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Sustainability of precast sandwich panel

Possible development towards Korean market

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The aim of this Bachelor's thesis was to introduce the precast concrete sandwich panel to the Korean construction market by comparing precast and cast-in-situ concrete construction. Of all precast methods, the sandwich panel was chosen because it can be applied to different types of structural system. To provide a comprehensive comparison, Finnish sandwich elements and general cast-in-situ wall in Korea have discussed in general construction efficiency. Furthermore, interviews were conducted with field experts to get an overview of the present Korean situation. Also, scientific papers were studied to support the possible solution for the market.

The final year project resulted in a thesis that explains the advantages and disadvantages of precast concrete in Korean construction market. The panel has potential, but as long as labour is cheap, cast-in-situ will be strong in the construction market. However, the environmental impact on construction field changes the situation.

The thesis can be used as a background document if a company wishes to expand to the Korean, or indeed any market in the region.

Keywords	Prefabricated construction, precast concrete sandwich panel, Korean construction market, environmental impact, sustainability.

Contents

1 Introduction

Environmental impacts of products are a global issue and construction is not an exception. Environmental consideration of industries has been affecting regulations and standards of construction. Some of the European countries have started to require building efficiency certificates to grant a building permit. This environmental consideration of construction is, however, very new. Therefore, some countries are not familiar with the notion yet.

For instance, in Asia, the construction market has not seemed to be interested in the environmental impact issue as much as the European market. However, the Asian market is not able to avoid the world trend. In Korea, the recent update of the national building code shows their interests in the environmental impact.

Recent research claims that efficient construction yields a better environmental assessment result and also better building performance. The most common construction methods, cast-in-situ concrete construction, and precast concrete construction are compared in this thesis. Each system has their advantages and disadvantages. The relation between the systems and their environmental impacts is discussed in the background chapter.

The markets of the precast and cast-in-situ systems differ. The European market has invested in sustainable construction earlier than the Asian market, so the Korean market is studied and discussed for possible implementation for sustainability.

The main research method is literature study. A simulation is made for the environmental impact on different wall systems according to both the Finnish and Korean building code. Samples are collected from product manufacturers' or construction consulting companies' websites or brochures. Some of the product information is used on a general level but the actual performance of the products cannot be assured in this paper. Conversation and interviews with experts in the construction market are not recorded or transcribed. Some of the discussions are only in Korean.

Internet sources and manufactures' information are treated carefully not to be biased. Published papers are noted in the reference. Some of the references are available only in Korean. The procedure of translation may cause misconception. Therefore, this paper is not liable for any direct, consequential or incidental damage or any claim by the reader out of using the information. In all cases, only the reader is responsible for the implementation of information.

2 Background

There are many structural systems in construction projects, such as skeletal frames, shear walls or the mixture of hybrid systems. The construction methods also differ in materials that can be steel, wood, and concrete. Concrete has for long been the most common material in building construction. Concrete has several advantages for construction, for instance, it is flexible to shape and has the strength for stability with long service life. Concrete is a composite material. The characteristics of concrete vary depending on the cement and aggregates types and their quality. Designing and constructing concrete buildings require complicated management. (Alfred et al, 2001;Betoniteollisuus Oy; Brzev, 2011;Kim et al, 2005)

There are two main methods to use concrete in construction, cast-in-situ concrete, and precast concrete construction. The main notion of the division of the two methods is how to cure the concrete. Concrete is a composite material that contains water for the material to have liquidity, which proves flexibility of concrete. Therefore, concrete reaches its service strength when it dries up, The drying is called curing. In the cast-in-situ concrete construction, concrete materials are treated on site, whereas, in the precast concrete construction, concrete materials are treated in factories. (Alfred et al, 2001; Brzev, 2011)

The cast-in-situ system is like building a sand castle, whereas the precast system is like building a block house. In the cast-in-situ construction, concrete work involves skilled labour for ensuring the quality. Installing the mould for the concrete is very delicate so that than the concrete would be poured into the mould. Curing takes time, in most of the countries y haves regulation for the curing time period, usually 20 to 28 days. Because of the curing process, the cast-in-situ system attains a more monolithic structure, which has fewer joints, compared to the precast system. In the precast system, the concrete elements are treated in the manufacturing workshops. The precast system requires a delicate design of the elements, i.e. mean precast concrete building parts, and their joints. (Alfred et al, 2001; Brzev, 2011, Kim et al, 2005)

The precast system and cast-in-situ systems have both advantages and disadvantages on construction. The following chapters discuss the general usage of each system, a comparison of them, their environmental impacts and also a case study of both the cast-in-situ system and the precast system in China.

2.1 Construction system

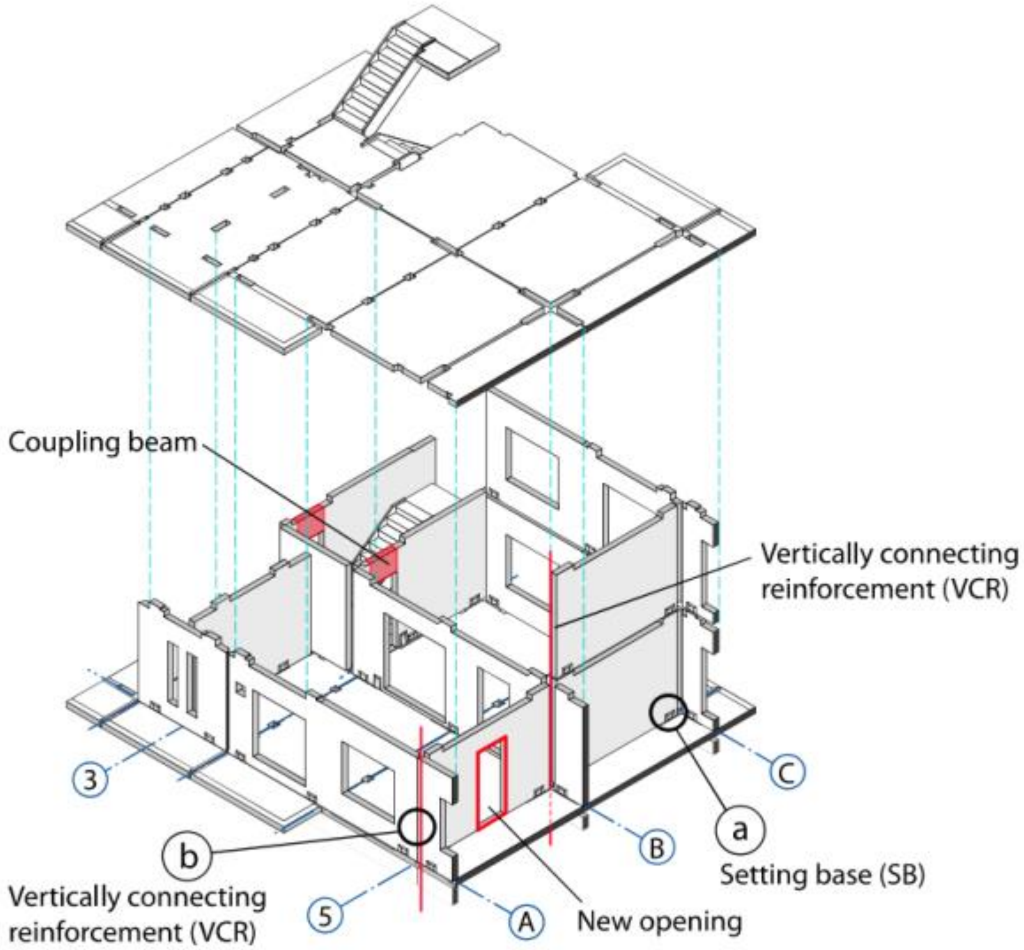
The cast-in-situ construction is preferred in some markets, such as in China and Korea. There are many aspects, which influence the trend of the market. Both countries have cheap labour. The cast-in-situ construction requires more labour on the site than the precast construction. Increasing labour costs have started to affect the construction market so that less and less skilled labour is available with cheap price. As a result, the market starts to show interest towards the precast system. (Cao, 2015; Kim, 2005)

The period of construction is closely connected to the cost of the project. Because of that, the precast construction system was developed to shorten the construction period. The cast-in-situ system requires more time and labours compared to the precast system. For instance, in the cast-in-situ construction, concrete work requires many raw materials, such as cement, water, aggregates and also reinforcements, and each of them needs suitable management, whereas, in precast construction, most of the concrete work is done already when the products are delivered to the site. Assuring concrete quality is important for the stability of the building. In the cast-in-situ system, the quality of the concrete is dependent on the skilled labour on site, and on the curing time. The precast elements are usually assured by the manufacturers. (Alfred et al, 2001; Liu et al, 2013)

The advantages of the precast system is obvious compared to the cast-in-situ system. When the building is built, in cast-in-situ construction, it requires skilled labours to fulfil the quality of the building and it takes a longer time for erection with complicated material management on site. Less construction material handling on the site can lead to reducing waste assumption. Also, the company where they provide concrete can recycle leftover material efficiently to other productions. The precast system erection requires cranes and less labour to check the location of the elements by design. The precast elements are all cured and ready for assembling on site, so only the joining of the elements is left as site work for precast system erection. (Brzev et al, 2011; Cao et al, 2015; Einea et al, 1994; Kim et al, 2005; Liu et al, 2013)

The joints of the precast system is usually the main reason why the system is used for low-rise buildings and avoided in strong seismic regions. However, Japan and New Zealand, where seismic forces are strong, are two of the leading countries using the precast system commonly. (Einea et al, 1994; Liu et al, 2013)

The precast system demands a complicated design process compared to the cast-in-situ system. In the cast-in-situ system, the quality of the building is made on the site while in the precast system, the responsibility lies with the building designers. As a result, the time span for the design process of the precast system is longer than that for the cast-in-situ system, and that is why the system has a reputation of high costs for the design. (Armbruster et al, 2012; Einea et al, 1994; Li et al, 2014; Kim et al 2005)



Kuvio 1. Composition of wall type precast concrete element (Takagi,J., Minami,S., Kitayama,K., 2012)

In some countries, the precast system is developed as prefabricated construction. Prefabricated construction means that the building elements are manufactured off site and assembled on the site. Because of that, in some markets it is called off-site construction. The prefabricated construction method is used in not only concrete construction but also steel and wood construction. However, for the concrete construction, only the precast system is able to achieve the notion of the prefabricated construction. Figure 1 shows precast element composition of a building. In figure 1, the structure has a shear wall system, which has walls as a load bearing structure. (Alfred et al, 2001; Brzev et al, 2011)

