ADAPTIVE SCHOOLS:
EXPLORING HOW DESIGNING FOR DISASSEMBLY CAN EXTEND THE LIFESPAN OF MATERIALS AND BE APPLIED TO THE FLUCTUATING REQUIREMENTS OF TEACHING FACILITIES

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Architecture

at

Dalhousie University
Halifax, Nova Scotia
March 2018

CONTENTS

ABSTRACT

This thesis investigates how designing with disassembly in mind will extend the lifespan of materials and decrease the environmental impact of construction.

The most suitable programs to test this concept involve projects that benefit from built in flexibility, ease of expansion and would benefit from the ability to be disassembled and reassembled on another site.

The program being used to test this theory is elementary schools within the school district of Coquitlam where the demographics and population fluctuate resulting in schools being closed in some parts of the district and schools being opened in other areas.

The project will be evaluated by looking at constructing a core of classrooms and learning commons which would expand and contract to meet the enrollment demands around the district. This approach will have built in flexibility to meet the ever-evolving teaching methods of the district and individual teachers.

ACKNOWLEDGMENTS

I would like to thank my thesis team, Susan Fitzgerald and Ted Cavanagh for all the helpful feedback and input while developing my thesis. I would also like to thank the support I received from Claire Long and my family in Vancouver.

CHAPTER 1: INTRODUCTION

Buildings are often viewed as static objects instead of the dynamic ever-changing configuration of elements they are. Time as a major factor in building is also often an overlooked element in the design process. Buildings are also constantly changing and adjusting to meet new requirements of the users. "Architecture, we imagine, is permanent. And so our buildings thwart us. Because they discount time, they misuse time . . . almost no buildings adapt well. They're designed not to adapt, and constructed not to" (Brand 1995, 2). Stewart Brand emphasises this point, that time is not designed into buildings, therefore they do not adapt well to future situations. There is now more time and money spent changing buildings than constructing new ones (Brand 1995, 5). Therefore, it is reasonable to allow for adjustments and changes within the initial design of a building. It is through designing for disassembly (DfD) and designing for repair (DfR) that perhaps the overall process of adjusting buildings throughout their lifespan can be made easier.

In the past many architects have been tempted to work with prefabrication as an approach to this problem and as a way to deal with material efficiency. Prefabrication and modularity often becomes a factor with large scale projects to simplify the construction process. However, these forms of prefabrication are often too specific and work only on a case by case basis and do not lend themselves to be used in future projects. Whereas looking at components at a smaller scale, perhaps looking at the joint and how materials meet and are assembled can lead towards a reasonable approach to being disassembled.

Our world-wide material stock is dwindling and people see the need to think environmentally when building since the construction industry uses a large percentage of the world's resources. As Konrad Wachsmann believed in the 1930's perhaps wood construction is a useful approach to building, especially at the scale where wood excels (Wachsmann 1961, 88). Wood is in theory a sustainable material if it is harvested and used correctly in order to maintain a certain level of stock. It is also a material which acts as a carbon sequester. If we can extend the usefulness of wood products beyond the building's life and into the actual life span of the material itself we can make better use of the material stock we have. This can be accomplished by designing with disassembly in mind so that the materials can be used and reused in future building projects. A solution and a way to build with this idea in mind is designing for deconstruction, this means that components are assembled instead of constructed on site.

The test of this thesis are elementary schools in Coquitlam, British Columbia. The idea of disassembly works well since it starts with assembly. This means that there is less skilled labour required to assemble the building on site compared to standard construction and most importantly a majority of the components can be built offsite and then assembled on site at a much faster pace. This works well with school systems because ideally additions and adjustments can be prepared during the school year and then they can be assembled on site when the school is on break.

A focus for the design becomes the connectors and connections of the different building elements, how they can be simplified for ease of assembly and disassembly and how they can function properly with the materials involved. This strategy works on multiple levels within the function of the school itself. Large structural and building changes would involve professionals, smaller building adjustments could be undertaken by employees of the school district, room level and spacial adjustments could be done by the staff and minor room adjustments which would still require some level of disassembly could be done by staff and students themselves. Students would therefore have the added benefit of learning about their built environment by assembling and disassembling it themselves.

Thesis Question

How can a component approach to architecture, allowing for disassembly and adaptation extend the life span of materials, thus decreasing the environmental impact of construction?

A test case for this theory involves designing for disassembly to accommodate the fluctuating primary school enrollment throughout the school district. The resulting flexible building spaces facilitate the evolving methods of teaching and number of students.

CHAPTER 2: VIEWS ON PRE-FABRICATION

Using components as an approach to building is not a new idea of how to build, Knaack states that "the first systematisations applied to the smallest unit: bricks" which was around 7500 BCE (Knaak 2012,7). Whereas when we think of prefabrication and system building today we are referring to "much larger and more complex components" (Knaack 2012,7). The idea of prefabrication as an approach or solution to building crisis or just building in general has often been tempted by many architects through the 20th century and Davis summarizes this idea when he says "although most buildings are not made on assembly lines in factories, like automobiles, their production uses many of the same principles. Many architects, and many people in construction, dream of an even more "rationalized" building process—one that features greater interchangeability of parts and a broader use of prefabrication" (Davis 2006, 243). From this idea of interchangeability comes flexibility and adaptability, which are all key actors when designing for disassembly. The use of prefabrication can therefore land anywhere on a broad spectrum which would also affect the degree of direct interchangeability. However, by simply adopting disassembly as part of design, prefabrication can play a significant role. For this thesis I will work with the idea of assembly of components over large scale prefabrication.

Often the word prefabrication and modular buildings brings up negative feelings for architects and Knaack believes this can be attributed to the fact that "it instigates a fear that intelligent thinking and creative architecture, as well as the architectural profession itself, are becoming obsolete" (Knaack 2012, 8). Again, this is where this thesis takes a different approach to components. By utilising them correctly and perhaps differently I believe that architects have the opportunity to have a significant impact on how the architectural profession deals with material usage and therefore expand their role. Also, this approach to components would increase the amount of creative thinking involved in projects and reduce architecture's environmental impact by using an approach of disassembly in their building projects. This should not alter their artistic design ideas, just change their approach to how they design the components and assembly. This may require more design time, however according to Fernandez the time spend designing has little material or environmental impact compared to the waste and expenditure of materials used trying to realise a design that is not thoroughly thought through (Fernanadez 2006, 298).

Prefabrication and modular or component construction can be approached in several different ways; the entire building could be built in a factory and shipped to site as one modular unit, individual "modules" of the building could be premanufactured and then assembled on site or the approach I will use in this thesis is to use adaptable components in the construction which in theory could be used in several different configurations or different buildings entirely.

Gruning summarizes two different ends of the spectrum of modular construction by looking at the "building block versus the building system; the focus on individual building units versus integrated, total pre-fabrication of the whole building – these differences characterize the difference between Wright and Wachsmann" (Gruning 1995, 25). When looking at wood construction and wood pre-fabrication he continues by stating that "pre-fabrication has thereby been freed from the somewhat overwhelming influence of high tech; the way to a more complex, more varied application of building technology has been opened" (Gruning 1995, 26).

Approaches and Results of Pre-Fabrication

Components and adaptability can be a useful approach to how we design buildings. Modularity and a systems approach to architecture has been on architects' minds for most of the 20th century, with numerous attempts being made and several industrial production companies developing. It can be argued that practically all buildings use a degree of modular or components approach. Parts of buildings are no longer created and built on site, instead components are manufactured in factories and warehouses and simply assembled on site. The notion of building as an action has changed today, it is more like assembling. Leatherbarrow states that "architectural construction has become a process of assembly. No longer does site labor involve cutting, joining, and finishing of raw materials; instead it entails the installation of components" (Leatherbarrow 2002, 215). These components take on a wide range of forms, they vary from the modular bathroom, the complete modular home which is build and then assembled on site, to windows and doors which are fastened to frames using standard connectors. One of the most basic components is dimensional lumber which is created in mills and meets very strict standard requirements. The majority of large projects aim for a varying degree of modularity in their design, this helps in the construction, cuts costs and can also make the project appear more cohesive. These forms of modularity are often designed and re-designed for each individual project and thus are not interchangeable (Braham, 176). Building with an idea of disassembly and adaptability gives these building components an opportunity for a much longer lifespan. Wood products can offer a much broader opportunity for adaptability and flexibility in their future uses (Brand 1995, 117). It is through the type of wood products used and the ways in which the wood is assembled and connected that adaptability can be designed into wood construction.

When Peter Cook is talking about prefabrication and the industrialisation of building in the 1970s he says that "the situation which now can be called experimental will be strategic as well as operational; it will involve the design process, its economics and its marketing potential as much as the beauty of its detailing" (Braham 2007, 191). I believe there is an opportunity to deviate slightly from past universal design approaches by designing components with the possibility for adaptability, but without a finely detailed system for assembly, since it is not universal it is therefore not transferable to other buildings and projects. Whereas when Cook talks about how component building and modularity is usually approached he says that "the clever assembly tends to involve the clever multi-directional joint and every investigation and experiment in this area reiterates this problem" (Braham 2007, 191). The notion of the "universal joint" is an interesting solution, however it is difficult for the construction industry to adopt a universal solution and have it applied to all construction. Therefore I argue that it is more important to adopt a different design mentality, not a specific design solution. The idea here is to design for deconstruction, therefore designing with the idea that the building's components can be taken apart or deconstructed at the end of the building's life instead of demolished and sent to the landfill. This methodology focuses more on creating connections which can be easily taken apart instead of creating the ideal "universal connector".

Wood Construction and Wachsmann

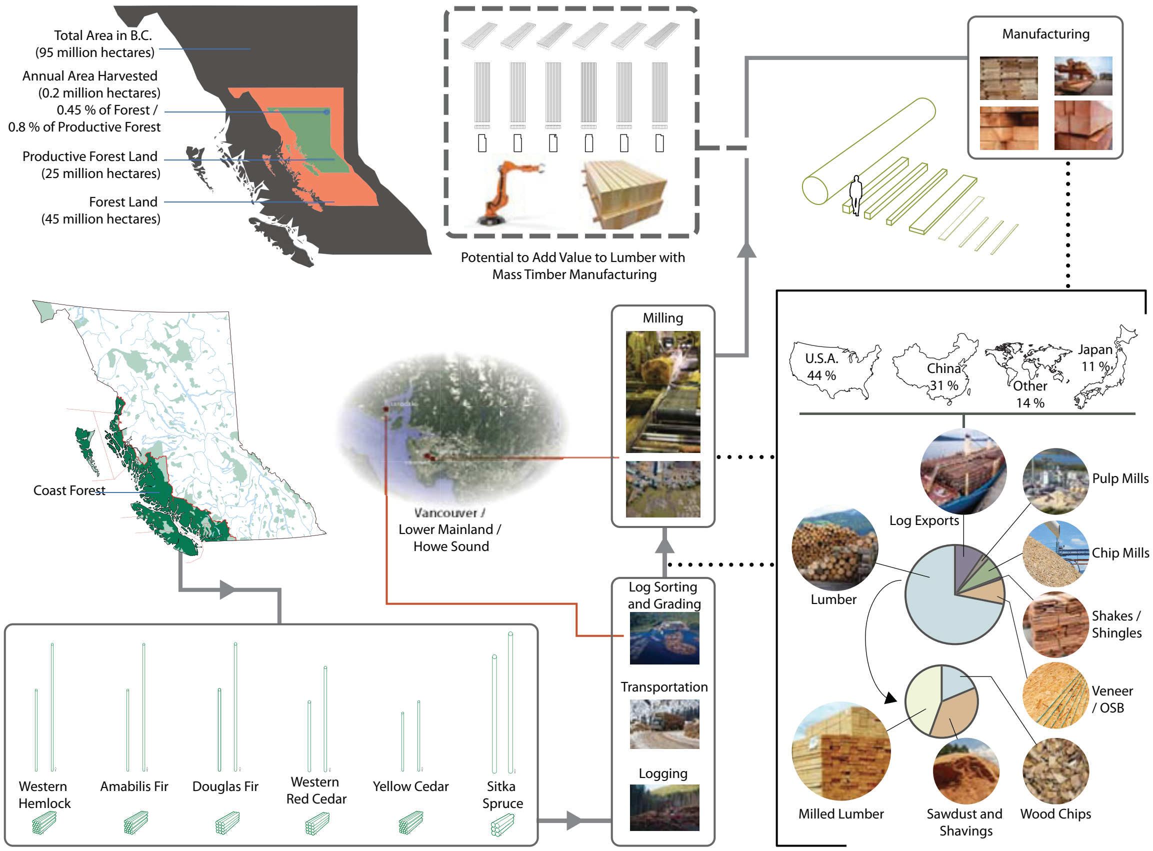
Wachsmann writing in the 1930s was trying to look at wood construction in a different way and thought because the process of creating wood has changed so drastically, so should the way in which it is utilized in construction (Wachsmann 1961, 7). When talking about the wooden home Wachsmann says that "a traditional, highly-developed craft has evolved into a modern machine technology; new applications and new forms are being developed" (Wachsmann 1961, 7). Even in the early 20th century Wachsmann believed that "wood simply as lumber – as traditionally used by the carpenter – is not longer able to meet today's requirements. But as a standardized, machine-produced, pre-fabricated product wood can compete in terms of cost and utility with any other building material" (Wachsmann 1961, 7). To some degree Wachsmann's ideas have come to fruition with the plethora of engineered wood products on the market today. These include products such as basic gang nail trusses, glue laminated timber and beams, parallel strand lumber and mass timber products. These are a few of the developments that have been made with wood products since Wachsmann was writing about the need for an evolution in how we design with wood. He continues by saying how "new methods of working with wood have changed the appearance of buildings. Now a new model needs to be developed. While such a model can hardly be compatible with the current commonly held concept of 'the wooden house', this new model organically flows from and is a continuation of a centuries-old tradition of building with wood" and then emphasizes "how working with wood in a new way can reflect a transformation in the way we build" (Wachsmann 1961, 7). This shift in the way we build with wood can currently be seen in the surge of mass timber buildings globally and in Vancouver specifically, with the UBC Brock Commons, Wesbrook Community Centre and the UBC Earth Sciences Building to name a few. Building with wood has significantly changed since the mid 20th century, with this recent trend towards mass timber, but also with glulam beam structures all which can be built without the requirements of large scale raw lumber. However, I believe there is a potential within the way we assemble buildings instead of the materials themselves.

As buildings are not static objects, building culture is also constantly evolving. In a healthy building culture: change, learning and adaptation is beneficial and helps established aspects of the building culture to remain (Davis 2006, 16). It is difficult to question the light frame model for building, especially now that it has continued to be so widely adopted almost 100 years after Wachsmann was questioning its merit. Brand sees the current trend "in construction during this century has been towards ever-lighter framing . . . flimsy to the touch, and incapable of aging well" (Brand 1995, 113). This starts to bring into question why we have continued to build with such a temporary mindset, perhaps it is time to build with longevity in mind instead. When Wachsmann is talking about nailing as a strategy for assembling wood he says, "this method does not fit in our concept of solidness and durability: by using this method the Americans have quite consciously made qualitative concessions" (Wachsmann 1961, 14). With Wachsmann's panel method he also saw the benefit of creating a system in which "this type of house can at any time be easily dismantled and reassembled at another site with no loss of material" (Wachsmann 1995, 28). He saw this as a significant benefit to his method of construction. For Wachsmann is seems that disassembly meant that his system could be used on multiple sites for multiple buildings. While this is one significant benefit to his system, I also believe that the continued lifespan of these panels and the material involved is another upside of this system. Perhaps this also means that the building while holding carbon within its walls and material, it also represents a dollar amount which if and when the building is disassembled creates a return on the initial investment into the building.

