owner with regular inspections at least 2 times a year (before and after winter); and internal building risks covered by the tenant/owner/occupier. Internal areas include any service cupboards inside the apartment where there may be leaks (water intake cupboard, heating system interface unit); bathrooms, kitchens and any private saunas, which could be done by the apartment resident on an ad hoc basis; i.e. this could be on the basis more of "keeping an eye out for any signs of moisture damage/smells etc. "rather than more formal inspections.

When the resident moves into the property a condensed and easy to follow building handbook (like the one provided with a new car) could be provided to them which explains how the building has been constructed, how it all works, and what they should expect from it. This could highlight moisture risks associated with CLT so that the residents are fully informed on this matter; so many times in our industry problems can arise because of a simple lack of care and effort to communicate to the residents' "oh dear, I did not know the building was made out of wood; why did they not tell me before ?". This building handbook could include some explanations setting out why CLT was chosen, what its benefits are, and most especially how warm and comfortable a CLT building can be to live in. So; here is what is good and great about CLT; but please watch out for signs of water damage/moisture ingress etc;

The main intake water supply could have leak detection equipment which through algorithms/machine learning could identify if there are any water leaks and this could be communicated to the building owner in the first instance so that leaks could be quickly identified and resolved.

It is recommended as above that a research project is considered as part of this overall project and this could include the integration of sensors into some parts of the construction to monitor moisture content figures; this data could be relayed back to the maintenance team but it must be made clear that this should never be in substitution for regular inspection and maintenance of the structure.

A steering group is recommended for the project with the maintenance department of the developer being actively involved (if not already) during design and construction as an advisor so that long term maintenance and management issues are properly considered and addressed at the design and construction stages.