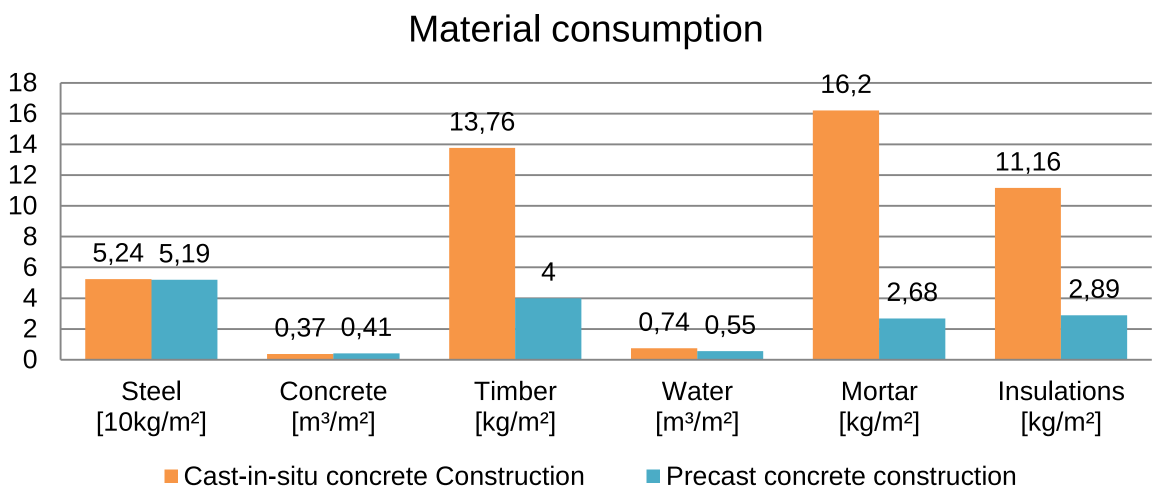
The benefits of prefabricated construction are not only about the cost but also the environmental impact of the construction industry. International standards and regulations have been updated towards better efficiency with less environmental impact. Energy and material management of construction projects is important for financial reasons and for the sustainability of the construction. There are studies about prefabricated construction showing that it has less environmental impact than the cast-in-situ construction. (Alfred et al, 2001; Li et al, 2014)

2.2 Case study

Cao (2015) made a study in China that compares the cast-in-situ system and the precast system with the similar size of the residential buildings, which both have 9-storey. The construction area of the precast system is 23,068m^2, and the construction area of the cast-in-situ system is 23,401m^2. Cao uses the word 'the traditional system' for the cast-in-situ system, and 'the prefabricated system' is used for the precast system. Cao claims that the precast system construction has the advantage of energy consumption and material efficiency. The life span of the material and structure of the buildings differ according to the quality of construction. (Armbruster et al, 2012; Cao et al, 2015)

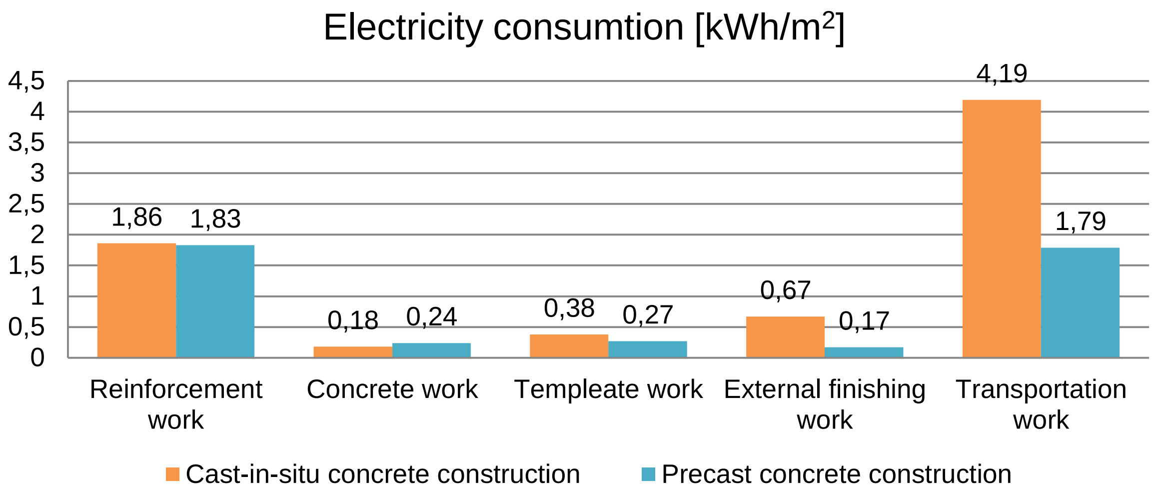
The cast-in-situ system construction consumes more material and energy to fulfil the building quality. The process of managing the site takes more effort and labours compared to the precast system construction. For instance, the thermal insulation of the external wall is treated differently in each system. In cast-in-situ construction, insulations are added after the curing of the structure. It demands delicate management because the insulation material is sensitive to moisture and dirt on site. The process of attaching the insulation requires skilled labours to fulfil the lifespan of the external wall and structural stability. Nevertheless, the lifespan of post-attached insulation is 25 years. The maintenance of the insulation also requires high-skilled labour. (Cao et al, 2015; Department of the Environment, Community and Local Government of Ireland, 2015)

In the precast system construction, the external or internal insulations are attached to the precast elements in the manufacturing process. Therefore, insulation material handling on the site is not necessary for the precast system construction, and it also results in reducing waste. The precast system saves over 70% of thermal insulation compared to the cast-in-situ system. The precast element insulation has 50 years of service life. A precast element may be produced for internal or external purposes with built-in appliances, such as door frames, windows, electricity or plumbing openings. (Betoniteollisuus Oy; Betoniteollisuus Ry, 2015; Cao et al, 2015; Elematic et al)



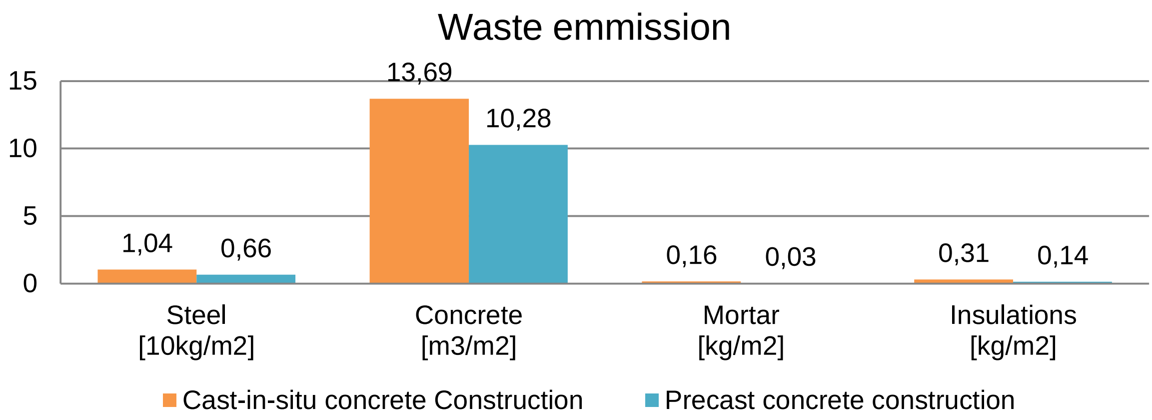
Kuvio 2. material consumption comparison between Cast-in-situ concrete construction and precast concrete construction (Cao, X., et al., 2015)

The precast system has significant savings on material efficiency, waste generation and greenhouse gas emissions that are the main aspect for environmental assessment evaluation. Figure 2 shows the difference in material consumption between the traditional construction, the cast-in-situ system, and prefabricated construction, the precast system, in Cao's study. In the precast system, approximately 10% more concrete is used than in the cast-in-situ system but more of all other materials are used in the cast-in-situ system in general. In cast-in-situ system construction, structural moulds are made of wood and in the process of the construction, the mould it tends to break or be spoiled easily. In the precast system, the moulds are made of steel and their lifespan is much longer than that of wooden moulds. Mortar is saved because it is only needed for joint filling. The quality of precast mortar may need to be better than that of mortar in the cast-in-situ system for the stability of the element joints. (Cao et al, 2015)



Kuvio 3. Electricity consumption between Cast-in-situ concrete construction and precast concrete construction (Cao, X., et al., 2015)

Figure 3 shows the electricity consumption of the traditional construction and prefabricated construction. The cast-in-situ system requires many materials on site, which causes high energy consumption on transportation. Only concrete work consumes more energy in the precast system.

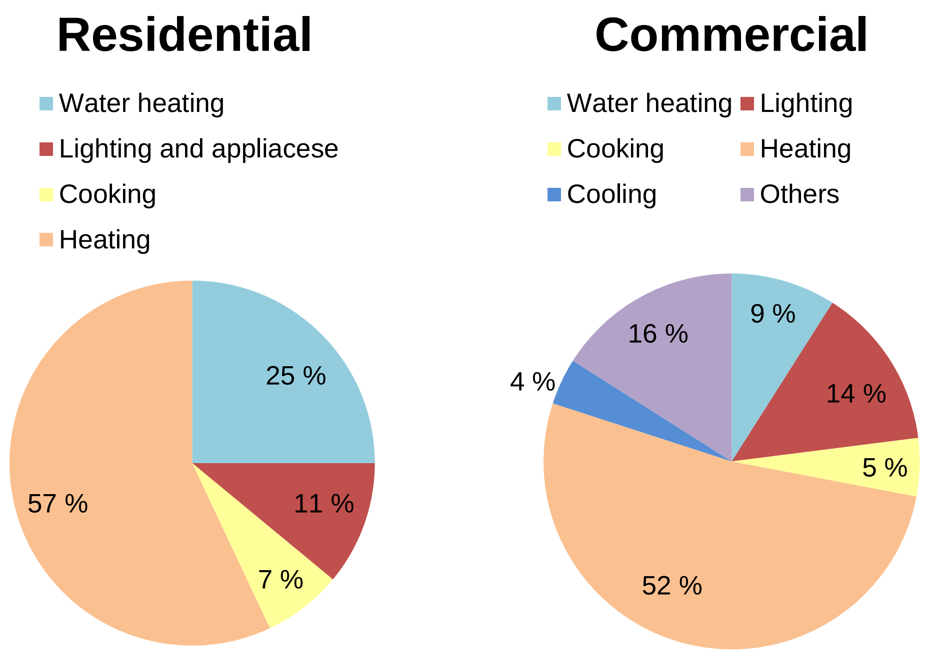


Kuvio 4. Waste consumption comparison between cast-in-situ concrete and precast concrete construction (Cao, X., et al., 2015)