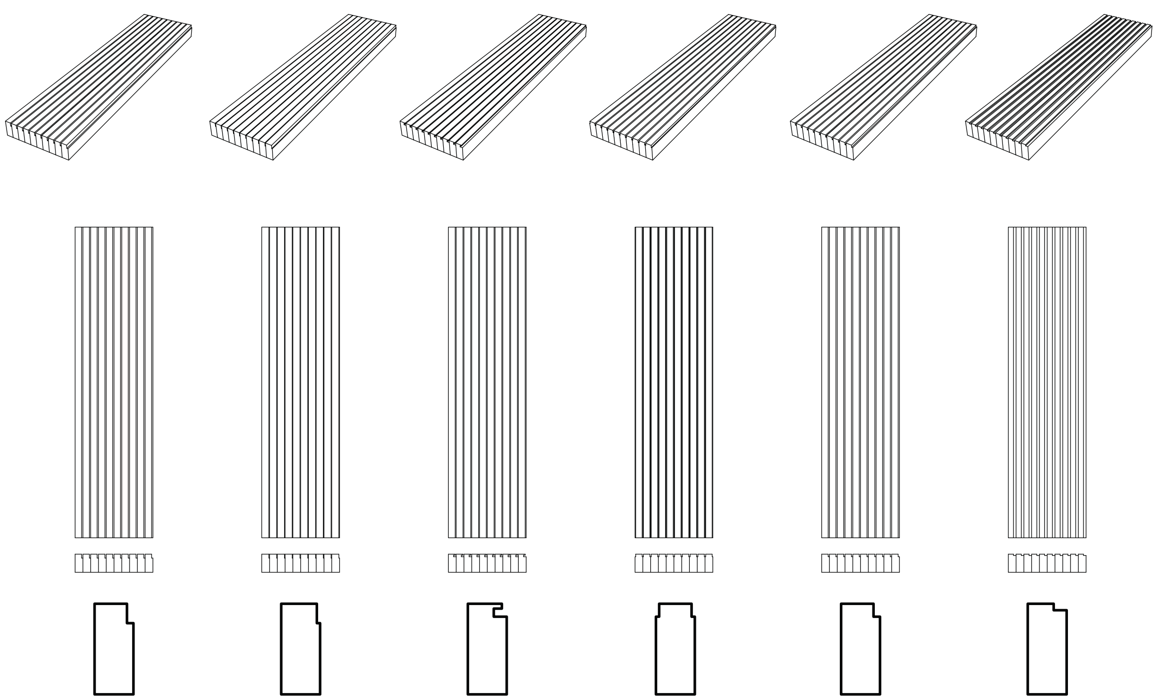
This embodies the idea of designing for disassembly. I believe this idea can be pushed even further and architects should design for maintenance and disassembly. Designing for disassembly has the benefit, as Wachsmann believed, of being able to reassemble the building at a different location. He might have been championing this idea for its adaptability, however I see the environmental benefit as another major factor in this approach looking towards the future. The idea being that the components can be disassembled from the designed building and then reassembled in a new construction project. The major idea here is that the materials themselves have a much longer potential lifespan than the building and can therefore be used in multiple projects if they are assembled in a way to facilitate easy disassembly.

CHAPTER 3: MASS TIMBER PRODUCTION POTENTIAL IN VANCOUVER

Perhaps it is time to reevaluate accepted building practices in wood construction, the way in which light frame construction was established does not make it a practice which can not be questioned. Ted Cavanagh states that “destabilizing the dominant historical narrative is one step on a path to considering alternative understandings of how we build . . . any revision of accepted methods is complicated” (Cavanagh 2016, 307). There is indeed potential to questing the established light frame construction of today, and perhaps one reason is to question the values embodied within it. Perhaps a construction method that focuses on cheap and easy construction without looking towards the end of the building’s life and how it will be taken apart is one of the problems with this established method of construction. Throughout the 20th century the establishment of dimensional lumber standardized much of north America’s housing practice. This led to housing being designed around the 8’ stud wall, resulting in far less cutting of raw materials on site. Mass timber construction has started to have a strong foot hold in Europe and is starting to develop in Canada. The stand out projects in Canada like the UBC Commons project deal with multi storey housing units, taking advantage of the material as an alternative to concrete and steel. However, I believe there is a place for it in single storey construction, especially in the framework of this thesis where the goal is to design for disassembly and design over several additive phases. These mass timber panels form both the structure and the interior finish of the school. The use of DLT panels or dowel laminated panels works well within this thesis’s parameters because the panels are produced and laminated with only wooden dowels, thus there is no glue or adhesives used in the process at all. These types of panels work within this framework of disassembly in two ways, either



Logging system in British Columbia with potential for mass timber construction added (data from Province of British Columbia 2017)



Examples of possible dowel laminated timber profiles the entire panel is disassembled into its smaller dimensional lumber and used as framing in a future project or more appropriately the entire panel is removed from the building and used as a structural panel in the next generation of construction projects. There is also the possibility within the school district to disassemble portions of the school, including the helical structural piles and relocate the school itself to a location where it is needed.

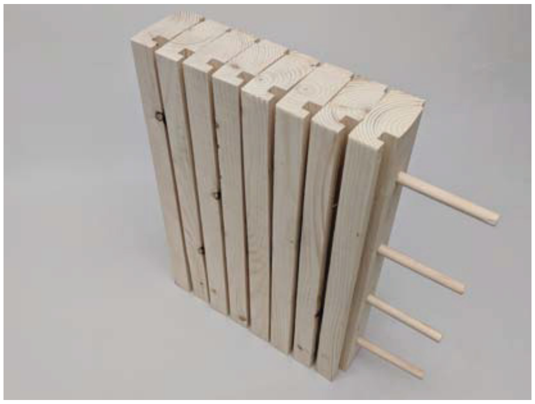
The production of mass timber in itself is a form of component production because the panels are put together in a shop setting, shipped and then assembled on site. The connection types of this panel system lends itself to the eventual disassembly and reuse of the building's materials because bolted connections can be used to assemble the panels on site, screw type fasteners can also be used in panel assembly on site allowing for possible future disassembly.

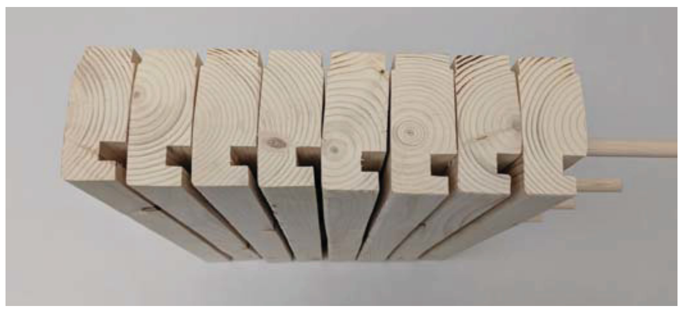
As production facilities are currently changing and flexible robotics and CNC machines are replacing much of the repetitive human labour in factories and shops. The production of DLT panels is ideally suited for this type of manufacturing because edges of the lumber can be tooled in numerous custom ways to create custom profiles and connections. This would be carried out by a machine process and then the panels are laminated by hard wood dowels pneumatically inserted through the layers of lumber. With this degree of customization possible within the controlled environment of the shop there is the opportunity to create the connections within the panel themselves to allow for an easier on site assemble of the panel components.

After analysing some of the lumber industry in British Columbia, the industry as a whole is sustainable on a 125 year cycle of tree harvesting (B.C. Gov 2017). By designing with disassembly in mind the life span of these mass timber products can be extend beyond the life span of a single building. This approach would make the lumber industry in British Columbia more sustainable compared to a system where only light frame construction is practiced and much of the lumber is discarded into landfills after the house's demolition which is on average only 40 years. (Kieran, Stephen and Timberlake 2008, 89)

Another issue with the logging practices in British Columbia is that a large percentage of the lumber harvested is exported as raw lumber and is processed in other countries. This is where there is opportunity to add value to the lumber within British Columbia instead of the current practice where other countries add value to the lumber, thus increasing the dollar amount of the raw lumber which originates in B.C. Instead mass timber panels could be produced locally within much of the existing infrastructure of Greater Vancouver, and then exporting these panels, thus adding a significant amount of value to the raw lumber.

Cedar DLT panels tests with squared edge and facet





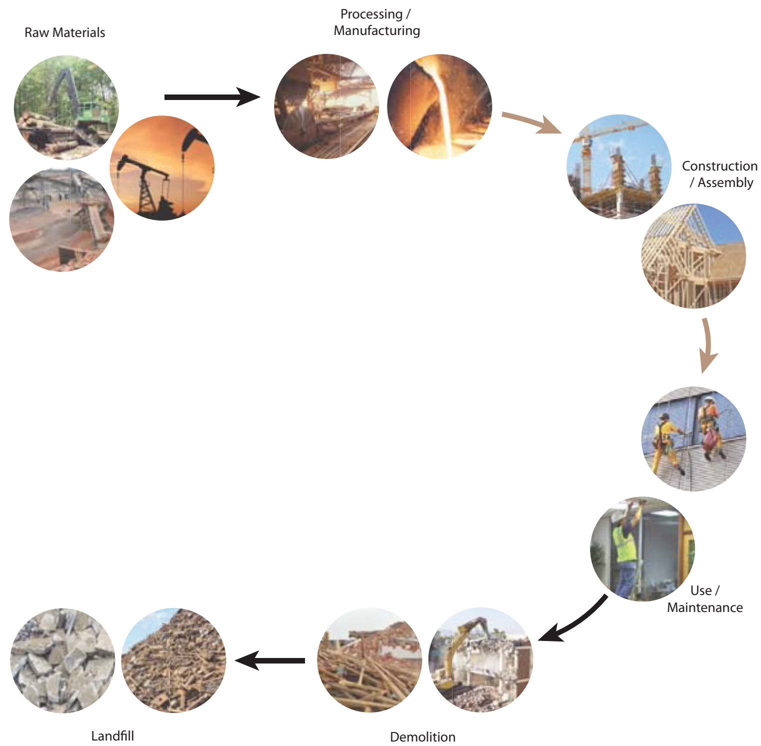
Spruce DLT panels tests with single blade cut and acoustic grooves for sound dampening


Spruce DLT panels tests with double blade cut and squared edge finish

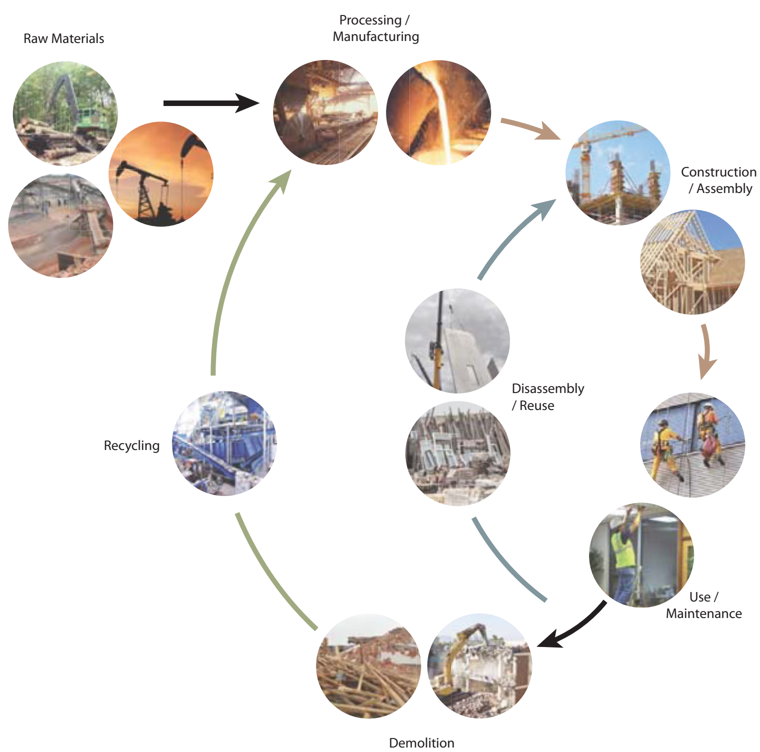
CHAPTER 4: DISASSEMBLY & DECONSTRUCTION

"No future can be as blessed as the present with the material and energy resources currently available" (Fernandez 2006, 305). The building industry and therefore architecture continues to consume greater quantities of material as more synthetic materials and polymers are introduced into modern building culture while the total world-wide material stock is constantly dwindling. It is through architectural design that the continual use of resources can be altered with the help of a component approach to building, especially wood construction. Perhaps we can change the current trend of disposable buildings. "The architect is the ultimate actor working to most effectively align the resources of construction with future needs" (Fernandez 2006, 303). A main idea behind sustainable design is that it is "simultaneously concerned with the present and future needs of society" (Fernandez 2006, 304). Designers also have the opportunity to envision what the future needs of society may be, and in this case perhaps what the future material requirements of society could be.

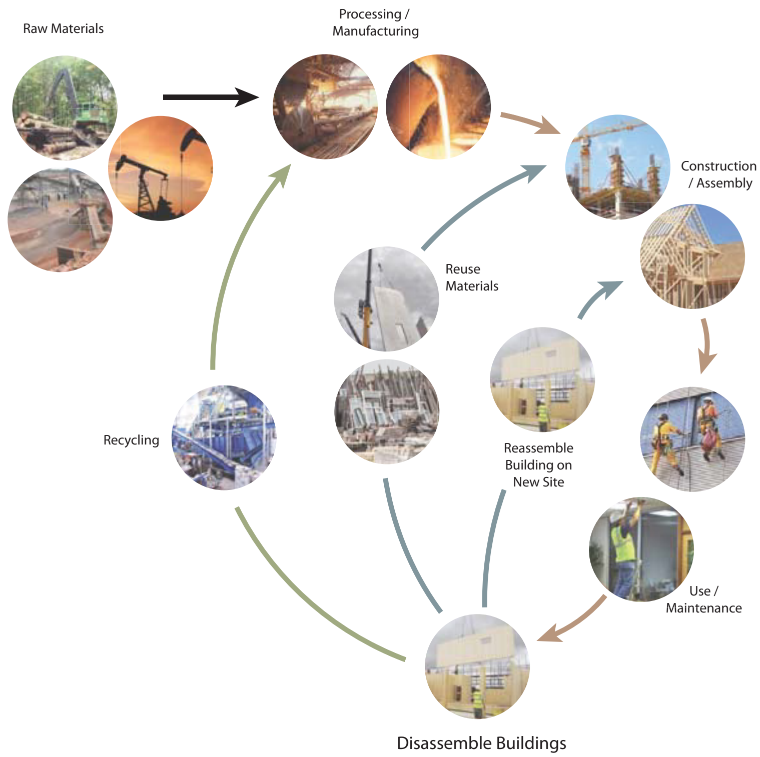
The principles of disassembly and deconstruction should be applied to the initial concept, assembly and construction of a project because in theory these are the same ideas. The Russian Constructivist Iakov Chernikhov wrote about four types of connections; amalgamation, combination, assemblage and conjunction and he favored assemblage as an ideal connection in machines and in architecture. He wrote that "assemblage can be characterized by that constructive look which finds particular reflection in the machine. The elements maintain their separate identities whilst being grouped into one whole" (Ford 2011, 197). The components therefore come together to create a building, but it is how they are assembled that is particular in this case, they remain separate and therefore maintain the ability to be removed and disassembled as separate parts.