Figure 4 shows the waste emission comparison between the traditional construction and prefabricated construction. According to the cast-in-situ construction procedure, more materials are needed and it causes more waste emission. For instance, in material consumption, the precast system uses more concrete, yet the waste emission is less than the cast-in-situ system. In Cao's study, the precast system has better efficiency than the cast-in-situ system in general. An environmental assessment evaluation was done for the entire process of construction and the result indicates that less environmental impact is caused by the precast system. (Cao et al, 2015)

2.3 Environmental Impact

Construction and maintenance of a structure spend energy. Energy consumption causes environmental impacts on the earth. The international standard organisation started to develop environmental standards for construction for decades ago. Their standards affect the national standards in all the world. Each country develops the standards according to its climate and market conditions. Green building councils and environmental assessment and evaluation systems are established. Some of the evaluation systems are now used not only domestically but worldwide, such as LEED and BREAM. (Canadian Precast/Prestressed Concrete Institute, 2015; European Concrete Platform ASBL, 2007)



Kuvio 5. EU building energy consumption for residential and commercial buildings (European Concrete Platform ASBL, 2007)

According to the European Union commission report (2015), building maintenance energy consumption takes 40% of the entire energy assumption in Europe. A building's performance differs according to its purpose, such as industrial, residential, and commercial. For instance, residential buildings are designed with the assumption of constant occupancy while commercial buildings are designed for occupancy during the weekdays and working hours. The essential function of the building is the same: it should keep the occupants comfortable if the building accommodates occupants. Acknowledgement of the building energy use is the first step to making the building efficient according to the building type. Figure 5 shows the different energy consumption in residential and commercial buildings. Because of that, each building may have different energy solution for optimisation. Finding the energy leakage and how to improve the energy efficiency will save general operational costs. (Armbruster et al, 2012; EU Commission, 2015; European Concrete Platform ASBL, 2007)

The majority energy consumed by residential and commercial buildings goes to space heating. If the building has residents, thermal comfort must be achieved. There are many ways to construct energy efficient buildings and it is connected to the insulation for saving heating and cooling costs of the building. Achieving a high efficiencyt seems to require high technologies and cost. However, Armbruster (2012) claims that it does not cause extra costs if the design of the building is good. The energy consumption should be considered in the design phase to affect the design process and construction process. This saves additional costs for modifying during the construction. There are some easy solutions to achieve high efficiency, such as appropriate selection of automation systems with heat recovery units. An existing building is less flexible in reducing energy, whereas new construction has more potential possibilities. (Armbruster et al, 2012; European Concrete Platform ASBL, 2007)

Thermal flow through the walls of the building is a major factor in reducing heat gain or loss of the buildings. Outdoor temperature varies each hour, day and year, the external envelope of the building gains and losses heat according to the climate. However, the main technologies of reducing the thermal gain and loss in the building are that make the building airtight. U-value is one indicator that shows how airtight the building envelope is. The lower number, U-value notes for the building material, shows superior performance of the material. According to the Finnish building code, the minimum U-value accepted for the external envelope is 0.17 W/m^2 whereas for windows and doors it is 1 W/m^2 for new construction. The building envelope is the basic part of the buildings. If the envelope is airtight, it will reduce heat losses or heat gains through the building envelope. Armbruster (2012) claims in that simply by adding more insulation to the envelope, the energy costs can decrease by 5 to 20 percent in some climates. (Armbruster et al, 2012; European Concrete Platform ASBL, 2007; Finnish building code D3, 2010; Precast/Prestressed Concrete Institute, 2011)

A high-efficiency building may cost more than a regular building. However, the environmental impact on the buildings cannot be neglected. Therefore, the construction market is connected to other industries closely. Life cycle assessment and building grading system evaluate the building materials and the construction procedure on energy consumption. The price of energy price has been increasing and it will not go down. European Committee has already decided to reduce the use of fossil fuels and the connection with the energy changes the regulations in European countries. The evaluation of the building will become ever more a necessity, not a recommendation. As a result, high-efficiency performance with low energy consumption buildings is demanded in the construction market. (Canadian Precast/Prestressed Concrete Institute, 2015; European Concrete Platform ASBL, 2007; High Concrete group, 2009)

3 Precast concrete sandwich panel

A sandwich panel is a manufactured product with layers of precast whythes insulation in between. The word ‘whythe’ is used for the layer in the American market. The precast concrete sandwich panel has many names such as insulated precast concrete panel, sandwich wall, sandwich element, prefabricated precast insulated wall and so on. (Precast/Prestressed Concrete Institute, 2011)

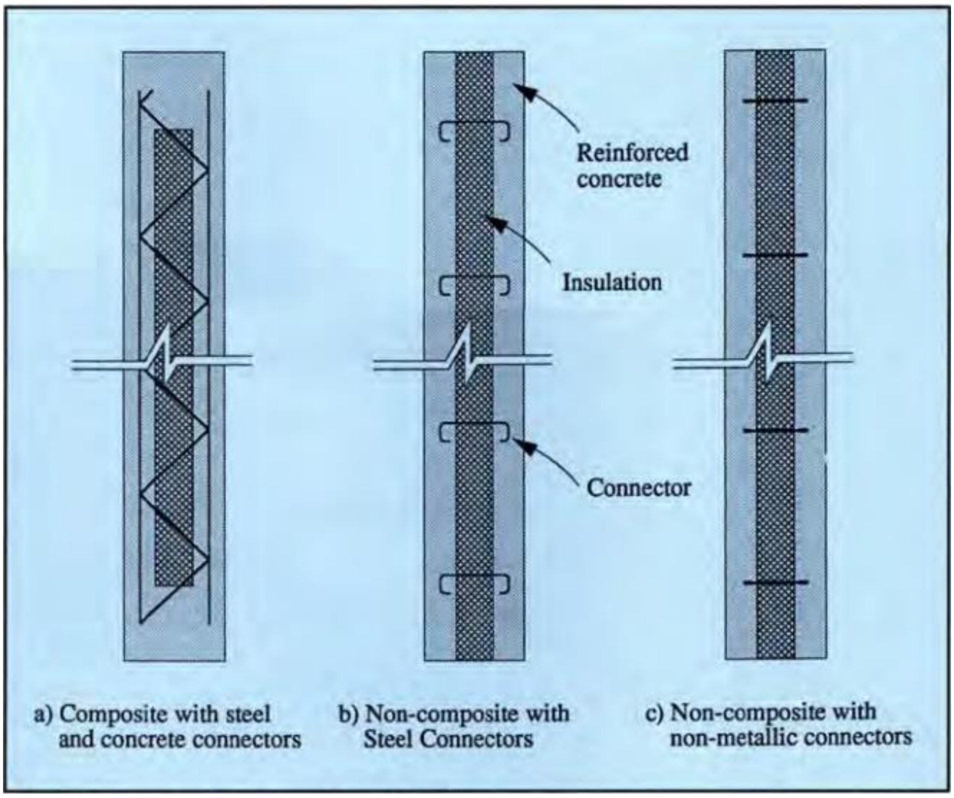
A precast concrete sandwich panel has some advantages compared to precast solid panels. According to Cao, the lifespan of the insulation is longer and the erection time of the structure is shorter (See also chapter 2.1). The insulation, which is inside the precast concrete sandwich panel, is attached to the panel in the manufacturing phase. Connection parts inside of the panel makes strong adhesion between the concrete layers and the insulation. The use of precast concrete sandwich panel diminishes material consumption and shortens construction time. Material consumption of the panel is closely connected to reduction of raw material handling and labour load on site. A precast concrete panel is available in a variety of options. Materials, sizes, and scales can be decided depending on the project or the clients’ demands. (Li et al., 2014)

The range of diversity is wide and different depending on the precast market. This study is concerned with the general features of precast concrete sandwich panels. Some examples were selected to support possible development for countries where they are newly adopting the precast system. Following chapter will explain about distinctive characteristics of precast concrete sandwich panels.

3.1 Characteristics of a precast concrete sandwich panel

Having insulations between the layers gives not only advantages but also disadvantages to precast concrete sandwich panels. The development of concrete has been possible because of steel reinforcement. Concrete has strong resistance to compressive force, but not to tensile force. The steel reinforcement is added to concrete structures as a complement. Fortunately, concrete and steel have similar thermal characteristics. While a building exists, many physical and chemical reactions happen both from the inside and the outside of the building. Concrete and steel have similar thermal characteristics which prevents inessential reactions and simplifies building physics calculations. For instance, a concrete structure is calculated as a homogeneous material even though it consists of concrete and steel reinforcement. (Milner, 2006; PCI Committee on Precast Sandwich Wall Panels, 2001)

The insulation material and concrete have different thermal characteristics. The connection of each layer needs to be carefully studied to prevent unnecessary damages caused by construction process and maintenance after construction. The design of a precast concrete sandwich panel is closely connected to the structure stability and the performance of the envelope. While designing the panel, the connections of the layers are the most important aspect. (Milner, 2006)



Kuvio 6. Precast concrete sandwich panel types (Milner, 2006)