Comparing different approaches to construction: traditional



Comparing different approaches to construction: design for disassembly



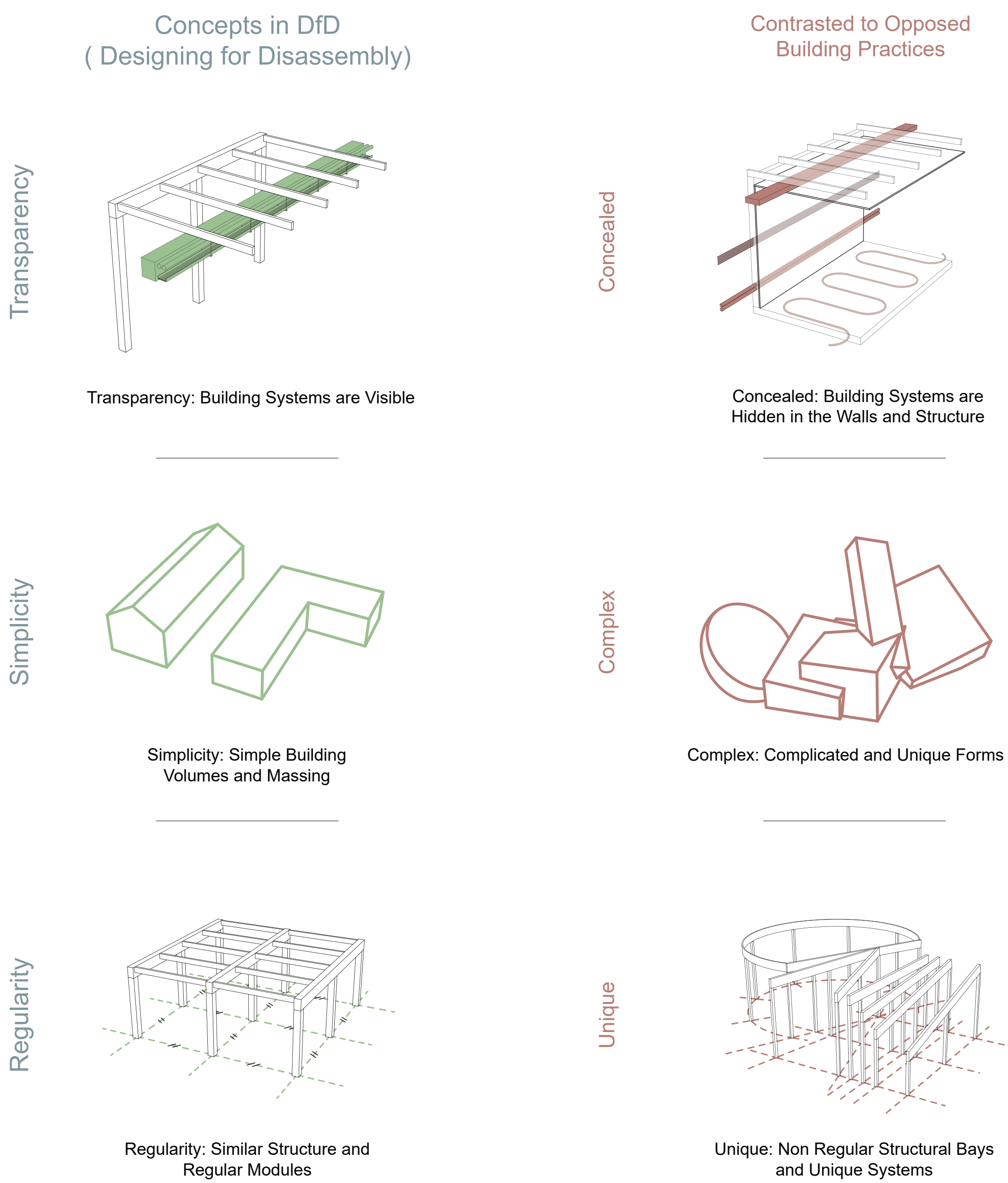
Comparing different approaches to construction: the approach in this thesis

With this thesis, I am looking at how building with components with different degrees of disassembly will allow a school to adapt and expand over days and years. With this I will also help demonstrate how buildings can eventually be disassembled and components used elsewhere. With this approach there will potentially be more design required than a school which uses more standard construction, however the materials used will be given longer lives and will have flexibility built into them from the outset. From Leatherbarrow's point of view most architecture is already just the assembly of components. However, these components are not often designed to be disassembled and many of the connections become permanent instead of temporary (Leatherbarrow 2002, 215). He also believes that architects should continue to be involved in manufacturing of these components or else manufacturing will stagnate and not evolve along with materials (Leatherbarrow 2002, 164). This is another opportunity for designers to be involved, if they have the intention of creating adaptable building components these can be realized by continually being involved in the manufacturing itself. They can affect how components will be used in a building and therefore how they will be assembled and disassembled on site. Perhaps to provide the adaptability in buildings it comes down to how they go together and how they are joined. Chernikhov saw the joints as the most important component and referred to them as “constructive assemblies” and said that “in every construction amalgamation lies the idea of humanity’s collectivism. In the close cohesion of diverse elements is reflected the concord of all man’s fine aspirations” (Ford 2011, 197). Perhaps thinking about how materials are assembled and disassembled reflects the value we place on those materials, if we don’t see their usefulness after their initial purpose then they will not be assembled in a manner that they have a use in the future.

There are a multitude of reasons why buildings are demolished or reconfigured, therefore designing for disassembly will benefits future stake holders who are responsible for the later stages of a building’s life. When Peter Cook talks about the use of system building and pre-fabrication, he states that the results would be that “the house, or large building, can similarly respond to the changing tastes and requirements of successive generations” (Cook 2007, 191). When looking at these expectations by architects like Peter Cook, I believe adapting how building components are assembled can lead to some significant results, including ideas of user built structures and a reduction of the environmental impact currently caused by continual construction and demolition.

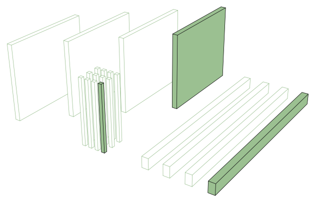
Assembly as Construction

When we look at assembly as the mode of construction it means that the components arrive on site in varying degrees of completion and are simply assembled instead of constructed. If projects are designed for disassembly it also means the owner would be able to repair, replace and alter portions of the building, in this case a school, more easily. This would lead to less demolition over the lifespan of the building and would significantly extend the lifespan of the materials by either being able to repair or upcycle the materials into other projects. The eventual team who oversees the end of life of the building would be able to salvage a much larger percentage of the building with greater ease if the components are installed with disassembly in mind.



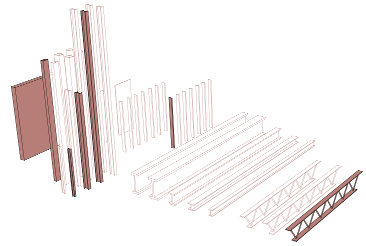
Designing for disassembly strategies versus traditional construction practices

Limited Components



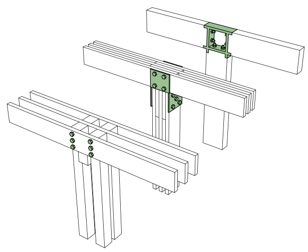
Limited Number of Components

Many Components



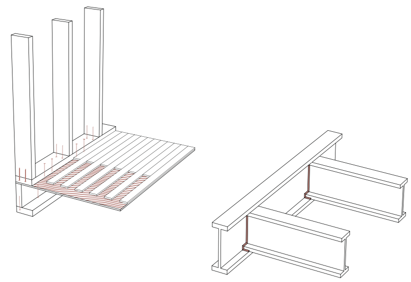
Multiple Components: Plethora of
Building Components / Composite Materials

Clear Joints



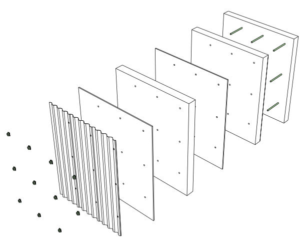
Joints Are Not Hidden / Easy to
Separate

Hidden Joints



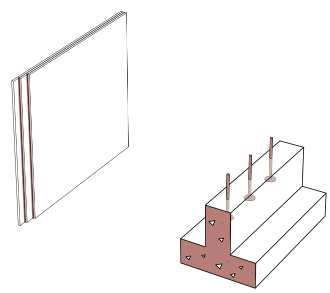
Joints Are Hidden in Walls and Structure /
Permanent Joints
Nails, Adhesives, Welds, Composite Materials

Separable



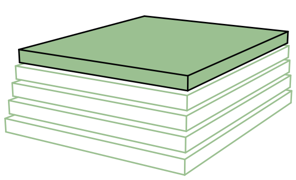
Easily Separable Materials

Not Separable



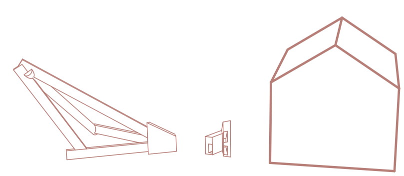
Materials Can Not be Separated:
Glues, Chemical Bonds, Concrete

Prefabrication



Design for Prefabrication / Large Sections

Non Standard



Non Standard Building Components,
Therefore not Usable in Other Buildings

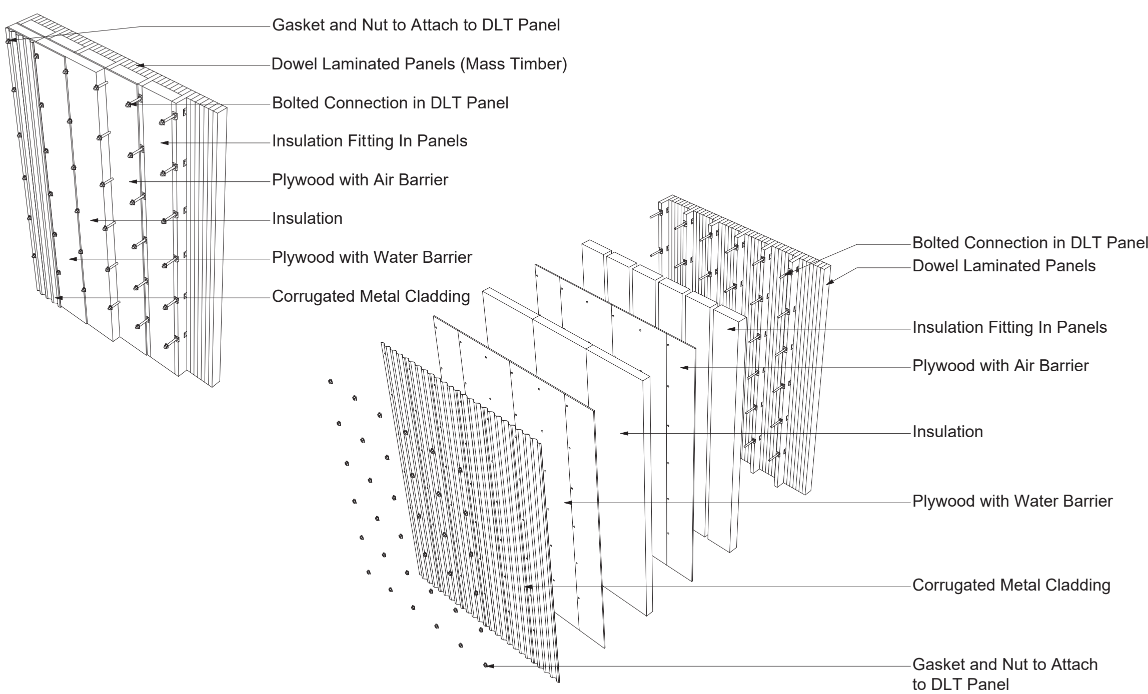
Designing for disassembly strategies versus traditional construction practices

The goal is not to reinvent the whole construction industry; however, I believe that designing with a slightly different approach can be quite affective. Davis categorizes the types of changes and where they could productively appear by saying “we must look to much more evolutionary changes, ones with the following features: they do not reject the positive features of the existing production system, They allow for their own evolution and change by respecting the skill and intention of people who will take them up—people who may not have originally instigated the changes or invented the new technique, They are introduced gradually enough that the building culture can tolerate them on its own terms or they support existing positive social trends” (Davis 2006, 324). Designing for disassembly meets all of his criteria, because it works with the social trend towards more sustainable building, it does not create a new system of production because it mainly uses existing construction materials. This way of designing can also be adapted slowly, entire construction projects do not need to incorporate this system, however gradually more and more parts of projects can be designed with this in mind in order to reuse portions of the building when they are disassembled at the end of their life.

Time always seems to be a factor in school construction projects. From their inception there is usually an urgent need to have them built and children in the classrooms. While they are being used it is important that they are not out of commission for long periods of time. This is where a faster site assembly method could be very beneficial and Keiran highlights this point, saying that “assembly is fast; construction takes much longer” (Keiran 2008, 80). Limiting site work has many positive affects; it can be a cost saving mechanism because site work is often more expensive than work in a controlled environment. Less construction on site also leads to more accuracy in the project because it is easier to control and test assemblies in a factory where the production is done in a controlled environment and portions or complete parts of the project can be assembled to verify their accuracy. Another factor with in limiting on site construction, especially in Canada is the weather. Pre- assembled components can be manufactured in a workshop and shipped to site in varying degrees of completion to be assembled. The limited time spent on site allows for the materials and workers to be out of the weather, allowing them to work year-round and out of the elements.

Connectors

A major factor with designing for disassembly is looking at the physical connectors and how the building components are assembled. I have categorized connection types into 3 different categories, with many sub categories from there. The division is initially based on the idea of deconstruction versus demolition. The table below lays out a matrix of these types of connectors and what they imply for disassembly. Connection

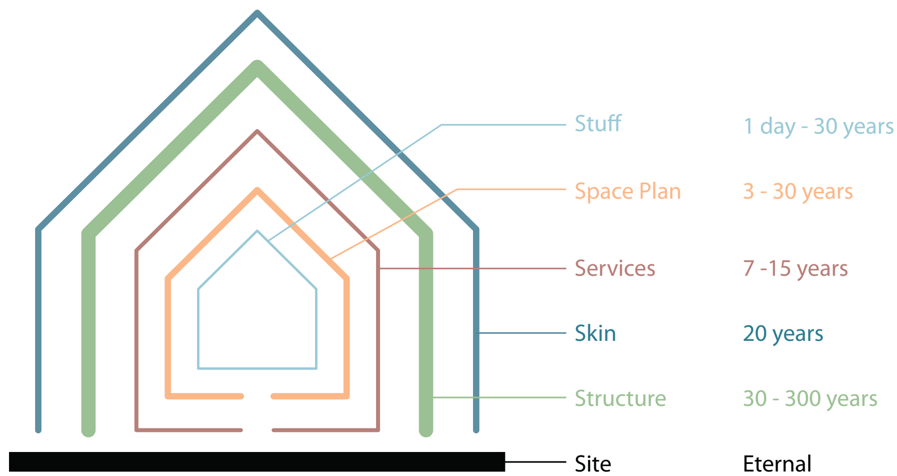


Layers of the wall system to allow for maintenance and disassembly types like glues and concrete create chemical reactions and materials are bonded together often irreversibly, thus creating a permanent connection which is impossible to disassemble or deconstruct. This allows only for demolition, therefore very little of the material is available for reuse or recycling and often ends up in the landfill. Recycling techniques are also often energy intensive, thus adding to the embodied energy in the material, compared to disassembly in which the material does not require to be significantly altered before its next use.

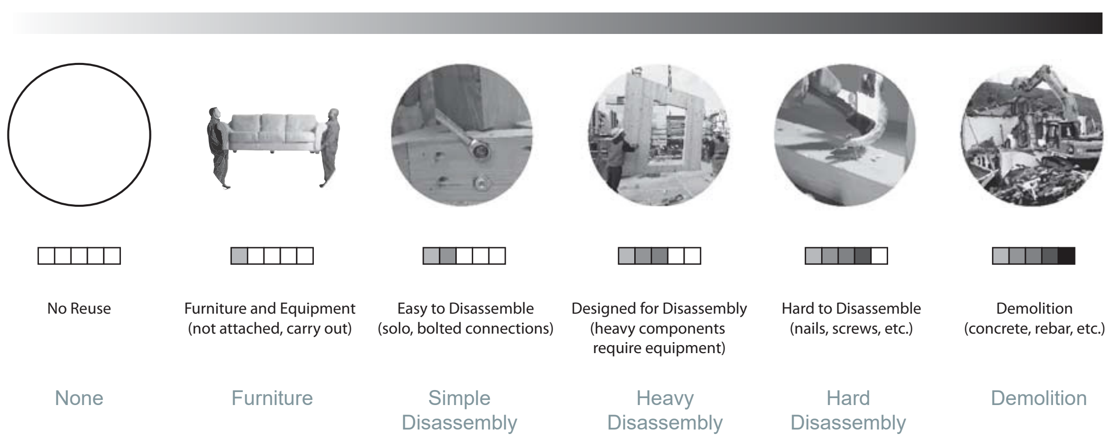
There are connectors which fall in the middle between disassembly and demolition these would be connectors like nails and gang nails most often used for timber frame and truss assemblies. These types of connectors are difficult to deconstruct because they were not designed to be removed, therefore the deconstruction of these types of members is very labour intensive and often when materials that were assembled using these types of connectors are sent to the landfill and fall into the demolition category. These types of connections also do not lend themselves to maintenance since they are not easily removed and adaptation becomes more complicated.

The complication of connections which are not easily disassembled make maintenance unapproachable and therefore not convenient for a remote property, home or business. When maintenance is built into the construction it opens up this routine to far more people.

The final category is the group of connections which are designed for assembly and therefore disassembly. These are often bolted types of connections. Often within the industry these types of connections are more costly and are therefore often not used. However, this is because the building is being designed simply as a product, without any future in mind. This is how Balkrishna Doshi thinks about housing, that it “should be seen as a process and not as a product” (Drexler 2012, 7). By using connectors that work well with disassembly it makes repairs and maintenance easier and renovation and additions are more straight forward and simple.



Stewart Brand's six shearing layers of change (Brand 1995, 15)



Levels and categories of disassembly

It is these types of connections that change the way in which a building is constructed, put together or assembled. This can become an important factor depending on who will be constructing the building. Using assembly and disassembly as a construction method opens up the actual building process to more people. As Stephen Keiran states "Assembly can be performed with rudimentary skill and just a few simple tools. Construction, on the other hand, is complex and often requires considerable skill, training and specialized tools and equipment" (Keiran 2004, 80).

Flexibility and Adaptability to Extend the Life of Materials

Flexibility and adaptability are interesting themes to explore within architecture and especially sustainable architecture. To be able to incorporate adaptable components into building culture creates the potential for components or materials to have a longer, more flexible lifespan. The notion of flexibility can be useful in architecture, however "flexibility is of no value in the absence of the resources required for execution" (Kugot 2006, 54). It comes down to architects taking on this responsibly and the role of thinking about and incorporating adaptability into their designs. It requires some forward thinking and requires looking beyond the current project and current design itself. This approach requires the architect to think about how their design will be used in the future or what kinds of lifespan they can build into the buildings components.