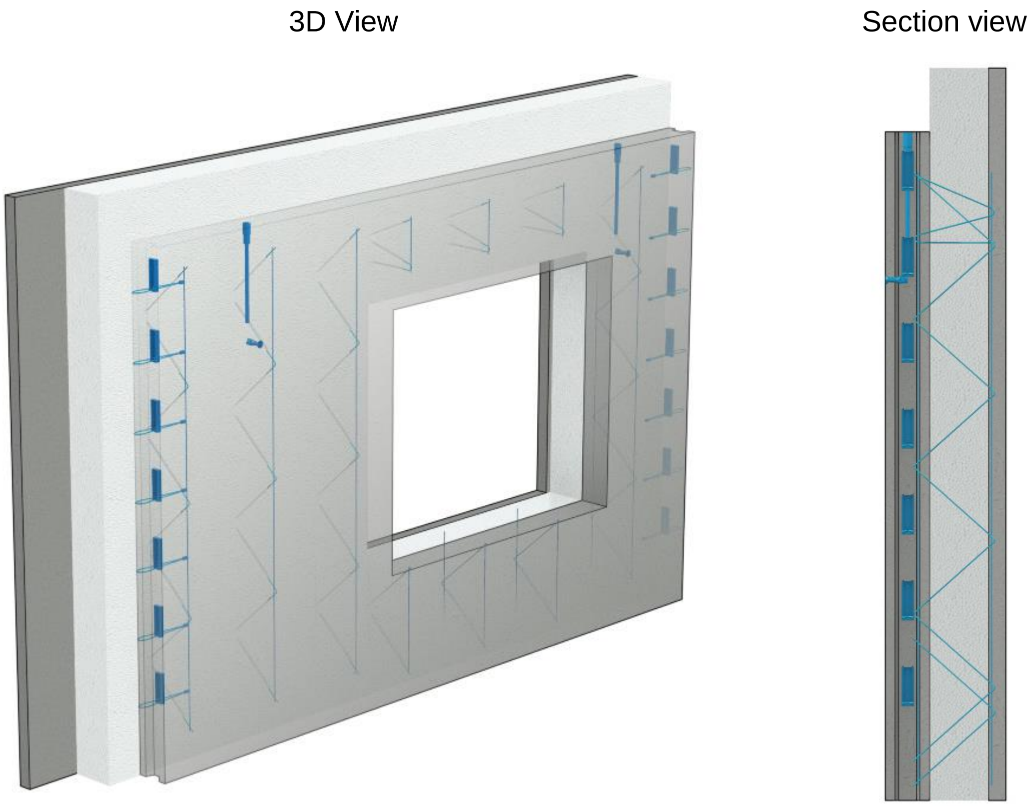
Figure 6 shows three different types of precast concrete sandwich panels. The terminology is confusing because firstly, concrete is a composite material of cement and aggregates, secondly, a concrete structure is usually reinforced concrete, which is a composite material, and finally a precast concrete sandwich panel is comprised of the previously mentioned composite materials and insulation materials. In this case, the term composite refers to the structural behaviour. The term composite connection means that the panel layers act as a single structural part. The loads are exerted to the panel and a composite connection is assumed so that the entire panel holds the load, whereas in the case of a non-composite connection, it is assumed that the each layer takes the load differently. (Milner, 2006; Precast/Prestressed Concrete Institute, 2011)

A composite connection has stronger adhesion than a non-composite connection. The design with a precast concrete sandwich panel is somewhat different depending on the market. In Nordic studies, despite of a composite connection, the regulation dictates to consider each layer separately. However, in American studies, the calculation only treat non-composite connections as separate layers. Regardless of the connection type, a precast concrete sandwich panel reacts as a composite structure. (Alfred et al, 2011; Einea et al, 1994; European Concrete Platform ASBL, 2007; PCI Committee on Precast Sandwich Wall Panels, 2011)

For instance, in Nordic design, the thicker layer of the panel is considered as a load bearing layer. In American design, if the sandwich panel has a composite connection, the whole wall is considered as load bearing. It makes a difference between the required thicknesses of the panels in each market. In the American market, the precast concrete sandwich panels tend to be thinner than in the Nordic market. (European Concrete Platform ASBL, 2007; PCI Committee on Precast Sandwich Wall Panel, 2011)

However, both composite connections and non-composite connections of the insulation have better adhesion than precast concrete solid walls with insulation. The connection of the insulation is added to the precast concrete sandwich panel in the casting phase to strengthen the attachment. The composite connection is used for load-bearing walls or self-bearing walls. Non-composite connection is used for hanging walls or self-bearing walls. (Milner, 2006; PCI Committee on Precast Sandwich Wall Panels, 2011)

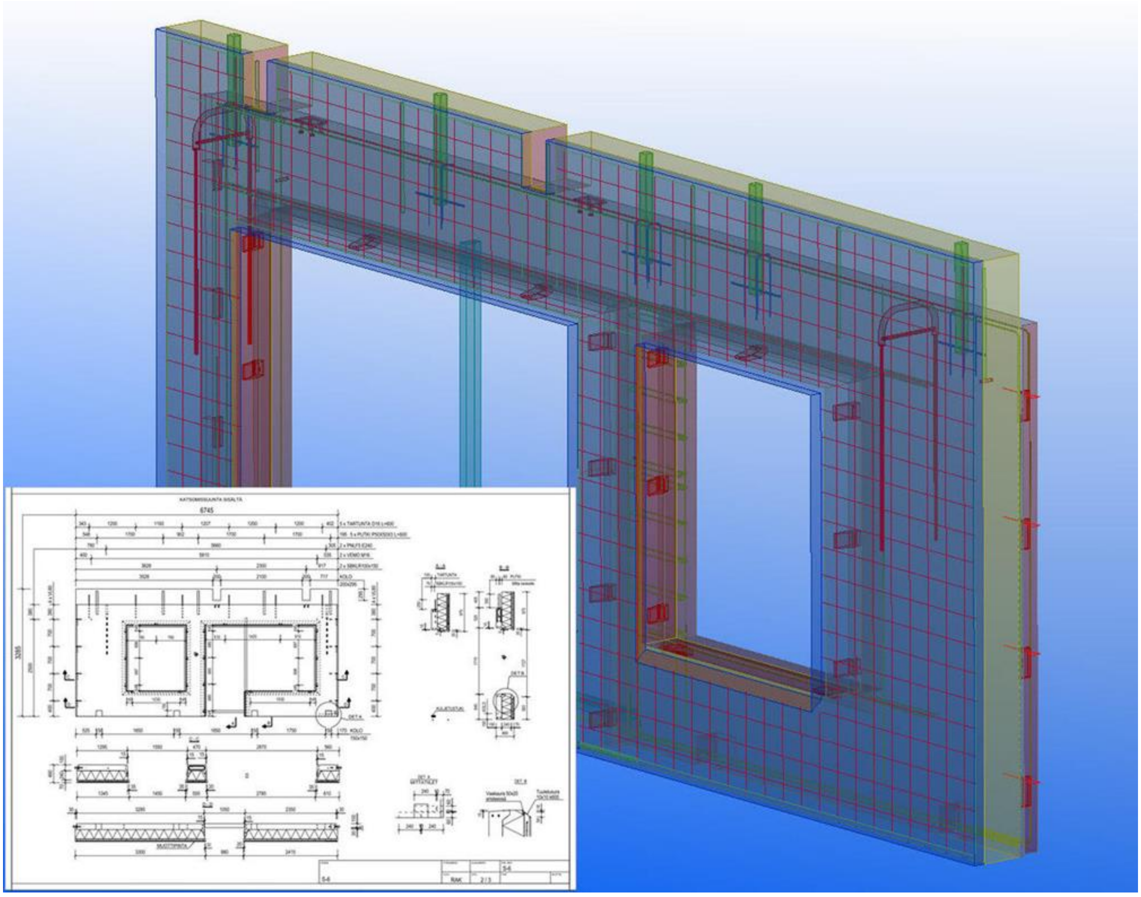
The manufacturing of a precast concrete sandwich panel is different than the manufacture of a solid panel. A precast concrete solid panel is a panel without insulation, it can be a load-bearing, self-bearing or hanging wall, depending on its size, thickness and location of installation. The precast solid panel is the most common precast element in the precast market. A solid panel consists of connectors and other appliances for structural stability and installation process, such as, lifting hooks or anchors, supporting pins and ties. The solid panel can also be classified as both composite and non-composite, the same as the precast concrete sandwich panel. (European Concrete Platform ASBL, 2007; Milner, 2006; PCI Committee on Precast Sandwich Wall Panel, 2011)



Kuvio 7. Composte precast concrete sandwich panel with connection and installation parts. (Peikko group, 2015)

A precast concrete sandwich panel also needs connectors and reinforcement similar to those of precast concrete solid panels. Furthermore, the sandwich panel requires specific ties for insulation not present in the solid panel. The classification of the connections of precast concrete sandwich panels is mainly based on the types of ties. Figure 7 shows a precast concrete sandwich panel sample in both a 3D model and a section view. Figure 7 shows the connectors inside a precast concrete sandwich panel. In figure 7, in section view the diagonal ties connect the insulation layers and precast concrete layers. The example panel has a composite steel connection. (Milner, 2006; Peikko group, 2015)

The manufacturing process is done in a factory with controlled quality inspections to assure product performance. Most manufacturing companies provide structural product information for engineers. The material of the panel affects the range of pricing but the range of the selection is flexible. The precast concrete element market is increasing, which gives more options for the consumers. (Li et al, 2014)



Kuvio 8. BIM modelling of sandwich panel

Nowadays, factories producing precast elements use automatic processing systems, which decreases the prices and cost of labour. It is possible because the sizes and scales of precast elements are usually standardised. The standard sizes and scales make the use of BIM modelling easier, as the designers can use them as reference for their design. Figure 8 shows a BIM of a precast concrete sandwich panel with its manufacturing drawing. The standard of the precast concrete elements are shared among manufactures to provide similar products in the market to keep the production load. The precast concrete element standards lead to lower prices and better quality. Furthermore, the transportation of the products becomes easier. (Betoniteollisuus Ry, 2015; Nieminen; PCI Committee on Precast Sandwich Wall Panels, 2011)

An advantage that comes from using precast construction is the shorter construction period. The precast concrete sandwich panel is a manufactured product with attached insulation so it does not require site work for insulation attachment, which is a difficult task because of the delicacy of the material. A precast concrete sandwich panel is a manufactured product with packaging. Consequently, the packaging protects the panel material from moisture and other contaminants, which may provide easier material management on construction site. Windows doors or other facade materials can be attached to the precast concrete sandwich panel depending on the design. This shortens the overall construction time. (Betoniteollisuus Ry, 2015; Department of the Environment, Community and Local Government of Ireland, 2015; PCI Committee on Precast Sandwich Wall Panel, 2011)