By building with assembled layers it allows buildings to be adaptable and flexible. Stewart Brand explains that "an adaptive building has to allow slippage between the differently-paced systems [layers] of site, structure, skin, services, space plan and stuff. . . timber-frame buildings conveniently separate structure, skin and services, while balloon-frame (standard stud construction) over-connects them" (Brand 1995, 26). He explains the benefits of separating the layers of a building, therefore allowing visual inspections of the components and facilitating repairs on all layers.

Design is the tool of the architect and I believe today more than ever with the help of digital designing, the opportunity for iterative and adaptable design is a practical approach to sustainable building. Design provides the opportunity to explore how flexibility can be built into a system and "the making of design proposals requires very little in terms of real resources, but consummating those proposals requires enormous material and energy investment" (Fernandez 2006, 298). This approach to design is more difficult to quantify to a client whose main concern is the current building at hand.

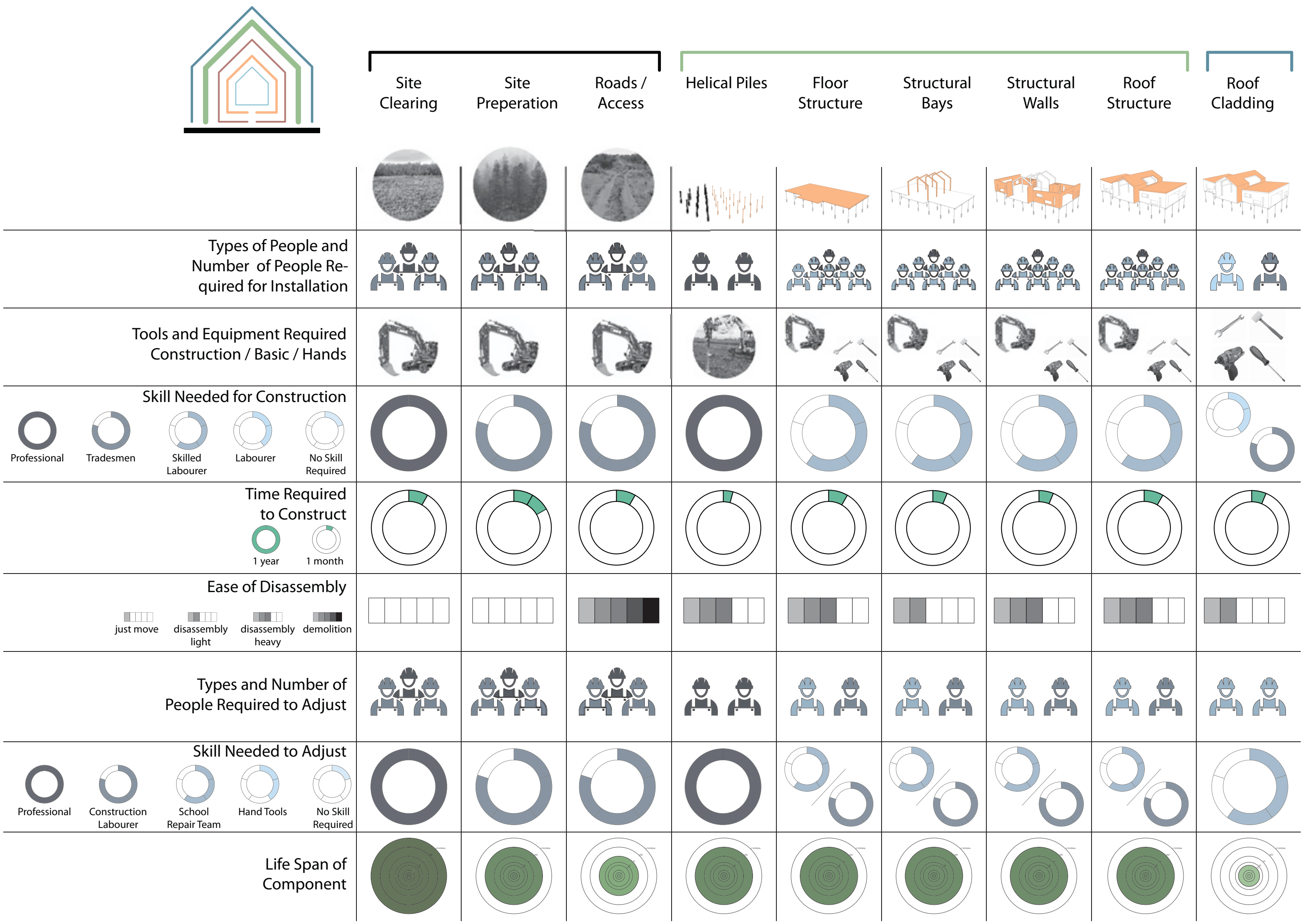
Putting time, effort into a future adaptation of a building is difficult to quantify in dollar value, however in material saved or long-term value added to the material could be substantial. Designers should concern themselves with the long-term effects and results of their building projects, instead of ending their design and vision at the completion of the building. Hans Drexler summarizes his views on this point by saying that

> Yet planning processes generally focus only on the construction of buildings, for the intentional horizon of many planners unfortunately ends with the completion of the building. This short-term vision is insufficient for the sustainability of a building. Longevity of the materials and building components play an important role . . . all this can be evaluated when the entire life cycle – construction, operation and maintenance as well as demolition and disposal – is examined (Drexler 2012, 37).

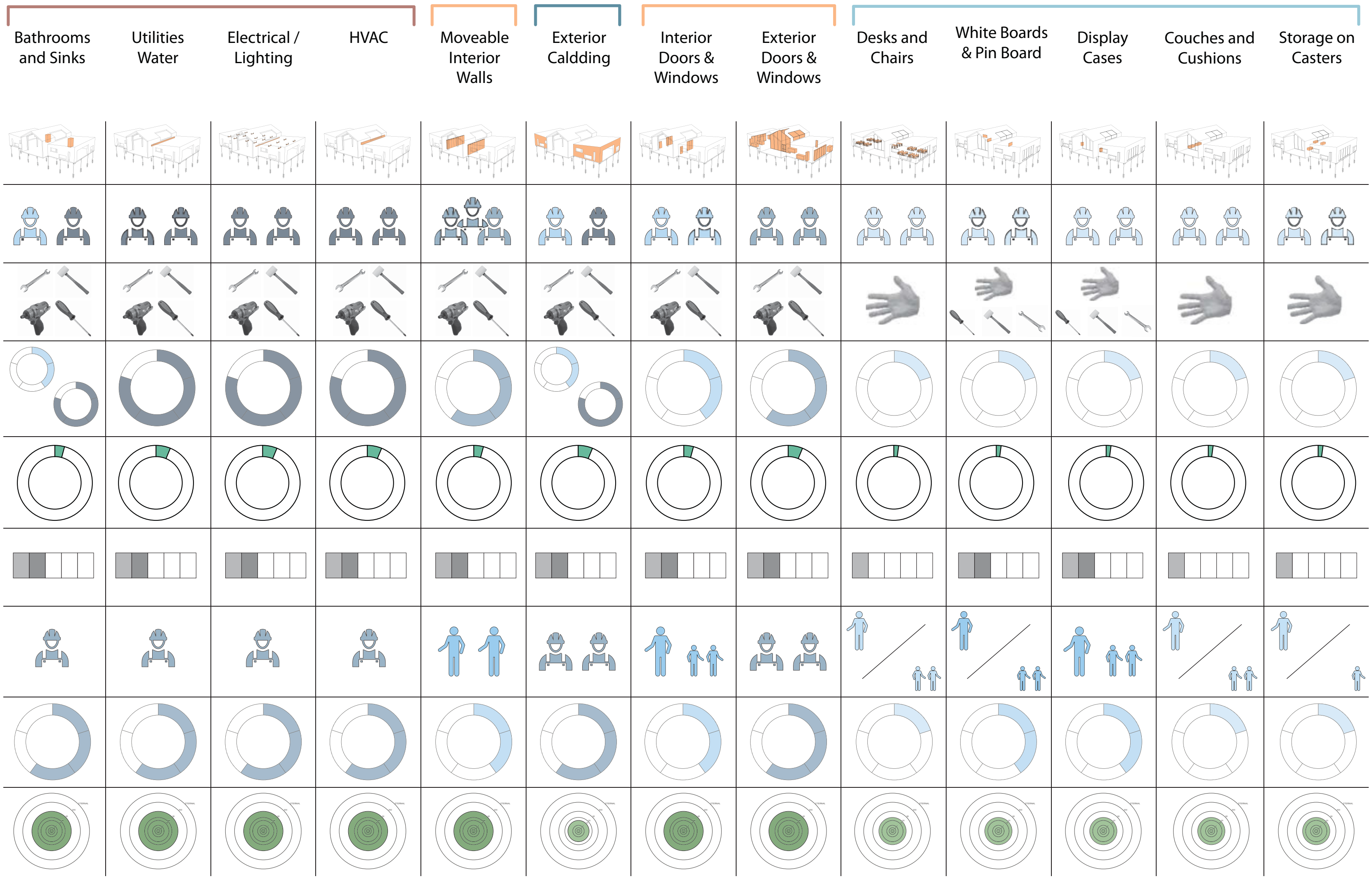
This reinforces the idea of designing with the material's lifespan in mind. Architects should consider a broader spectrum of what the building will be throughout its lifespan and ultimate conclusion. By incorporating disassembly into this timeline, the end of the building does not necessarily mean the disposal or end of the material's life.

Technology Evolution

As technology becomes an increasingly significant part of our lives, it means that more aspects of our lives are becoming 'black box' items. This is to say that we as the users do not know or understand what is inside the device and how it functions. People simply understand the inputs and outputs of the device, but are not capable of altering, adjusting or repairing the device or any of its inner mechanisms. This could also be said about the way we currently build; the inner workings of buildings are often not clear or revealed to the owner or user or in this case young students. Most of the current construction is a series of layers, building's inner workings are hidden away, which in turn also makes buildings difficult to adjust, repair and adapt. With traditional post and beam construction the structure was very clear and anyone could observe parts that required maintenance over time. Fewer layers existed in these traditional buildings, thus the maintenance could be performed by the owner. By implementing a construction system that is designed for disassembly, the owner can understand how the building is assembled and therefore how it can be maintained and simply how it works.



Construction layers of the building, describing how people will interact with them



Construction layers of the building, describing how people will interact with them

CHAPTER 5: LEARNING AND TEACHING

Learning Through Building

Teaching through making and assembly is another benefit of DfD, and this is an opportunity to allow teachers and students to learn about how the building they use daily actual goes together and functions. Davis describes traditional building culture by saying that "in traditional building, this kind of knowledge—and learning—is always present: in the reading of a piece of land to know whether it is a good place to build; in determining the layout of the building; in knowing when and how to make adjustments to the plan, or which piece of timber to use where. These subtleties, which can be described in words, can only be learned by doing" (Davis 2006, 111). This idea embodies the possibilities that can be gained by creating a building where the assembly of parts is clear and can be observed by the users of the building opposed to buildings where all connections, details and systems are concealed and covered up. By designing a building with assembly in mind instead of traditional construction there is much less skilled labour involved at the final assembly stage, therefore the users, in this case students and teachers, can assemble many of the parts themselves and through this assembly they develop a much greater understanding of their own building.

Children Learning Through Construction

When buildings are designed for disassembly, it also means that they are designed to be assembled on site instead of traditional methods of construction. This method therefore provides the opportunity for older students from high schools to participate in the on site construction or assembly of the project. As expansions of portions of the building are required high school students could aid in the assembly of these additions. This is possible because of the simplicity of the connections, which means less skilled labour is required for the assembly and can be supervised by fewer skilled labourers. This type of hands on learning is increasingly becoming part of teaching practices and provides a chance for on site experience within the school system itself.

Children Learning Through Adjusting the Building

Elementary school age children also have the opportunity to learn about how things go together and are constructed by adjusting parts of the building and furniture elements themselves. There is a significant opportunity within this project to involve haptic learning within the classroom and school. This is where design and detailing at the student level can take place. The majority of furniture within a regular school design are items that students do not adjust or interact with. Whereas if it designed for assembly then students have more opportunity to interact and learn from the items within the classroom. Within this design the concept is that the majority of the furniture or wall items (white boards, display cases, display panels and cork boards) would be attached to the wall using french cleats and bolted connections. This allows the students to adjust their own classrooms on a daily basis and learn how these items are assembled. This allows them to learn basic mechanical assembly techniques daily within their own classrooms.

Children Learning Through Looking at the Building

The way in which the building itself is assembled is another way that students have an opportunity to learn. In regular building practices buildings and rooms are usually built with the idea of hiding joints, hiding structure, hiding systems and hiding how the building works and goes together. The juxtaposition of this is designing with clear and exposed joints, structure and systems. With this there is a degree of didactic learning inherent in the construction of the building itself. Exposed systems are part of the philosophy of designing for disassembly because they are visible and therefore easier to maintain and disassemble at the end of the building's life. This also allows students to see and understand how HVAC and electrical systems actually work within the building they use everyday. By using mass timber (dowel laminated timber) the opportunity to leave the structure exposed is possible. Students can see how the building is itself held up and how it works. Exposed wood structure also lets students spend their day in an environment that feels natural, they can understand and touch the layers of material that makes up the walls within their school. By using mechanical fasteners which allow components to be assembled and disassembled also present the opportunity to expose how these components themselves are put together and held together. The idea within this concept is that if a building is assembled in a way that is clear, then it is also clear how it can be disassembled later on. If it is put together in this clear way, students are also able to learn and understand how the building is held together and they have the opportunity to understand the space they are in instead of it remaining and smooth white box.

Learning Through Different Types of Construction Drawings

Since this technique of assembly deviates from standard construction practices it provides the opportunity to create different types of construction drawings or in this case drawings for assembly. David Brett talks about how "the first industrial revolution required new graphic conventions to communicate its need for precision" (Brett 1992, 1). This shows how there was a change in technology in the 19th century which led to the invention of a completely new way of representation. Perhaps there is an opportunity to take advantage of our current technological advances in how we are able to generate designs on the computer, which would allow teachers and students to understand their own schools more clearly. These drawings can be created in a different way to be used by the owners instead of the set which would be used by a contractor. This set of drawings could contain more three-dimensional components which would make them more easily understood by students and teachers who are also trying use them as a learning and teaching tool. They would read more like a set of instructions than a set of construction drawings, these instructions could work both ways and provide knowledge as to the disassembly of the building. The instructions would be diagramed with the kinds of tools required for each step, simplifying learning and adjustments by the users.

Thorough diagrams a maintenance cycle for the school district can also be created before the construction of the building commences. This document would clearly outline the estimated life cycles of the building's materials and layers and would indicate how and when they should be repaired or replaced. This cycle would highlight the longevity of some of the building's components, detailing that many of them could have lifespans beyond that of the building, it would encourage the act of disassembly and extend the life of some of the building's key components and using them in other school projects or other buildings.

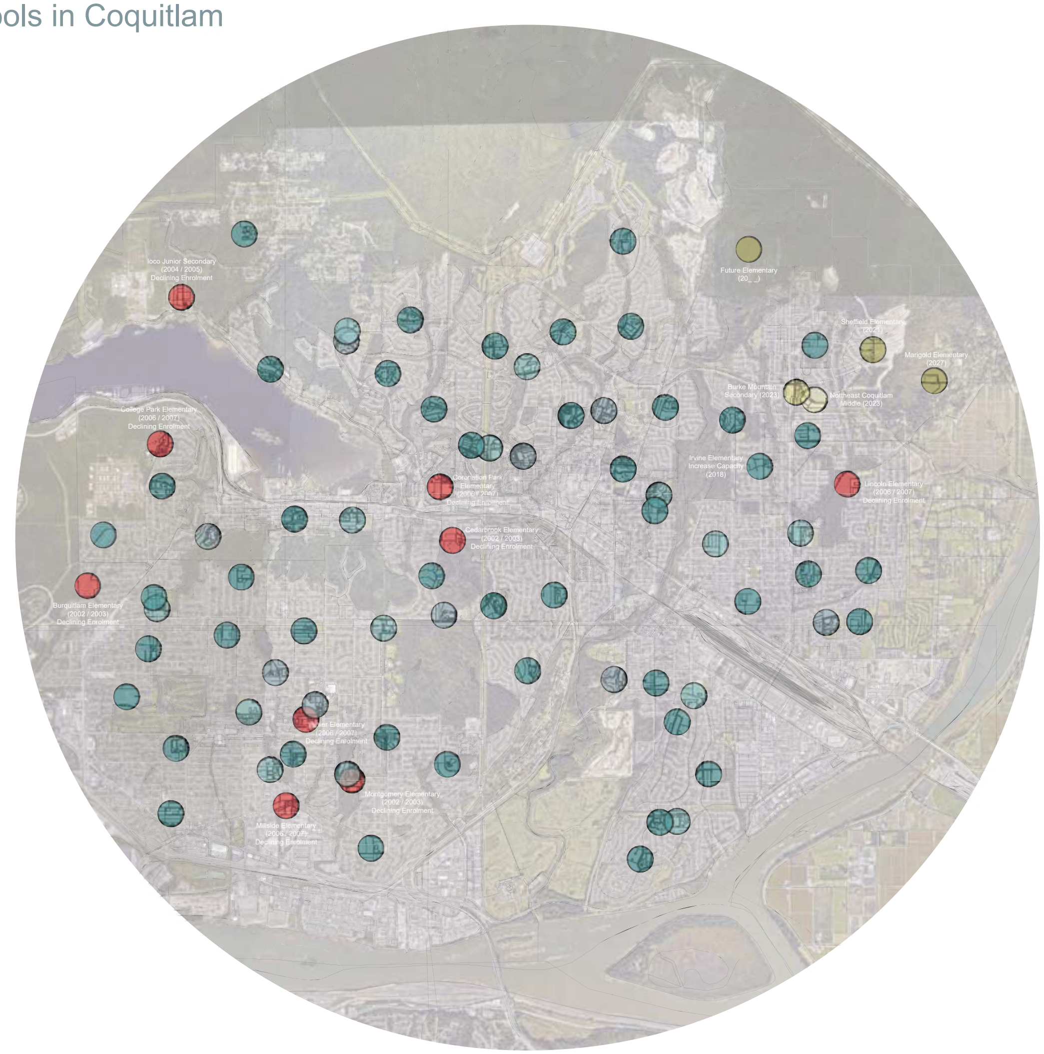
CHAPTER 7: ARCHITECTURAL STRATEGY

Reason to Test with a School

As teaching methods and classroom dynamics change, the physical schools themselves should be able to change and adjust to meet these new requirements. It is for this reason that schools are an appropriate means of testing the strategy of designing for disassembly. Schools would benefit greatly if their spaces are designed with flexibility build in. This would allow the spaces to be changed and adjusted to meet different teaching needs and different class types through different years of the building being used. Brand says that “all buildings are predictions. All predictions are wrong” (Brand 1995, 178). This is difficult for the architect to accept, however it exemplifies the fact that it is difficult to predict how users, in this case teachers and students, will want to use a space in the future. Therefore, designing a building that allows for flexibility removes some of this guess work and allows the users to adapt the building to suit their ever changing needs. Brand elaborates on this point while mentioning what he believes is the solution when he says that “architects often use a programme or brief, detailing the wishes of the potential users. But these tend to focus on what users want now. Too specific and short-term. Scenario planning avoids this” (Brand 1995, 178-181).

Within the school district of Coquitlam, British Columbia there is an opportunity to test the ideas of assembly and disassembly because of the fluctuating demographics and student enrollment within the district. The cities which are included in this school district continue to grow and become more dense, however age demographics within their borders are fluctuating at the same time which has resulted in lower student enrollment in some areas. This has led to a number of school closures over the past ten years, while other areas are seeing too much demand for student enrollment. This is especially true at the elementary school level

Schools in Coquitlam



Types of Schools, Schools that Have Been Close
and Schools that are Planned to be Built

- Elementary Schools (K-5)
- Middle Schools (6-8)
- High Schools (9-12)
- Closed Schools
- New Elementary School Planned
- New Middle School Planned
- New High School Planned

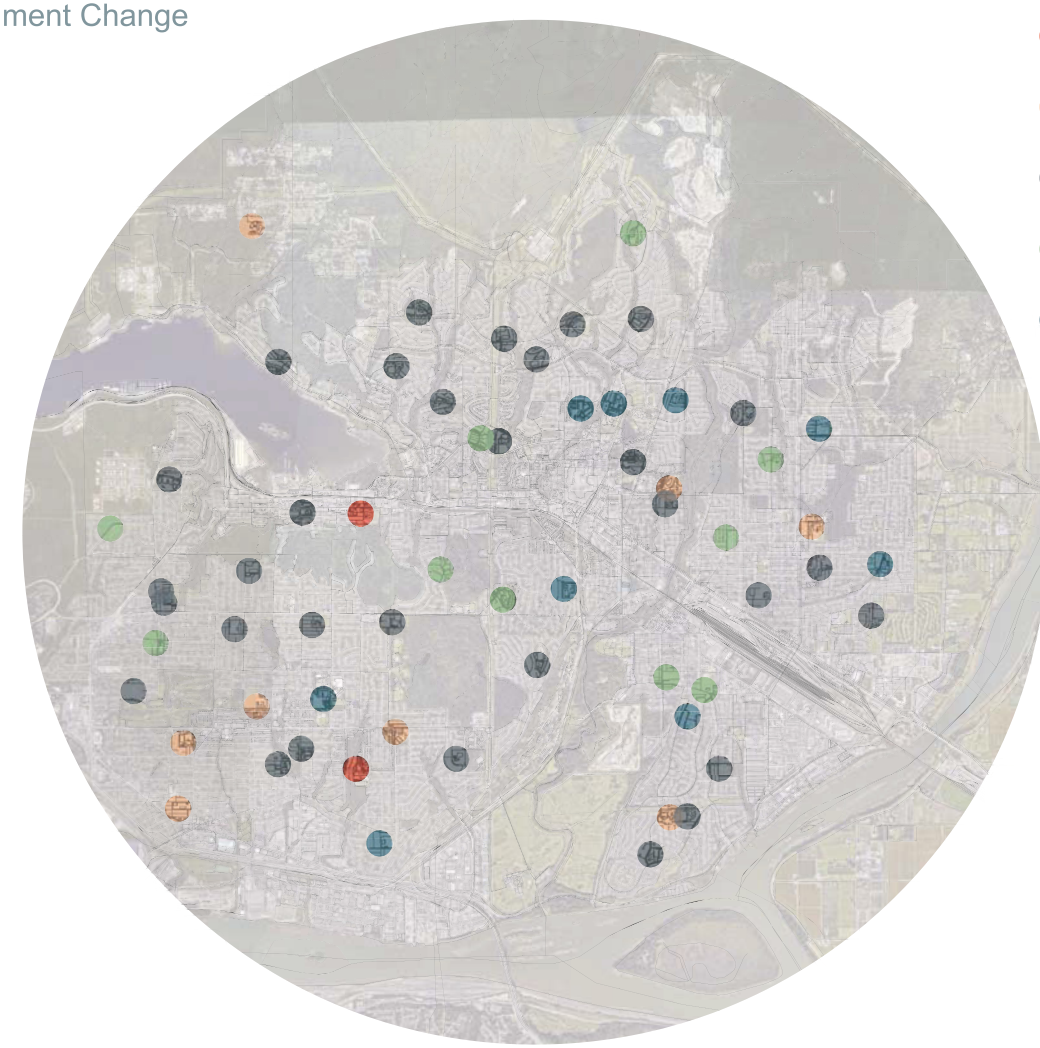
SD43 is the third largest district in terms of student enrollment in B.C. with approximately 32,000 students in 70 schools

45 elementary schools (k-grade 5)
14 middle schools (grades 6-8)
11 secondary schools (grades 9-12)
3 alternative education programs

Coquitlam Shown In Vancouver / Lower Mainland

Schools in Coquitlam (data from SD43 2017)

Enrollment Change



More than 25% Decrease

Between 10% to 25% Decrease

Between 10% Decrease to 10% Increase

Between 10% to 25% Increase

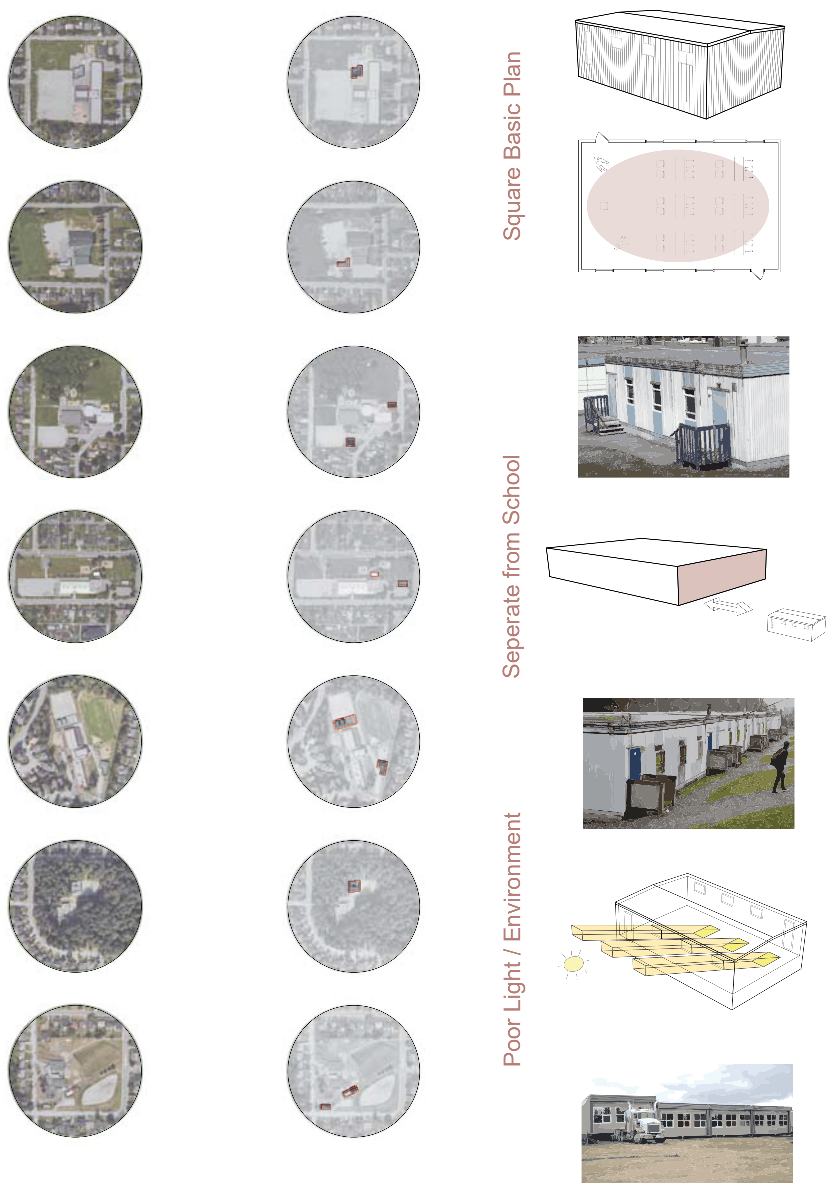
More than 25% Increase

Change of Student Enrollment in Coquitlam Schools 2015

Enrollment change in schools in Coquitlam (data from SD43 2017) which is resulting in overcrowding, long commutes to schools, low quality portable classrooms being used and new schools being built. This project works to address these issues of fluctuating school needs throughout the school district by designing schools that are easy to disassemble. This in turn means that they are expandable in a modular way that is made easier through the way they are put together. This also allows schools to be assembled on site more easily and grow to meet the quickly changing enrollment demands within a catchment area. Designing schools in this way also allows them to be partially disassembled as enrollment decreases in one area, and be re-assembled in another part of the district where they are required.

Problems with Portables

The current solution to accommodate higher enrollment than the school capacity allows is to install portable classrooms. Over half of the schools in the Coquitlam school district have extra classrooms in portables and some school districts in greater Vancouver have upwards of 700 portable classrooms to accommodate the high enrollment that exceed the school's capacity. The major benefit of these types of classrooms is that they are inexpensive, easy to install and can be relocated on a flat bed truck. However, there are also several reasons why the design in this thesis sets out to replace them as the solution to high and fluctuating enrollment. Portables are fabricated of low quality materials, which means that they are very disposable and usually discarded after a short lifespan. These low quality materials lead to a unfriendly internal environment with few windows and little natural lighting. Portable classrooms in Coquitlam remain separated from the school building, therefore they are never really part of the school itself. These classrooms are also single classroom units and do not allow for flexible classroom layouts, learning commons or any easy modifications to the classrooms setting. This design aims to maintain the benefits of portables being able to be relocated and serve as additional classrooms, however the aim is to significantly improve upon this current model through designing for disassembly. This will mean that additional classrooms and teaching spaces will be added onto the core school building, natural environmental conditions will be included (lighting and ventilation), the project will be designed mainly with wood to create a more pleasant atmosphere while also allowing for flexibility in how the teaching spaces are arranged and organized daily and yearly.



Portable classroom typologies and locations

CHAPTER 8: DESIGN

Siting of the Project

As the city of Coquitlam continues to expand on its northern boundary, the Coquitlam school district predicts they will need 5 additional schools over the next 5 years. Based on this data I have chosen a site where a proposed elementary school is planned to be built. The neighbourhood is currently being constructed by developers as a complete neighbourhood. However families are currently moving into quadrants of houses as they are competed. This means the demand for local schools will start slowly, before the planned elementary school is actually built. The proposed site development plan would be that a school core could be assembled on site when required, which could be earlier than the construction of an entire school. Since the building is designed for disassembly and designed to expand and contract, the project could expand incrementally during school breaks to meet the growing and changing school requirements.

How Teaching Has and Is Evolving

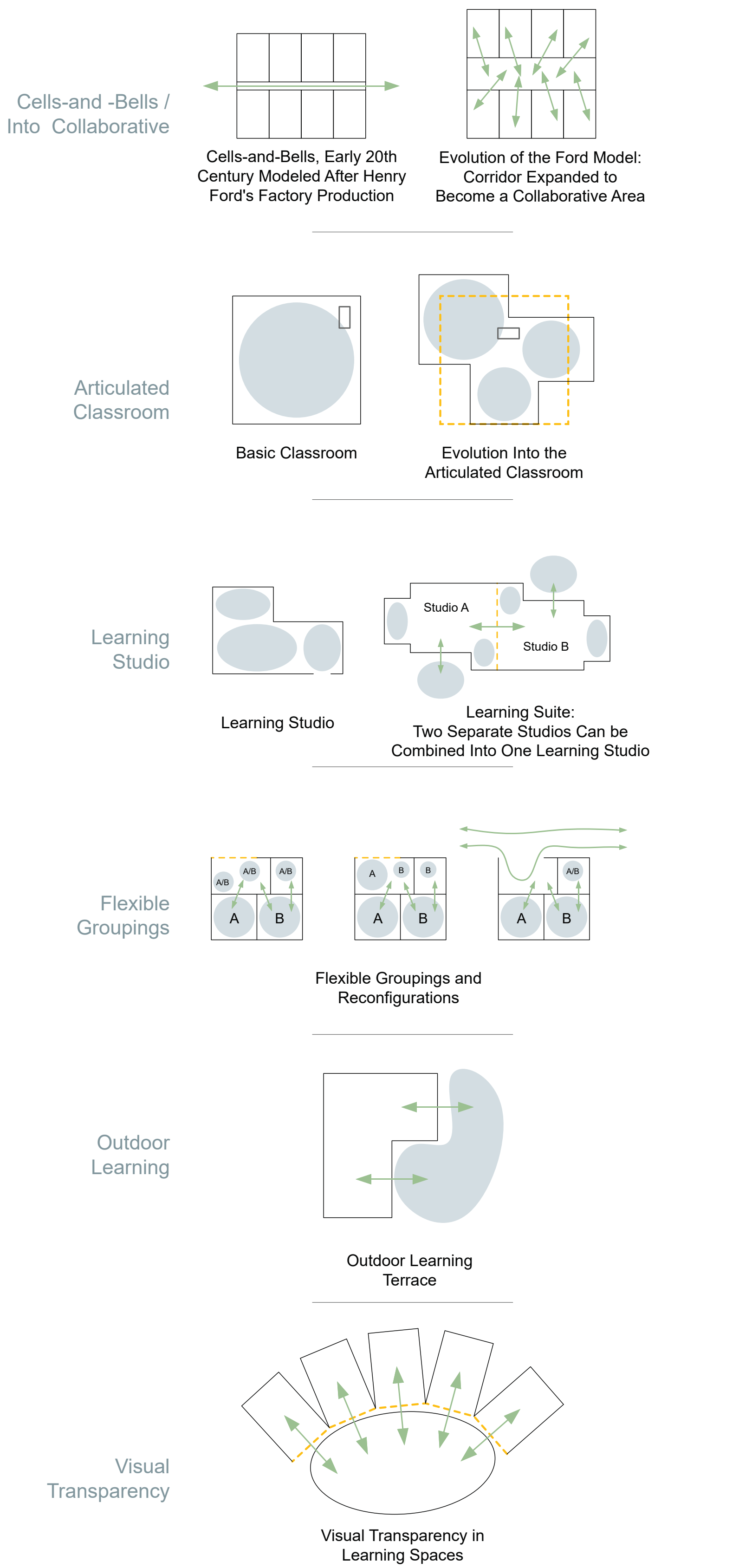
When buildings are constructed to realize the current requirements of the users they are less able to accommodate future unforeseen user needs (Brand 1995, 183). This idea becomes particular evident when looking at school designs and teaching methods. Throughout the 20th

Image of site on Burke Mountain

century school design and classroom layout changed significantly and evolved from the Ford type model based on factory layouts (Nair, Prakash and Fielding 2009, 25). Several methods of organizing a teaching space developed and they each have their own merit and are well suited to particular class dynamics or individual teacher preferences. It is this issue in particular that I addressed in the design of the project; the core structure is built with mass timber structural spanning elements which allows a large percentage of the interior walls which are non structural to be relocated and adjusted and allows them to accommodate different types of windows and openings.