3.2 Environmental impact of PCSP

Building regulations are affected by the market and global standards and updated according to those. The environmental impact on the construction market has been discussed in chapter #.# background. Recently the European countries, they start to limit the building material with the CE marking system, which makes the environmental assessment easier with standardised products. Building regulations tend to develop towards sustainability. These issues have an effect on the environmental grading systems of construction under development. The grading system takes into consideration the total energy consumption of the entire building, which includes the process of the building materials, starting from construction and also building structure design and maintenance. (Canadian Precast/Prestressed Concrete Institute, 2015; EU Commission, 2015; High Concrete group, 2009)

There are studies about how to get a higher grade in an environmental assessment. Environmental building assessment analyses the materials, the process of the construction and the building performance. The result is used to grade the building. Environmental building assessment concerns mainly the energy use of the parts of a building. The evaluation for the each part differs according to its expected performance and energy consumption during the manufacturing and construction procedure. For instance, an external wall should be air-tight for the building performance and the material should observe building material regulation. Precast concrete sandwich panel manufacturers advertise their product with the benefits they offer. Air tightness of the wall is one of the selling points. The panel has good thermal performance, durability and design flexibility. The production of precast consumes less than cast-in-situ construction, see also chapter #. background study case. The airtightness of a building depends on the connections of the building parts. (Canadian Precast/Prestressed Concrete Institute, 2015; Departement of the Environment, Community and Local Government of Ireland, 2015; High Concrete Group, 2009)

The insulation in precast concrete sandwich panels performs better than the insulation in regular solid walls. To compare the two, a building physics simulation is performed with the programme COMSOL 5.2, see appendix 2. COMSOL 5.2 is simulation software which analyses general physical phenomena. The heat transfer analysis of the walls is performed with two specimens, the most basic walls in Finland and Korea. The specimens are designed according to each country's national building code. The simulation shows the temperature changes inside of the walls, which shows the heat storing capacity of each wall. The result shows that the efficiency of a precast sandwich panel is twice that of a solid cast-in-situ wall. The difference of the climate and legislation may cause disadvantages to one of the specimens, but the walls are used in both countries commonly. This shows t the great difference between the building markets of the two countries. For instance, for the external wall, U-value in Finland is 0.17 while it is 0.34 in Korea, most likely due to the difference in climate. See appendix 2 for further description of the simulation.

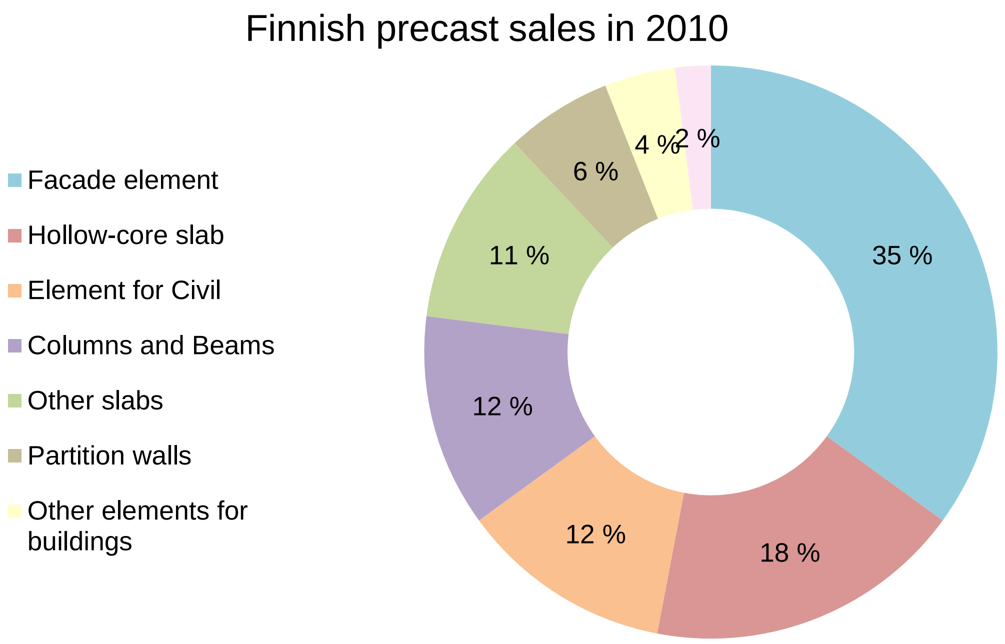
As mentioned above, the precast concrete sandwich panel is a processed product. Even cladding or finishing materials of the wall can be included in the product which, of course, reduce both the amount of waste, and construction time which leads to less energy consumption. One of the world's leading environmental grading systems, LEED, gives extra points for the precast construction in general. Especially, precast concrete sandwich panel causes less environmental impacts than the regular precast solid panel. (Canadian Precast/Prestressed Concrete Institute, 2015; High Concrete group, 2009)

3.3 Example

The precast system is already popular in some countries, where the labour cost is high and the possible construction period is short because of the climate. Recent research also shows that the interest for prefabricated construction is growing, perhaps because of the importance of environmental issues. Many countries try to develop their building regulations to encourage more energy efficient building. The prefabricated construction method is more efficient than the cast-in-situ construction when assessing the environmental impact. The following section introduces the potential and adoption of precast concrete sandwich panels. (Li et al, 2014)

3.3.1 Finland

The Nordic countries have a distinctive climate with a long winter. The regulations of the Nordic countries require more insulation than those of any other European country. The handling of the insulation material on site involves delicate treatment and skilled labour in certain climate, which takes extra time and energy. The prefabricated construction was developed in the Nordic countries to construct buildings during the wintertime in the short period.



Kuvio 9. Finnish precast sales in 2010 (Elematic, Graphic concrete, Peikko, Tekla, Betoni)

Finnish construction market has a long history of using the precast system since the 1950s. The construction field started to organise the system during the 1970s and 1980s. Harsh winters and very low labour load with high costs boost the development of the precast system in Finland. Finnish engineers established an association for precast concrete. Gradually the use of precast elements developed firstly from slabs to columns and beams and, finally, the walls. Modular design for residential buildings developed from precast system BES in the 1970s in Finland. In 2010, up to 75% of the residential buildings are built with precast system. Figure 9 shows the Finnish precast element sales in 2010. Precast concrete industries have expanded their business from structural elements only to façades and landscaping. Figure 9 shows common uses of precast concrete elements in Finland. Precast concrete panels are used for facades. There are companies that make graphical precast concrete panels. (Betoniteollisuus Oy; Elematic et al.)

3.3.2 Other countries example buildings

There are other examples of the use of precast concrete sandwich panels from all over the world since environmental impact has become an issue on the construction market. The first example is UNSW village that is located in Sydney, Australia. (See figure 10) It was built for student housing in 2010. The goal of the project was to be sustainable and environmentally friendly. The area consists of 19 buildings, each building with 9 floors. Precast sandwich panels were designed for high thermal efficiency to promote innovative challenge of the project. The workload of the project on site was 30 panels or 70 floor slabs per day. The entire construction took 6 months.

Kuvio 10. Residential building in Sydney, Australia (National Precast Concrete Association Australia, 2015)

The main challenges during construction were planning of the schedules for delivery of materials, labour workload, and transportation. The project ended without any extra construction period. The UNSW project claims that the environmental assessment of the building shows high efficiency. However, the resource of the project does not give any details of the rating system of evaluation used for the environmental assessment. Figure 10 shows the construction site and completed buildings. (National Precast Concrete Association Australia, 2015)

Kuvio 11. Industrial building in Ohio, USA (High Concrete group, 2009)

Figure 11 shows an industrial substation building in Ohio, USA. The building is built with a full precast system with precast concrete sandwich panel. The building was graded at the silver level according to LEED. (See chapter 2.2 for LEED) Insulation for the precast concrete sandwich panel is thermally airtight but that of air-tightness of the wall also prevents sound or vibration. The panels can be used for a plant or a factory, which require airtight conditions. (High Concrete group, 2009)

Kuvio 12. Renovation project 151 first side in Pittsburgh, USA used Sandwich panel for renovation. (AltusGroup, Inc., 2013)

Precast concrete sandwich panel can also be used for renovation work. Figure 12 shows an 18-storey residential building in Pittsburgh, USA. The original building was built in 1968. It is located in a developing area where there is busy traffic, so the site management of the project was a challenge. The architect claims that using precast concrete sandwich panel reduces logistics. Precast concrete insulated architectural cladding was used to provide thermal performance. Figure 12 shows the completed look of the first side building. The introduction of the project suggests that developing cities may need more and more renovation and using prefabricated construction helps to simplify the process of the construction. (Altus Group, Inc., 2013)

Kuvio 13. Lithuanian residential building (Consolis Betonika)

Design possibilities of precast construction are as wide as those of cast-in-situ construction. Different shapes and sizes can be designed, which makes the buildings distinctive. Precast construction is common in a few European countries. This suggests that the construction method is efficient in residential building with modern design. Figure 13 shows residential buildings in Lithuania. The residential building size and design varies. The construction contractor Consolis Betonika advertises about high-rise residential building from 4-to-25 storey. The company also suggests of a hybrid system that merges precast elements with other construction methods, according to on construction conditions. (Consolis Betonika)

4 Korean construction market

The Korean construction industry has suffered from the recent financial crisis of 2009. Fortunately, the domestic construction market, especially the residential market is large. There are many construction companies that mainly build larger interconnected residential district. A complex residential district includes residential buildings, business and public offices, day-care centre and school buildings, and in some cases hospitals and churches. The size of the construction for a complex residential district is usually a minimum of 3000 flats. (CAK, 2015; Choi, 2014)

The construction field is very slow to change. Contractors and clients are afraid to adopt new technologies and take risks. Cast-in-situ construction is the most common construction method in Korea. The reason of using cast-in-situ construction is the strict requirement and the highly developed cast-in-situ construction techniques. Korean construction market has tried to adopt the precast system in the 1970s. When Korean government start to build residential building in urban area, that the precast system was introduced for short period construction with less labour that time. However a lack of analysing and localising of the system for localisation and optimisation, brought problems. That caused joint cracking and moisture problems in the precast elements. The strength of the concrete structure reduces with these problems and it, in turn, leads to safety issues. All this caused high costs of maintenance to both residents and contractors, which in turn lead to the deterioration of the reputation of the precast system. (Choi, 2014; Kim, 2005; Yun et al, 2013)

Mr.Oh, a team manager at Hansung PCC, and Mr.Yim, a structural engineer at the R&D Department of the GS Corporation, visited Finland in 2014 to get to know about the precast system. During the visit, they explained the Korean market situations. The next paragraphs are a summary of the discussion.