Teaching methods themselves changed to an incredible degree during the 20th century and a significant shift is planned over the next ten years. Teaching has traditionally had a teacher speaking to or lecturing an entire class seated in rows in a rectangular classroom, however the emerging models are extremely different from this approach. Some emerging teaching methods include self directed teaching, inquiry based teaching with learning projects and coop teaching where classes join together. These methods lay out very different classroom dynamics where the entire class of students rarely gathers as a single group and are more often separated into smaller groups taking on very different projects simultaneously. Instead of a teacher lecturing a class, they have more of a need to supervise the class as a whole and bounce from group to group with ease. This creates the need for a learning space that is very different from traditional box classrooms and takes on the form of “learning commons” (Nair, Prakash and Fielding 2009, 27).

This project is designed to accommodate many different teaching styles by building flexibility into the building itself. Teachers area able to choose how they wish to lay out their class and learning commons while working with other teachers to create effective learning environments.



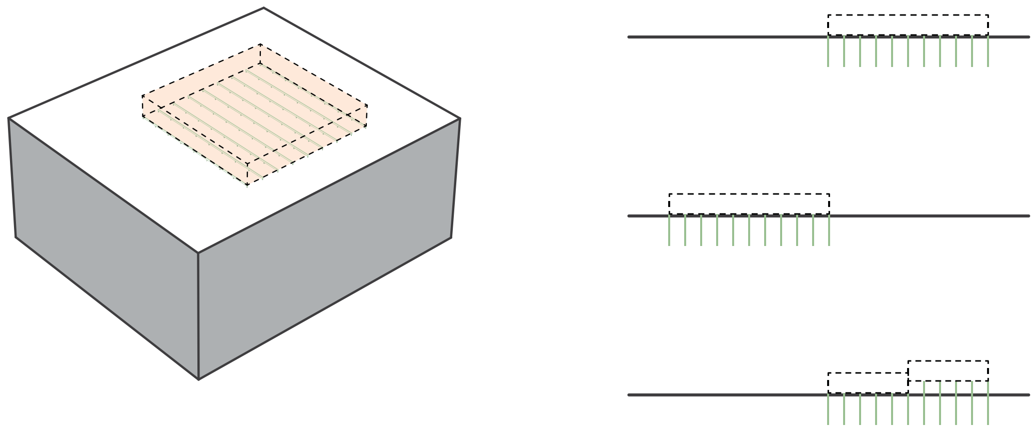
Classroom design changes and types (Nair, Prakash and Fielding 2009)

More substantial building adjustments and reconfigurations are also possible with more effort by construction crews instead of teachers. However these adjustments would still not require complete demolition and construction because wherever possible the building is designed to be disassembled and connections are left visible and accessible.

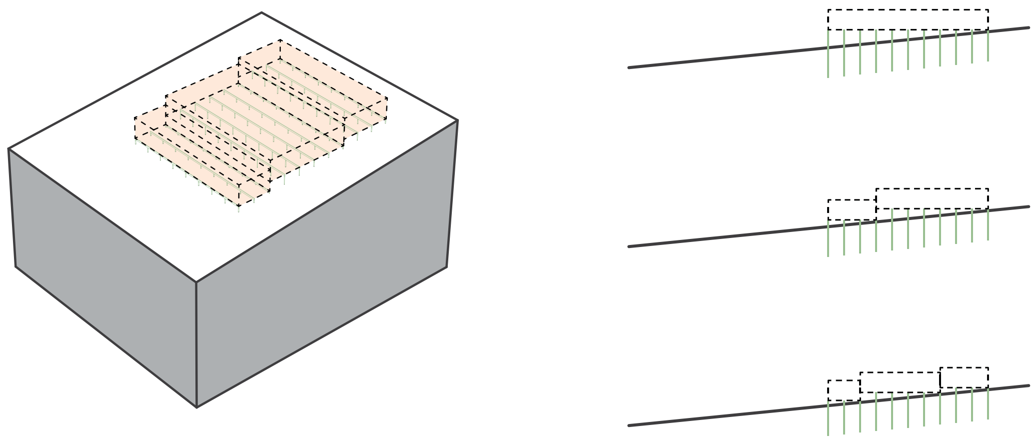
Herman Hertzberger talks about the shift in teaching styles when he says, “wherever traditional classroom-based education is not given exclusively and so the teacher is not the constant focus of attention, the need exists for nooks and niches to work in, more of less screened-off or shielded places where one or more pupils can concentrate on their own work” (Hertzberger 2008, 24). Here he lays out the basic reasoning for the articulated classroom, and why control over the spacial arrangements of classrooms is so important to remain flexible based on the students and teacher’s needs. These arrangements take on several names and configurations which include, learning commons, articulated classrooms, learning streets, learning studios, flexible groupings, outdoor learning, passive supervision and cave space (Hertzberger 2008) (Nair, Prakash and Fielding 2009). Instead of championing a particular way of laying out a classroom and school and forcing teachers to use that style for the duration the school’s existence, the approach in this thesis allows teachers to choose a layout yearly or even daily that suits their current teaching needs.

Design

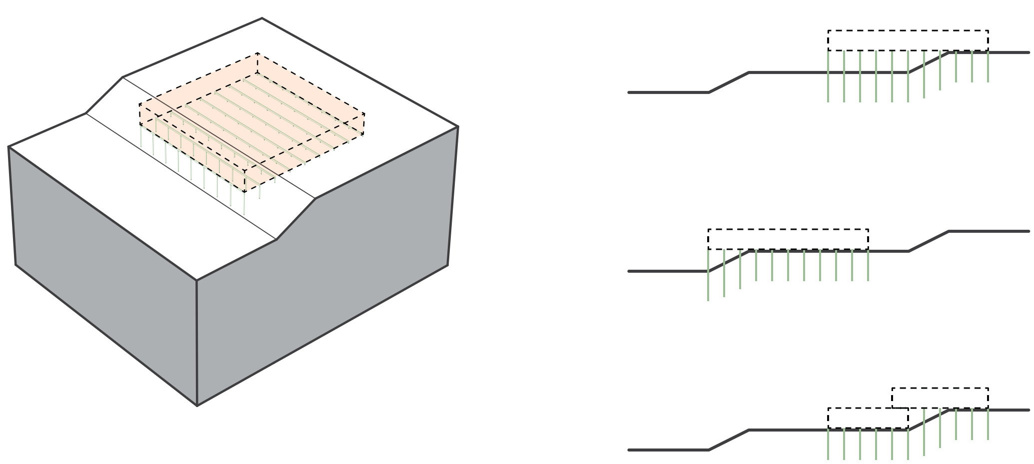
Since this thesis focuses on a system of assembling and disassembling classrooms and schools and relocating them to different sites around the district it requires a foundation system with a high degree of flexibility and adaptability. This is where the helical pile system is used. This system meets both the criteria of flexibility and disassembly because the system can be installed to create a foundation system in most soil conditions and



Pile installation options on flat site

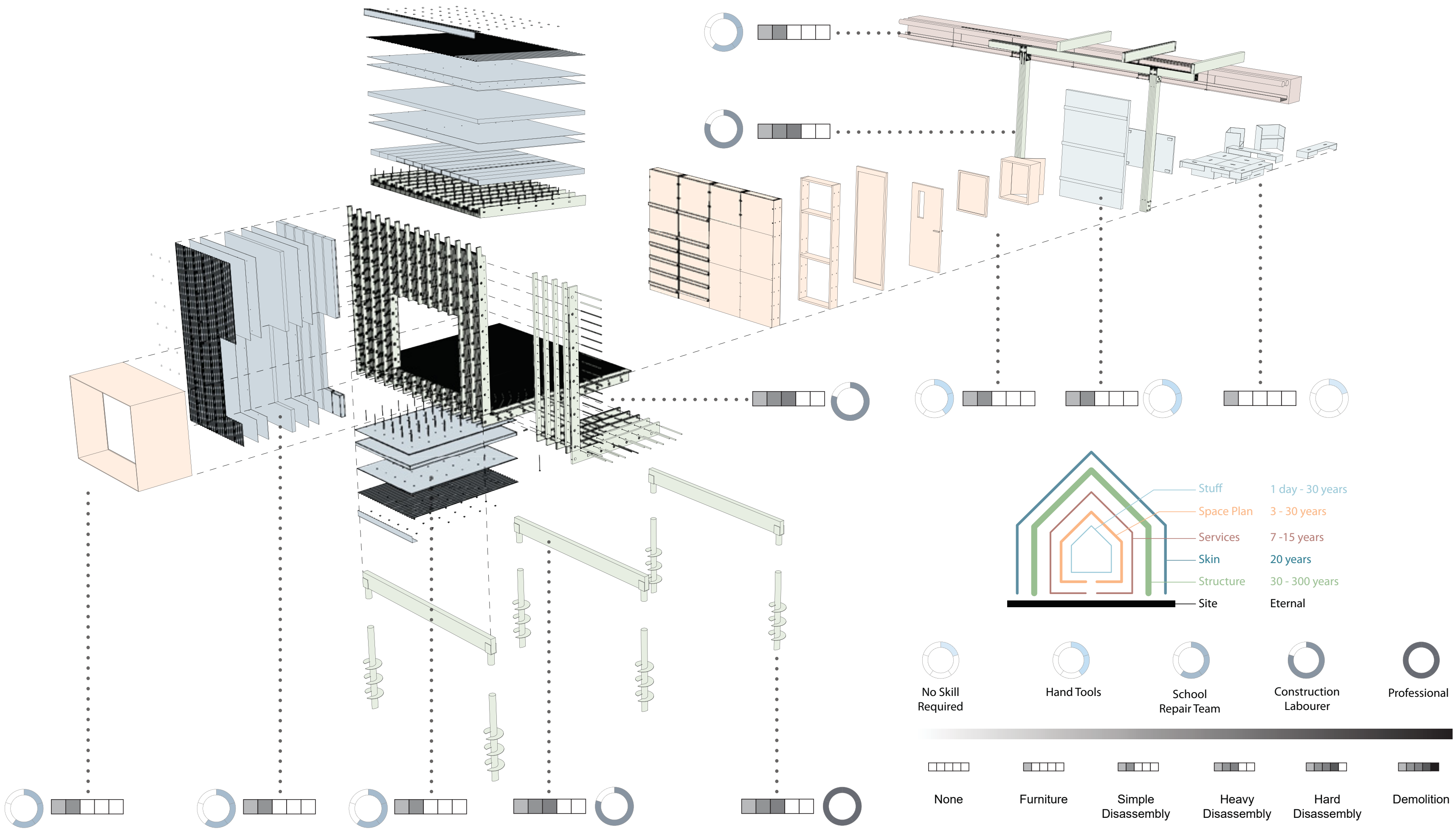


Pile installation options on sloped site

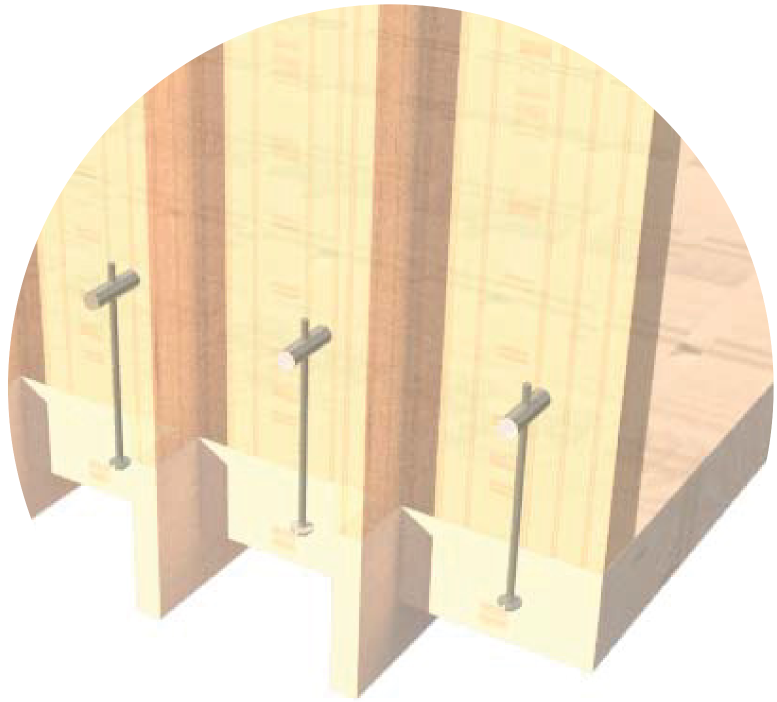


Pile installation options on stepped site can be removed to be used on other sites. Since this system can be used in most soil conditions it can be applied to all potential sites in Coquitlam and when installed it can fit all kinds of topography allowing the classrooms to be installed above.

The design works with layers in multiple ways, the structure and building envelope are layered, the levels of disassembly are layered and there are layers of how the school and classrooms function. The exterior walls are built with several layers that can be assembled with simple hand tools and disassembled for repairs, alterations and removal. The first key layer is the mass timber structure of dowel laminated timber which can be assembled in panels off-site and shipped to site ready to be assembled using mechanical fasteners. The structural panels act as the building's main structure and are assembled using barrel nuts and bolts which allow the system to be tightened on site. These panels also act as the interior finish giving the classrooms a natural wood interior and allowing students to observe what holds their building up and how the ceiling sits directly on the structural walls. The exterior insulation and cladding is then attached to the structural wall panel with a simple through bolt to avoid any kinds of screws, nails, adhesives or any connections that are difficult to disassemble later. The exterior cladding layer is a dark corrugated metal panel and the assembly is left visible for children to see where the bolts end up, which also creates a clear bolt pattern on the exterior façade. Incorporated within the exterior façade are sets of box windows, that also align themselves with the grid of the DLT panels and the grid of the corrugated cladding panels. These box windows serve to connect the inside to the outside by allowing children to sit in groups and set up reading nooks inside the classroom or in the window box on the outside of the school. These windows are also bolted into place and there is the opportunity to use different sets of windows as required by the classroom.



Exploded Axo of structure, cladding and interior walls (Brand 1995, 15)



Detail of DLT wall panel bolted to DLT floor panel

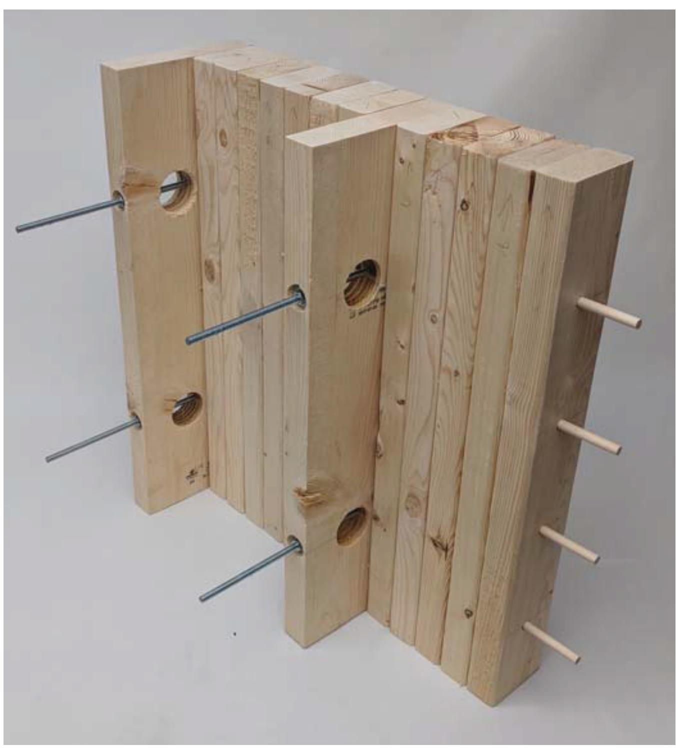
With the insulated structural floors and walls installed, the structural cores are installed for each classroom unit. These cores contain the basic necessities for the classroom units. They are built out of the same DLT construction as the exterior wall systems and are attached to the floor with similar bolted connections. These cores provide the main structural support for the roof systems while also containing the classroom's bathrooms, sinks and primary standalone HVAC units so that each classroom can operate independently.