Mr.Oh and Mr.Yim initiated the conversation with a summary of the lost reputation of the precast system in Korea. Usually, the choice of construction system lies with the client. In most cases, the clients are conglomerate companies. The atmosphere of Korean companies is also different from that in other countries. For instance, the hierarchy is strict. The designer might want to develop the system or design, but if the decision makers do not approve, there is not much a designer can do. In addition, there is a possibility that the decision makers, high-ranking in hierarchy, may not know the construction system at all. They may only have a business, not construction background, so it usually takes a long time to convince them to change the construction system.

Sadly, it is difficult to clear the tarnished reputation of the precast systems. Furthermore, the first investment cost of precast construction is higher than that of cast-in-situ construction. The benefits of precast construction are not obvious. The concept of precast system has not spread, but the interest has increased because of environmental issues. Mr.Oh and Mr.Yim mentioned that the decision makers have not been concerned about the life cycle of buildings because maintenance is the responsibility of the residents and the contractors.

According to Mr. Lee, an element inspector at Dong-su PCC, Korean market already has enough demand and experts to implement precast construction design. However, lack of production and installation techniques also the production quality issues need to be solved according to the local norms. Generally, precast construction requires compact scheduling for precast element design, element production, material deliveries and element installation. Proper scheduling assures a short construction period. The schedule needs to be considered in the design phase that gives more responsibility to the designers. In cast-in-situ construction, planning and scheduling are attributed to construction site managers. Lack of controlling precast element production information and planning of the element installation on site during the process of design is foreign in Korean construction, according to Mr. Yoo, C.E.O at ESEN design and tech. Because of that, most precast companies produce mainly infrastructure elements. (Jo, 2006; Kim, 2005; Yun et al, 2013)

Kuvio 14. General Korean residential construction (Choi, 2014)

Asian cities are growing fast and getting very dense, and most old buildings need renovation or refurbishment. Most Korean construction contractors prefer re-building to renovations so they can expand the capacity of the building. The most common size of a building is at least 25 storeys and if the building is going to be a new one, clients usually demand more than 30 storeys. Figure 14 above shows a typical residential construction site in Korea. (CAK, 2015; Choi 2014; Jo 2006)

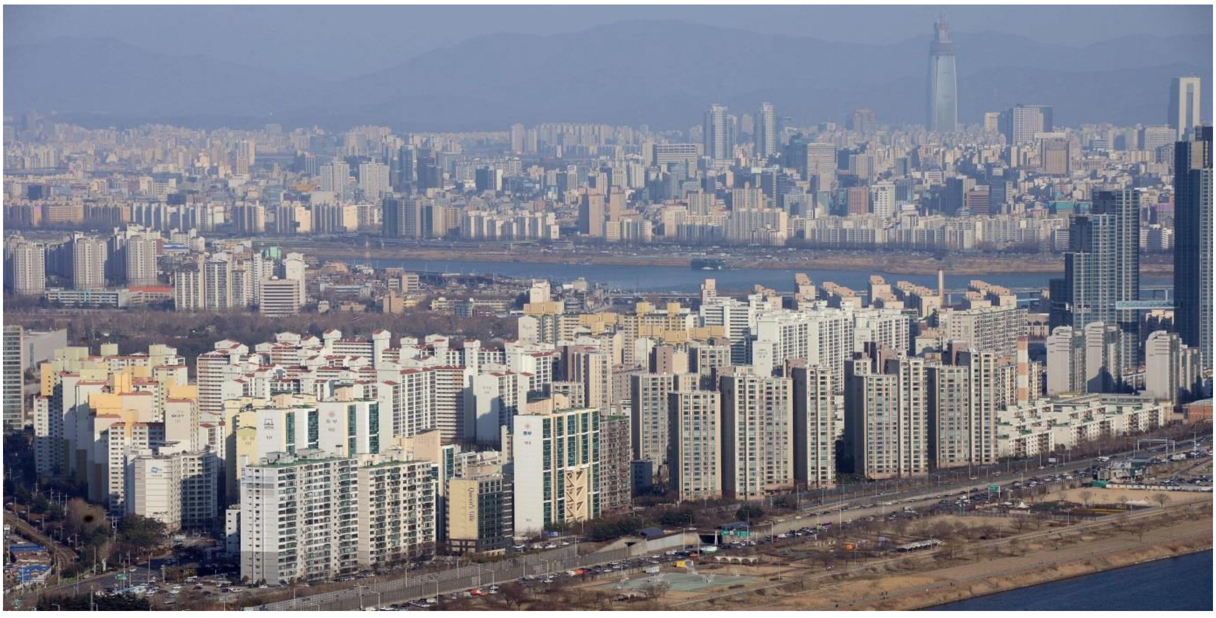
4.1 Cognitive factor

The Korean construction market needs to be changed to follow the world trend not only for financial benefits but also environmental distribution of pollutants by building materials. The atmosphere of a company may cause difficulties when working with international companies, according to the experts from Korea. Korean projects require more time and unnecessary documents to convince the decision makers, according to Mr. Yoo, C.E.O at ESEN Design and tech.

Mr. Yoo, C.E.O at ESEN Design and tech, mentioned the importance of BIM, building information modelling, in construction. The Korean construction system is very old fashioned in that most production drawings are done with autoCAD. It is very rare to have a 3D model ifc extension files, one type of 3D model file extension, for the construction projects, and the access to the model is limited to only engineers.

There is a close connection between the precast systems and BIM has. BIM helps communication among engineers, visualising the building design for defect and crashes, the information can be exported for planning schedule for the production and site management. According to Mr. Yoo, most of Korean project do not have a BIM programme and clients does not want to use it either because of its high first investment. The Korean regulation of BIM has updated in 2010 that public projects may use BIM project and if the building has built with BIM. The Korean government also established associates and organisations to support use of BIM for high building efficiency and mandatory conformity marking systems. (CAK, 2015; Kim et al, 2005)

The familiarity of cast-in-situ construction system may influence clients to choose that construction system. In some cases, cast-in-situ construction may cost less than precast construction. It is easy to find experienced labourers for the cast-in-situ system and the design of them is much cheaper than that of precast systems in general according to the interviewees. The precast systems or pre-fabricated systems are very new to Korean market. Expecting a full precast building may be too early for the market. Research and development are needed for localising and optimisation.



Kuvio 15. Common residential buildings in Seoul, Korea (Choi, 2014)

The boundary of architects and engineers are very thin, and they both do not have much of project attribution than the clients. They design according to the clients that are the major conglomerate companies. As a result, residential buildings look alike in Korea. Figure 15 shows residential buildings around Han River in Seoul, Korea. (Choi, 2014; Kim et al, 2005)

Every interviewee mentioned the first investment costs and exclusive existing contractors, designers and engineers that they do not want to change their working method. Mr. Lee, element inspector at Dong-su PCC, mentioned that some special projects had used a precast system, but the reports of them tell about lack of experience and high design cost. The time span was not as short as the project expected because of lack skill at installation and time schedule management. Unfortunately, the factors of design, management and development of the precast system are relevant to experience, which involves time. The problem in the Korean market is that the field associates do not wish to spend their time or resources on the precast systems.

For structural design, Korean building code requires high seismic activity with strict regulation, a full precast system may not be suitable for the size and height of the building. However, precast systems have used in some other countries where are high seismic zone such as Japan, New Zealand and China. There are hybrid systems such as steel frame with precast elements and cast-in-situ structural core with precast elements. (Kim et al, 2005; Liu et al 2013)

4.2 Objectives

Recently, Korean legislations have been updated to match international environmental standards. For instance, a building cannot be demolished and rebuilt if it has been built less than 10 years earlier. A new building must have a life span that is longer than 50 years. Building materials require certain types of environmental classification for the construction, such as for external wall the U-value calculation is necessary according to the region and building types. (CAK, 2015)

Until the year 1992, it was only possible to use precast systems up to 15- storey construction while cast-in-situ system allowed 20- to -25- storey buildings. In 1998, the regulation was changed to dictate the building height according to the construction system. For precast systems, the limitation is up to 65 -meters, which is approximately 24 -storeys for a residential building. The recent trend of residential building height is up to 35 -storeys for cast-in-situ construction. (CAK, 2015; Kim et al, 2005; Kim 2005; Jo 2006)

A hybrid system may be the one for the Korean market to start with. Combining cast-in-situ construction and precast construction has been done in some countries. The way to do it could be, for instance, have the structural frame for cast-in-situ, and then partially use precast elements for the envelope and floors. The structural frame can be other materials, such as steel or wooden frame. In Japan and New Zealand, where they have strong seismic force to the building, the frame system is built with the cast-in-situ system and other building parts are the precast system. The application of precast elements to other structural systems is not as advanced as full precast construction. (Cao et al, 2015; Jo, 2006; Liu et al, 2013; PCI Committee on Precast Sandwich Wall Panels,2011 Takagi et al, 2012)

According to Mr. Oh and Mr. Lee, who work for a precast manufacturing company, there is a possibility to supply precast elements in the Korean market. Precast manufacturers produce elements by order from clients. There are no standardised or modular sizes for the precast production, which means the mould and production lines are used only for one order at a time. A precast mould needs to be used at least 100 times for productivity. However, most of the precast manufacturers do not have enough orders to fulfill the productivity of the mould. Capacity utilisation rates are summed to be less than 80% of the maximum production according to Mr. Lee, element inspector at Dong-su PCC. (Jo, 2006; Kim, 2005)

Cooperation amongst precast manufacturers should be encouraged. The production orders should be opened up so each manufacturer could concentrate on standardised or modular size of precast elements. It would increase the efficiency of mould utilisation. Precast manufacturers should establish standards for each precast element and share the sizes so that the designers may design according to the sizes.