The structural cores allow the next layer of the building, the movable walls, to move freely around the grid without requiring any thought towards their structural function because they are designed as independent elements from the structure. Within each structural bay there are four movable wall panels that can be configured in countless different ways to meet the needs of the teachers, students, school and curriculum. The walls again are bolted together and can therefore be disassembled

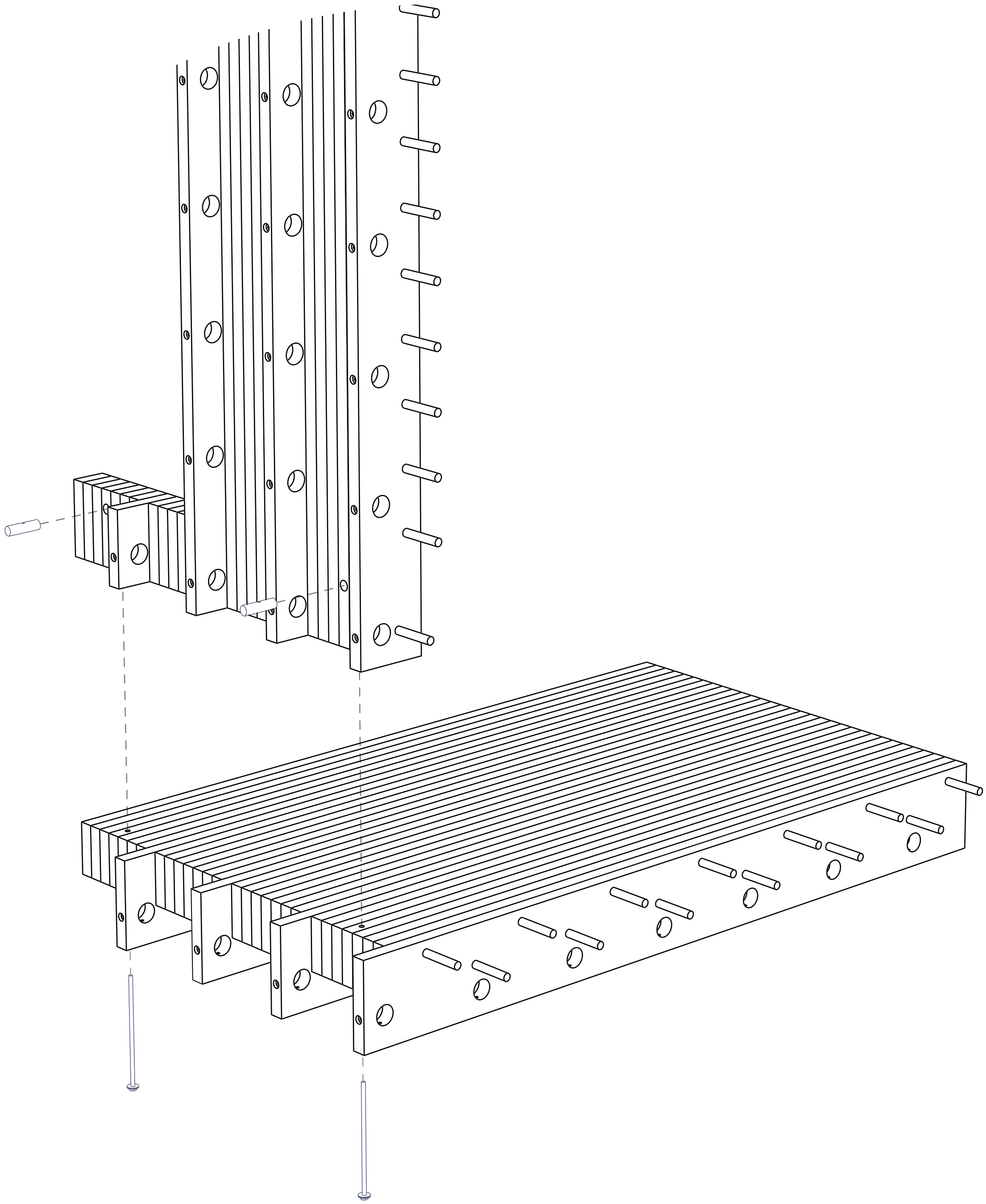
Exterior cladding showing bolt layout and window box seating

and rearranged by the students and teachers and can be incorporated as a learning exercise in itself. The reconfiguration of these walls can create different types of learning spaces and can open up the classrooms into the learning commons.

The wall panels are also entirely bolted together and three levels of plywood panels make up the surface finish of the walls. The same bolts that fasten the plywood panels are also used to attach a series of french cleats that allow classroom equipment that is usually fixed to the wall to be easily moved by teachers and students. Items that are possible to mount with french cleats and be relocated and adjusted within the classroom include white boards, acoustic panels, display cases, pin up boards, screen for video, velco boards, hangers and various shelving. By using this system that can be adjusted easily it makes teaching spaces more useful and adjustable. This also allows children to learn how these items go together and they get a sense of understanding how their classroom functions, instead of it being left as a mysterious white box.



Full scale mock up of exterior DLT wall panel (cladding, insulation layers, plywood and weather barrier layers all connected with bolted connection to structural DLT panel)

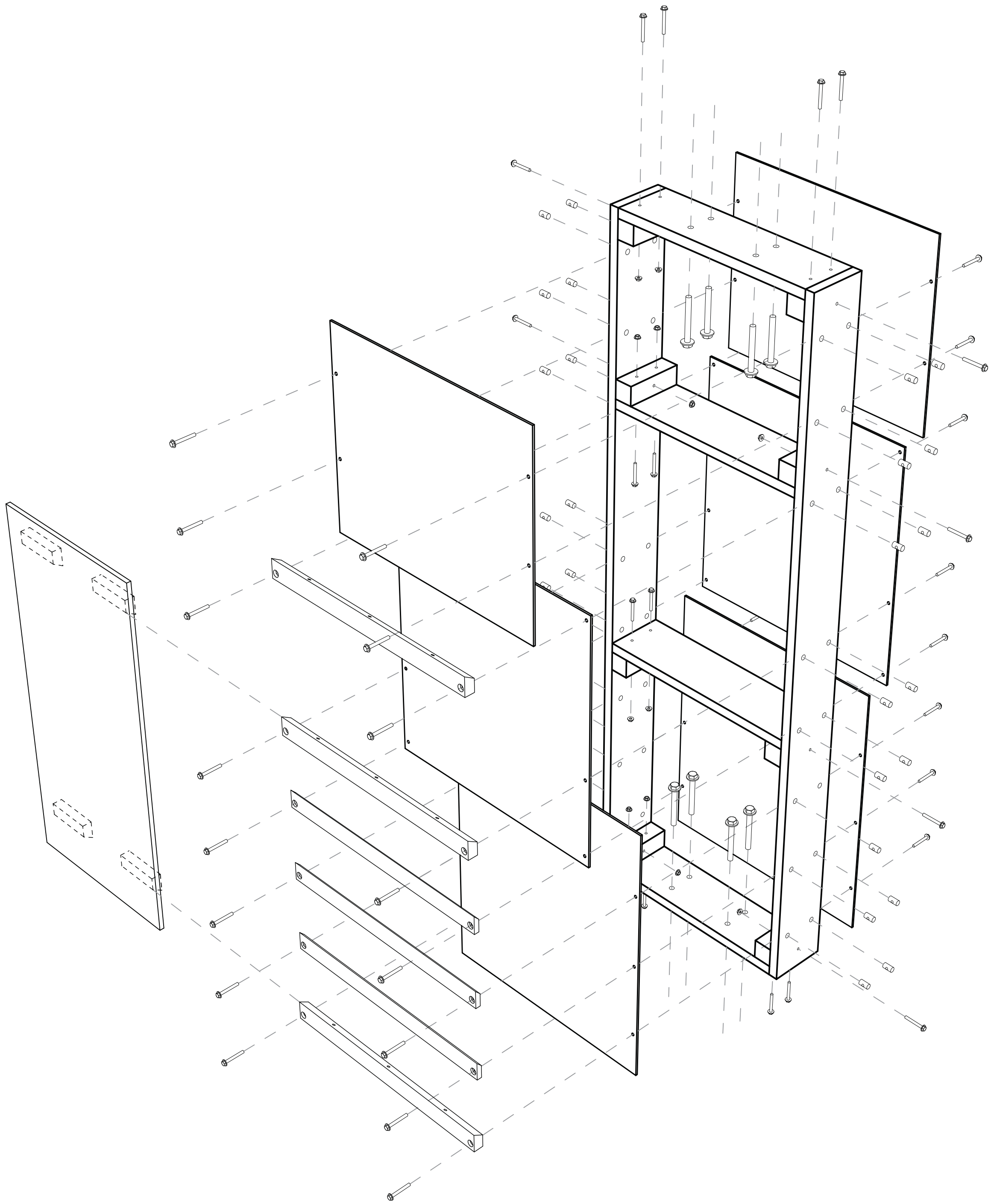


Exploded detail of DLT wall panel bolted to DLT floor panel

The wall panels are capable of supporting classrooms tools on their surface, however the plywood panels can also be removed which allows items to be bolted into the wall system. These items include doors, window

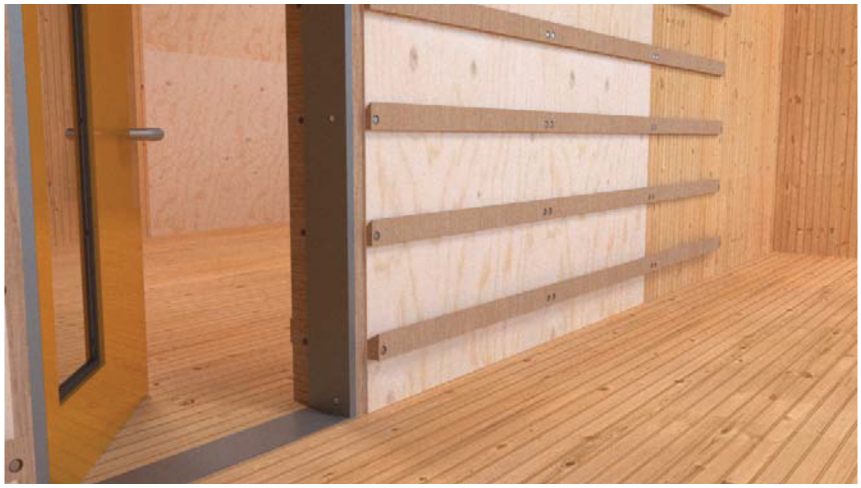
1/4 scale construction details of bolted interior wall panels and attached french cleat hangers

boxes, full height windows and display cases. Again this mode of assembly and disassembly requires only basic hands tools and can be adjusted by the teachers and students themselves which again provides the opportunity to learn from their classroom environment while also taking ownership and understanding how their built classroom functions.



Exploded detail of interior wall panel with french cleats

The aim of these different levels of flexibility and adaptation are to provide a learning environment where students learn from the building they attend daily, but also to allow the building itself to evolve with the changing methods of teaching. This flexibility is made possible through the



Wall panel with door assembly and french cleats

Wall panel with pin board mounted on french cleats

Wall panel with vertical white boards mounted on french cleats extensive learning commons that are part of each grouping of classrooms. These central learning commons can easily be visually connected to the surrounding classrooms when windows are installed in the panel walls. This allows student to break off into work groups and work at different kinds of work spaces and work stations within the learning commons while still being supervised by their teachers from the classroom. The commons are also large enough to be used as gymnasium space for students during inside lunch hour and during certain times of the day. The commons

Interior classroom with seating in box window and children adjusting the wall panels

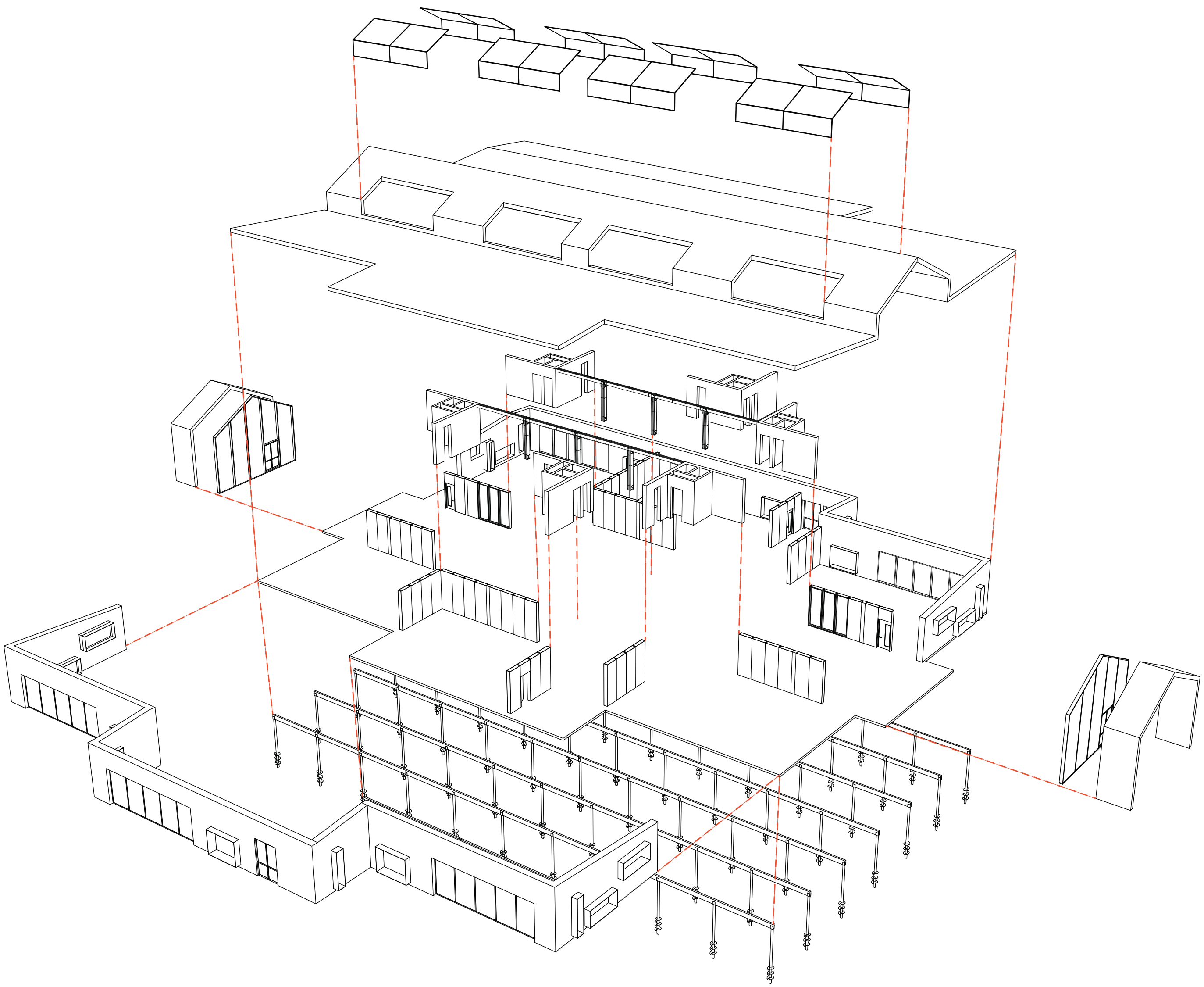
can be adjusted to suit different teaching methods, which would include spaces for small groups of students to work or read quietly in different configurations than what a standard classroom would allow. The commons can be reconfigured and unpacked to allow large groups to gather and sit together and the stage itself is located in the commons to allow for speeches, assemblies and performances. It is through an endlessly flexible building process and designing for disassembly that will allow teachers and students to adjust and cater their own learning environment to suit

Interior classroom with full height windows installed in wall panels allowing teachers to supervise the classroom and students working in the learning commons

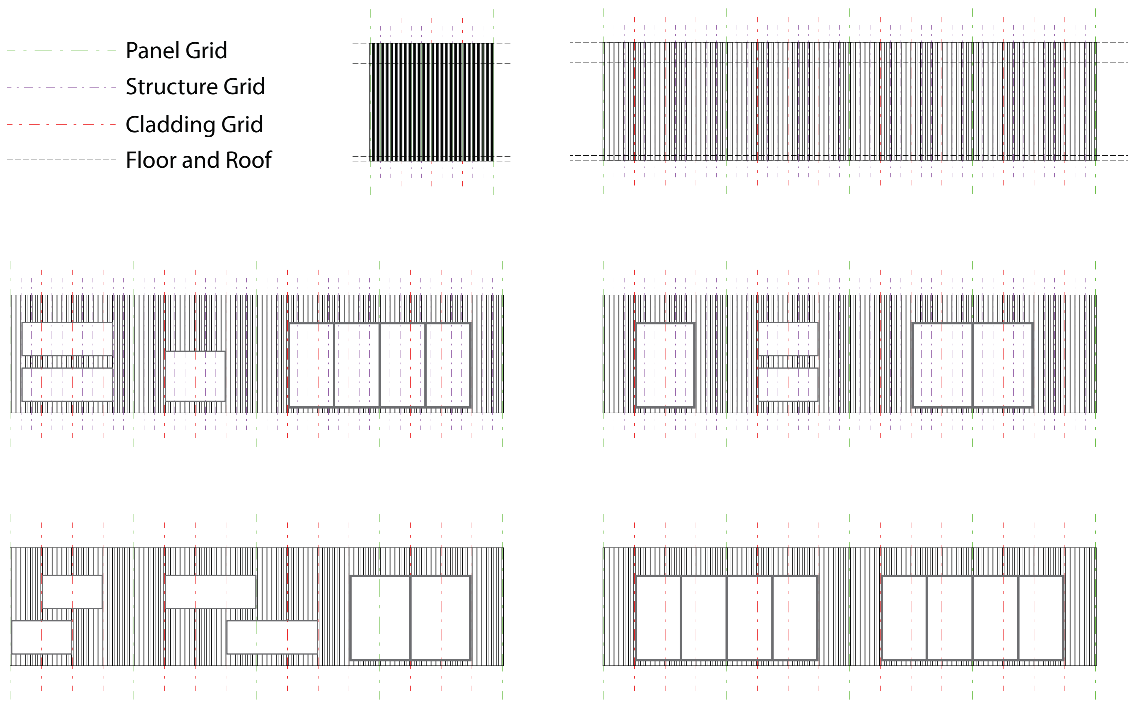
their changing needs. With this approach to building a holistic and didactic learning environment can be realized.