The environmental impact of building has had very little influence on the Korean construction market. The Korean green building council was only established in 2010, since then many regulations have been changed and they are starting to match the international standards. The technologies and studies are, however, far behind compared to other countries. The cast-in-situ construction generates more waste than precast construction because of that cast-in-situ construction project gets restriction and limitation of material management according to Mr. Yoo, C.E.O at ESEN. (CAK, 2015; Yun et al, 2013)

Environmental thinking impacts the Korean construction market leading to changes in the building methods. The external wall requires insulation to fulfil the regulations. The most common type of residential building in Korea is a high-rise building, 15 to 30 storeys high. The buildings are usually built with cast-in-situ system. There are two ways of installing insulation on cast-in-situ walls. The first one is that insulation is placed inside of the mould and the concrete is poured on top of it. This method requires delicate control of the concrete work and insulation treatment. The second way is to attach the insulation inside or outside of the cast cast-in-situ walls. This method prevents thermal bridges and condensation through the wall depending on the climate. (CAK, 2015; Department of the Environment, Community and Local government of Ireland, 2015; Yun et al., 2013)

Installing insulation on the wall needs skilled labour. The gap between the wall and insulation needs to be minimised to stop the penetration of contaminants hindering adhesion of the layers. Usually an attached insulation has 25 years of service life, so it should be possible to remove the insulation for maintenance later. The layer of external wall depends on the design, but usually the outer facade needs to be taken off for the replacing of the insulation. If the project uses precast concrete sandwich panels, it can fulfill the regulation and assure performance. (Cao et al., 2015; Department of the Environment, Community and Local government of Ireland, 2015)

Precast concrete panels can be used as facade layers. The texture and colour can be chosen according to the clients and the capability of the precast manufacturers. The weight of concrete varies and a facade element does not require as high strength as a structural precast concrete element. The facade material has a limitation of size and shape while precast concrete is flexible and its size limited only by transportation possibilities. (Elematic et al.)

5 Conclusion

Concrete has been the most common material for building construction and it has been studied with many different methods. The precast system and the cast-in-situ system are both very common methods to treat concrete. There are advantages and disadvantages for each system. Global warming shows signs of dramatic changes, alerting us to think about the environmental impact of construction seriously. The construction field is a huge market and it is connected to other industries closely, so the environmental impact of construction may be considered huge.

The precast system has been studied and developed in a few countries and it is considered to have less environmental impact than the cast-in-situ system. For instance, LEED, a construction environmental assessment tool in the USA, gives more points for the precast system compared to the cast-in-situ system. However, the precast system is not as common as the cast-in-situ in every market. Each construction market has its distinctive conditions and atmosphere to adopting a new system.

Korean construction market has suffered because of the global financial crisis. The traditional way of construction does not reach international standards. Therefore, the Korean market needs a breakthrough. Legislation and building code have been updated for adopting the precast system. The precast system is not familiar to the Korean market so that it is too early to expect full precast buildings yet. Starting from an element which can be applied to existing construction, such as a precast concrete sandwich panel, would be a nice first step.

Using precast concrete sandwich panel, better thermal performance can be achieved with less labour work and shorter construction time. Materials and energy consumption of using the panel has proved its advantages over the cast-in-situ construction through environmental assessments.

In conclusion, adopting the precast system in the Korean market is inevitable economically and environmentally. Unfortunately, the market is not ready to change the system yet. Furthermore, embracing the system takes time for experience and research. The precast system needs to be studied according to the market conditions and atmosphere to prevent a rushed, unskilled proceeding. In this paper, precast sandwich panel has been introduced but the studies were done in other markets, not in the Korean market, for an actual acceptation of the system. Therefore, further research is recommended prior to actual implementation.

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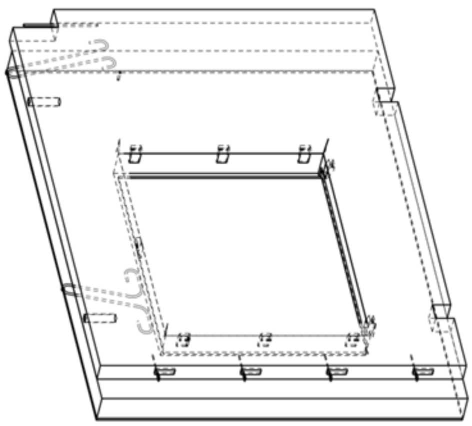
Standardized precast concrete sandwich panel

RAUDOITELUETTELO

TYY	NRO	LKM	LAATU	D [mm]	L [mm]	dL [mm]	PAINO YHT [kg]	a	b	c	d	e	u	v	x	TD	KOMMENTTI
A	5	2	A500HW	12	400		0.7	400									
D	6	4	A500HW	8	760		1.2	350	102	350						30	
U	8	9	A500HW	8	1130		4.1	106	417	100	417	100					
A	9	4	A500HW	10	2890		7.2	2899									
A	10	4	A500HW	10	2690		6.7	2695									
B	11	2	A500HW	10	3350		4.1	2880	500				90			50	
B	12	2	A500HW	10	4320		5.3	3855	500				90			50	
B	13	2	A500HW	10	3150		3.9	2520	665				90			50	
B	14	2	A500HW	10	1290		1.6	825	500				90			50	
B	15	2	A500HW	10	4120		5.1	3655	500				90			50	

RAUDOITTEIDEN KOKONAISPAINO [kg]: 39.9



SUUNNITTELUN LÄHTÖTIEDOT

Paloluokka	R60	
Rasitusluokka	XC1	,Sisäkuori
Suunniteltu käyttöikä	100 v	, Sisäkuori

TUOTETIEDOT

Betonipeite 1	Sisäkuori: Nimellisarvo 20 mm	Sallittu mittapoikkeama 10mm
Mittatoleranssi	Luokka N (2011)	
Pintakäsittely 1	Rappaus Ark. mukaan	
Pintakäsittely 2	Teräshierto	
Viisteet 1	Kynäpyöristys sisäkuoren reunohin	
Muotistanostolujuus	15 MN/m²	
Kuljetus- ja asennuslujuus	21 MN/m²	

VALUTARVIKELUETTELO

PIIR. NUMERO	LKM	MATERIAALI	PINTA-ALA [m2]	MÄÄRÄ	YKS
RKR-1	1				
		C30/37		1.23	m³
		Rappauslaasti		0.16	m³
			ELEMENTTI PAINO:	3.49	t

MÄÄRÄ		TARVIKKEET
8.10	m²	ERISTE PAROC_COS5gt 220.0mm
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1	kpl	NOSTOLENKKI S235J2+N Ø16, L = 2250
1	kpl	NOSTOLENKKI S235J2+N Ø16, L = 2250, LISÄTAIVUTUS
2	kpl	VEMO M16
4	kpl	VL80
2	kpl	PUTKI S235J2 250.0 P50*50*3
1	kpl	TARTUNTA A500HW 600.0 D16
5.3	kg	A500HW ø 8
33.9	kg	A500HW ø 10
0.7	kg	A500HW ø 12

MALLIPIIRUSTUS 28.2.2013

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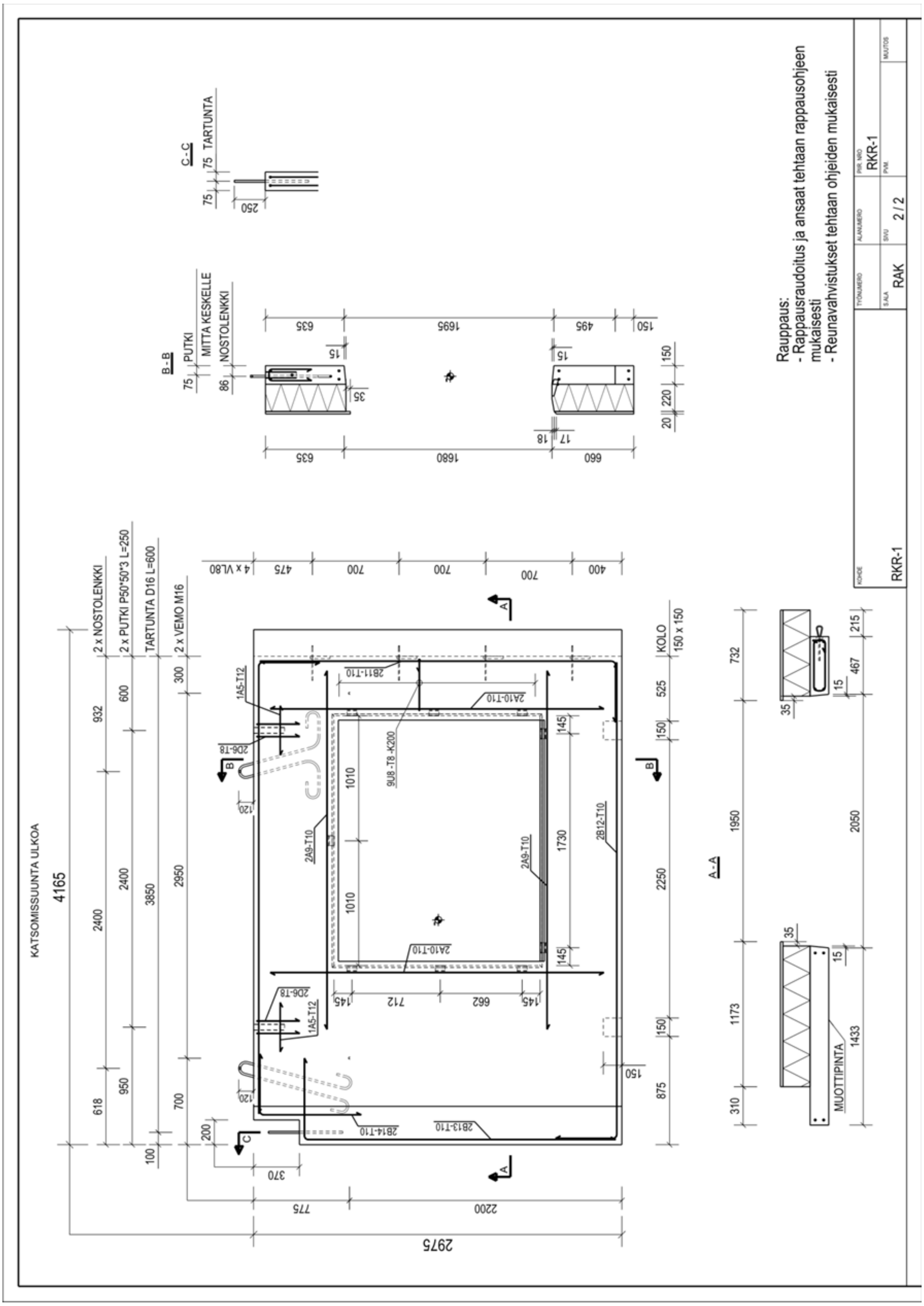
KATSOMISSUUNTA ULKOA
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4 x VL80
KOLO
150 x 150
A - A
B - B
PUTKI
MITTA KESKELLE
NOSTOLENKKI
C - C
TARTUNTA
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Precast sandwich panel and cast-in-situ wall COMSOL 5.2 simulation

1 General condition

Simulation setting is limited to the linear result based on the wall information available in building code and product characteristics from the product manufacturers. The main purpose of the simulations is to see the general heat transmittance denoted as U-vale.