Alternative display cases mounted in the wall panels to allow visual connection to the classroom and learning commons while also displaying student work

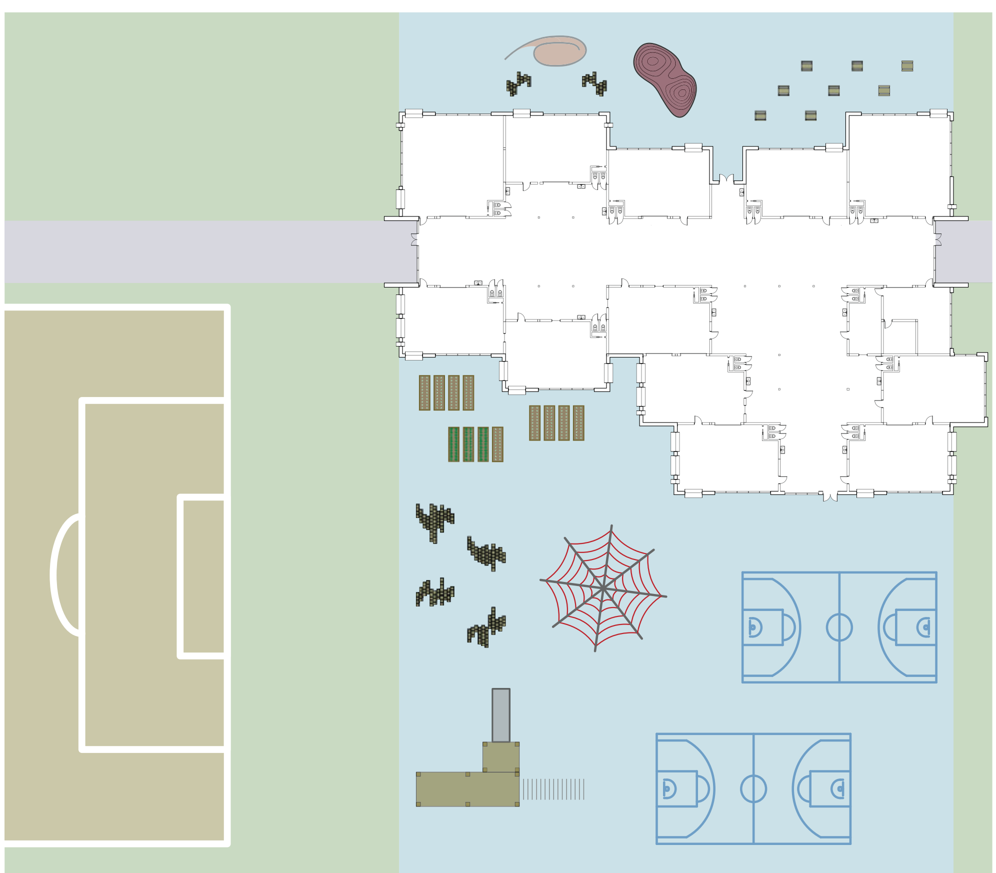
Centre learning commons and entry



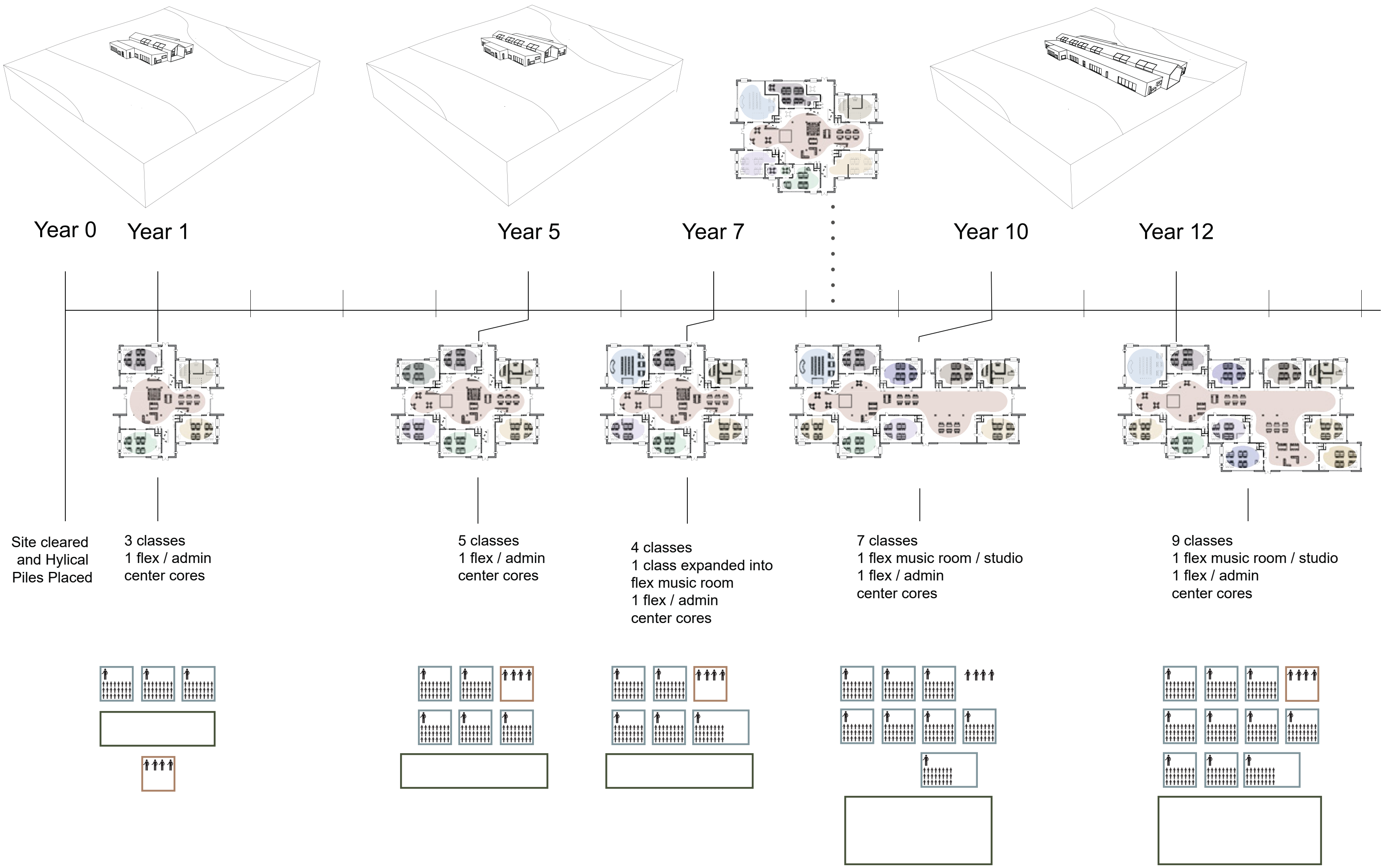
Exploded Axo of overall building scheme at year 7



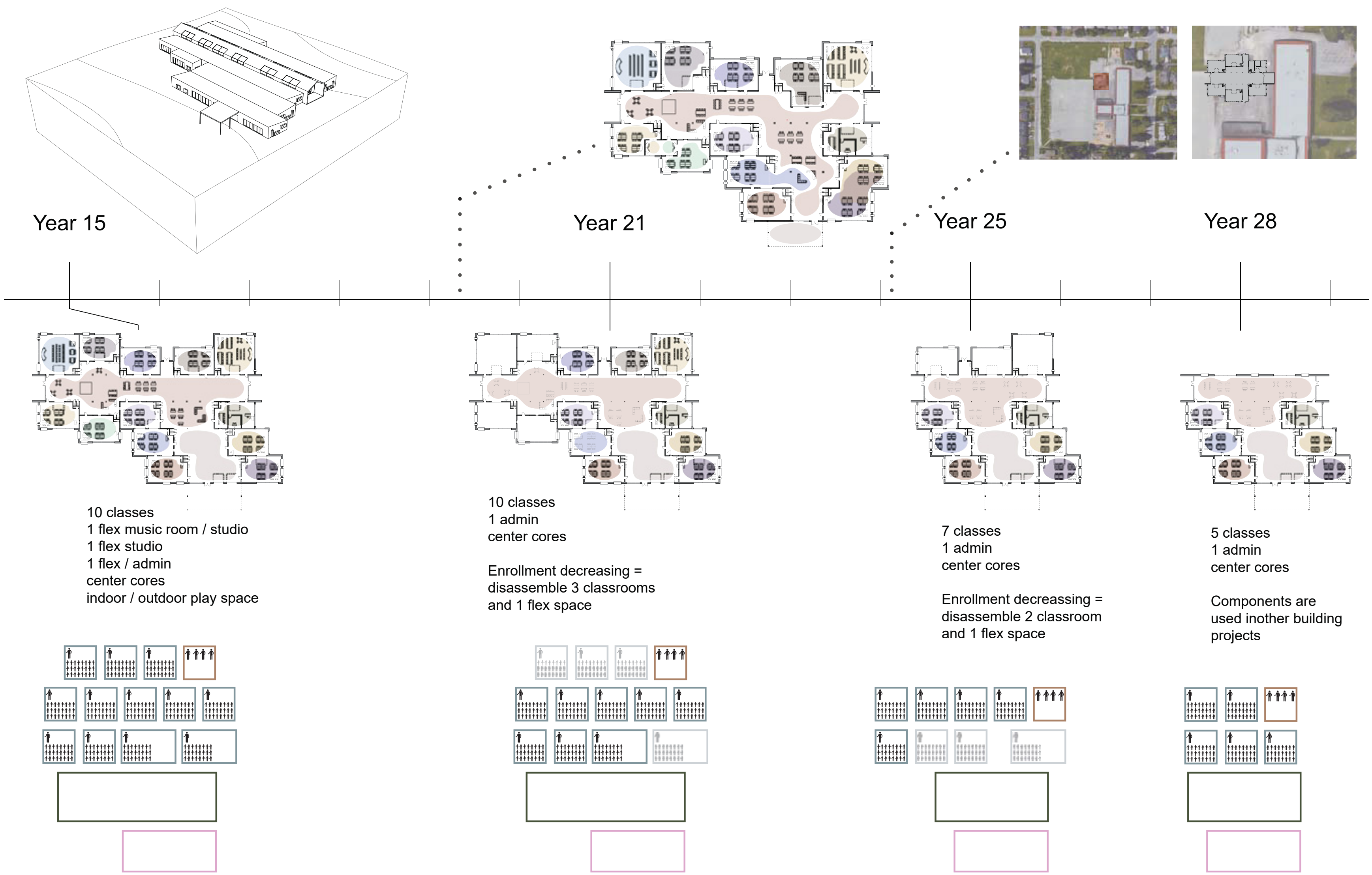
Elevation layouts (panels, structural grid, cladding panel grid and window layout)



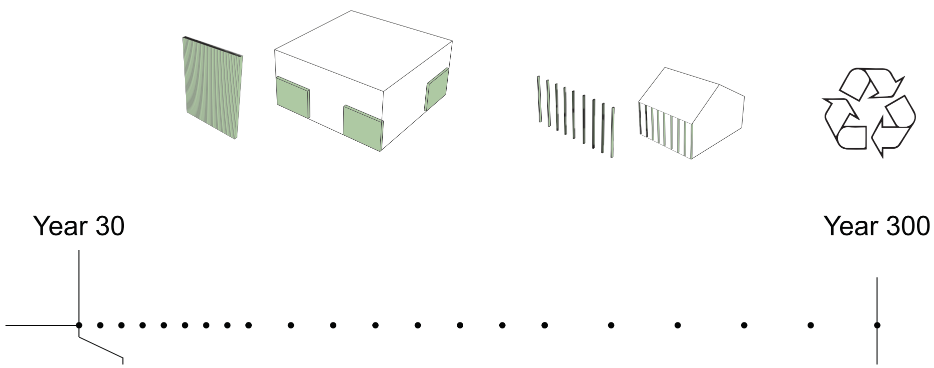
Site plan with outdoor seating, kindergarten play area, sports field, basketball courts, playground and planting boxes

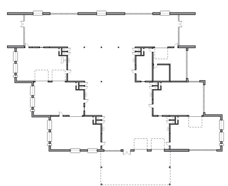


Timeline of project (associated rooms, massing models and plans showing layout changes)



Timeline of project (associated rooms, massing models and plans showing layout changes)





5 classes
1 admin
center cores

Components are used in other building projects

0 classes
0 admin
0 center cores

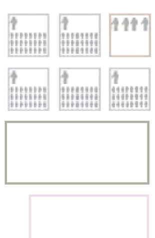
DLT Structural System is used in other project

0 classes
0 admin
0 center cores

DLT Panels are disassembled and dimensional lumber is used as structure in new building

0 classes
0 admin
0 center cores

Natural materials arerecycled @ end of life cycle



Timeline of project (associated rooms, massing models and plans showing layout changes)

CHAPTER 9: CONCLUSION

Designing for disassembly could have a significant environmental impact on the building industry, utilizing the actual lifespan of building materials instead of simply disposing of them when the building itself no longer has a use. This involves designing so that components can be disassembled instead of demolished as is common today. This can be accomplished by designing architecture with an extended timeline in mind, a timeline which extends far beyond the completion of the initial construction itself. A part of this approach would be designing buildings in which repairs on all layers of the building can be easily carried out and designing for flexibility. Flexibility becomes especially relevant for schools as teaching methods evolve and class dynamics change it allows school spaces to be easily adjusted. Flexibility in the way a room can be arranged and flexibility in how students interact with the space can make a school more useful moving forward because of its ability to adapt with the changes. Designing for disassembly also allows for schools to be expanded or relocated to meet the fluctuating nature of demographics and thus student enrollment throughout a school district. This addresses the problem of using portable classrooms and closing and opening schools within the same city as needs change. The focus on initially assembling the building also requires less skilled labour which means that less time and man hours are required on site. There is the potential for components to be made off site and simply assembled on site when there is a break in the school year. Having a school where its structure, systems and methods of assembly are clear and visible also create the opportunity for children to learn didactically from their environment. This is enforced by the statement by Nair when he says “transparent architecture and engineering systems are ideal in a learning setting because they can engage students’ imagination and spur learning about buildings as 3-dimensional textbooks”

(Nair, Prakash and Fielding 2009, 164). By approaching buildings from a direction of assembly and disassembly it is possible to reduce the environmental impact of construction while allowing users (students and teachers) to understand their own buildings more thoroughly and allowing for the buildings themselves to evolve and change through their lifetime. Christopher Alexander talks about how architects view buildings and says "there is a real misunderstanding about whether buildings are something dynamic or something static. The architect has such a narrow niche. Anything different from the idea that you make a set of drawings and someone else builds the thing is incredibly threatening" (Brand 1995, 112). Thus, changing how we view buildings and looking at them as a dynamic changing process over time instead of a static frozen ideal unoccupied piece of art, the interactions throughout the lifespan of a building can change significantly and architecture's impact on material resources can be greatly reduced.

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