U-value is one of the scales to evaluate the thermal performance of the structure. Its unit [W/m2K] consists of thermal resistance of the materials, thickness and thermal conductivity of materials.

Sandwich panel is a compound element so the characteristics of each layer material differ. Three walls have designed according to Finnish building code and Korean building code.

Finnish example has been collected from company PAROC, where produce sandwich panel insulation. In Korean market, there is no company or factory provide a standardised sandwich panel or insulation for precast so the value is adopted from ACJ Foam Technologies. Cast-in-situ wall has been chosen from building code for the capital area of Korea.

COMSOL 5.2 has been used for simulation. It simulates heat flux through the wall. The height of all simulation is 900mm.

Insulation characteristics and value have quoted from Finnish company "". The general value of concrete has taken from COMSOL 5.2 that the cement and mixture of them may differ in each country. Else another physical calculation follows COMSOL 5.2 calculation method.

Sandwich panel consist of many parts with steel reinforcement, but in this simulation, those reinforcement and other parts are not taken account for simulation. Moisture content, flow air rate, cold bridges and other indoor environmental indications have been omitted for simple simulation.

Finland and Korea have different climate so the coldest temperature of each country is estimated as -5 Celsius degree. Internal temperature is also estimated to +20 Celsius degree.

Surface resistance is chosen from Finnish national building code C4. Horizontal heat flux coefficient for inside is 1/0.013W/m^2K and for outside is 1/0.04 W/m^2K. Heat flux has analysed from external surface to internal surface.

2 Sandwich panel load bearing

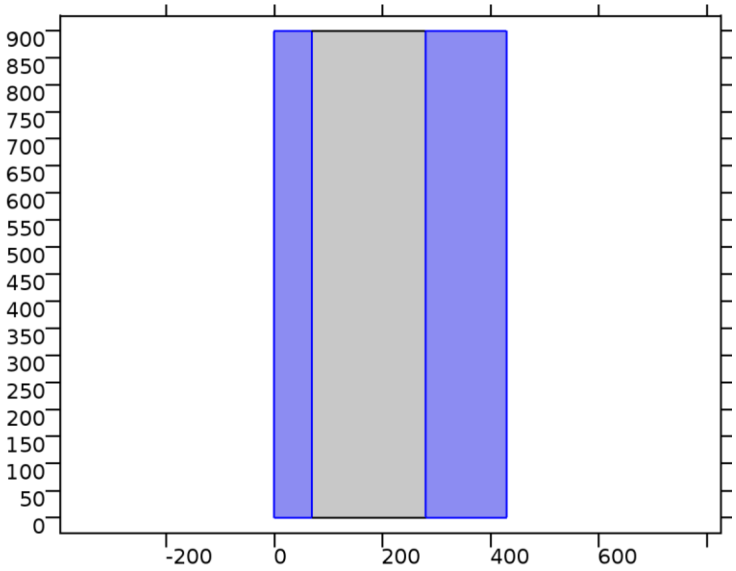


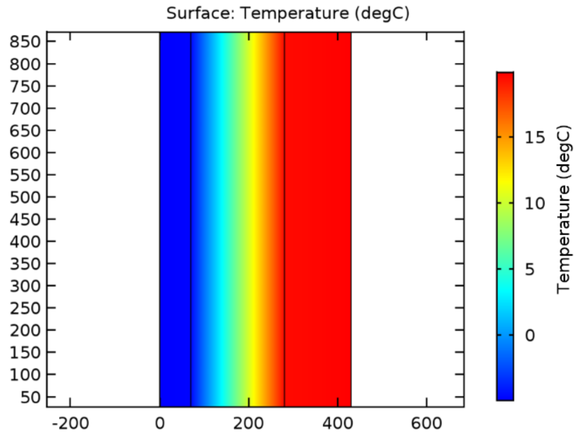
Figure 1 Precast sandwich panel (load bearing) linear model on COMSOL 5.2

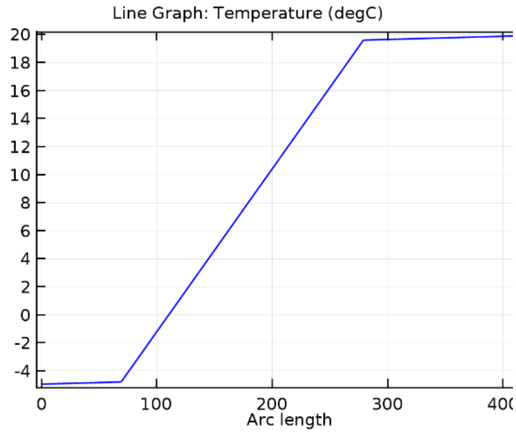
2.1 Definition

Precast sandwich panel for the load bearing purpose from PAROC. Simulation model consists of three layers. Figure 1 shows the simulation model. Blue parts show concrete layers of the wall. From the left side of layers, the first layer is 70mm of concrete as outer layers of sandwich panel. Thermal insulation is PA-ROC COS 5ggt and thickness is 210mm. The inner layer of concrete is 150mm which is considered as loadbearing part. Total thickness of the wall is 430mm.

Note. From PAROC pages, the same wall is estimated U-value 0.17 W/m^{2}K.

2.2 Result





Internal temperature through the wall

Internal temperature difference linear graph

Figure 2 Temperature changes inside of the precast sandwich panel (load bearing)

Figure 2 shows temperature change inside of the sandwich panel. Thermal insulation prevents sudden drop through the panel. Table 1 is the result of the simulation from COLSON 5.2

Table 1 COMSOL result (Precast sandwich panel load bearing)

Normal total heat flux (W/m^2)	**abs(ht.ntflux)/(Ti-Te) (W/(m^2*K))**
4.0662	0.16265

Heat flux through the load bearing sandwich panel is 4.06 W/m^2. Adding external and internal temperature according to the climate, -5°C and +20°C. COMSOL gives U-vale of 0.16 W/m^{2}K.

3 Sandwich panel non-load bearing

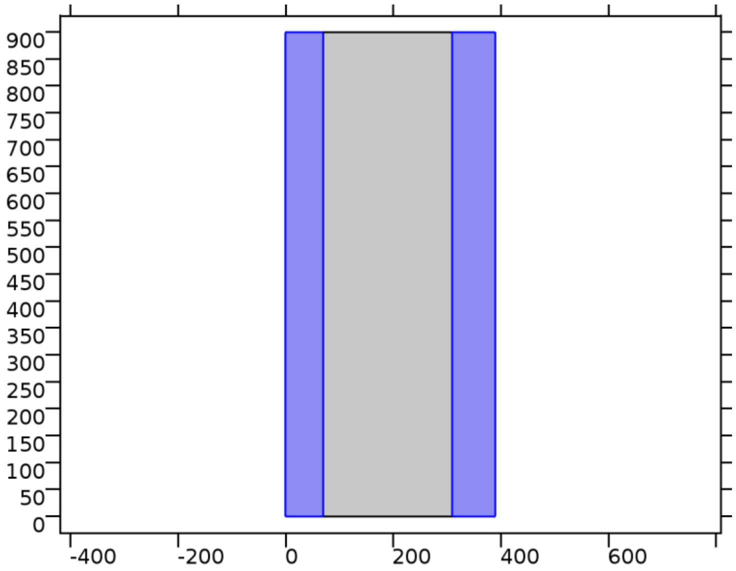


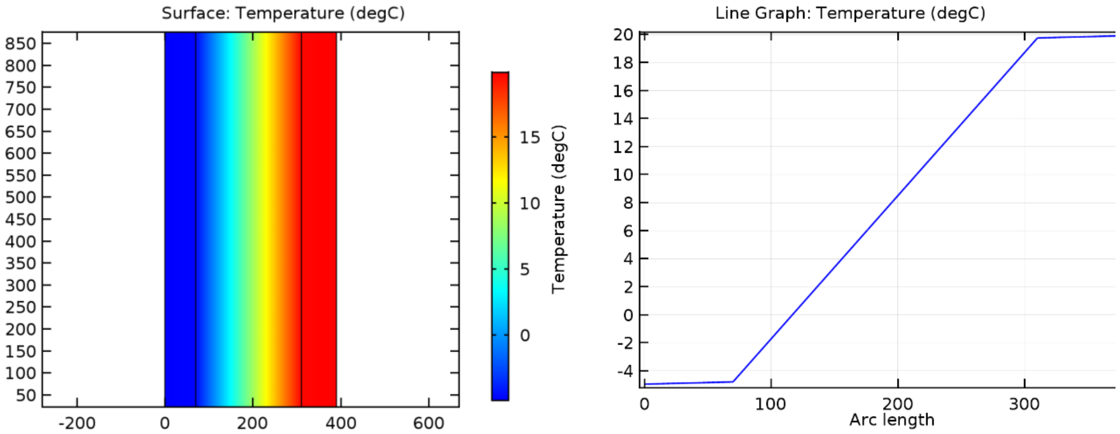
Figure 3 Precast sandwich panel (non-load bearing) linear model on COMSOL 5.2

3.1 Definition

Precast sandwich panel for the non-load bearing purpose from PAROC. Simulation model consists of three layers. Blue parts show concrete layers of the wall. From the left side of layers, the first layer is 70mm of concrete as outer layers of sandwich panel. Thermal insulation thickness is 240mm. The inner layer of concrete is 80mm which is considered as load bearing part.

Note. Thermal insulation has been assumed as rock wool the same as the load bearing wall.

3.2 Result



Internal temperature through the wall

Internal temperature difference linear graph

Figure 4 Temperature changes inside of the precast sandwich panel (non-load bearing)

Figure 4 shows temperature change inside of the sandwich panel. Thermal insulation prevents sudden drop through the panel. Compare to the first model, precast sandwich panel (load-bearing), there are only small differences between two models. Table 2 is the result of the simulation from COLSON 5.2

Table 2 COMSOL result (Precast sandwich panel non- load bearing)

Normal total heat flux (W/m^2)	abs(ht.ndflux)/(Ti-Te) (W/(m^2*K))
4.0920	0.16368

Heat flux through the load bearing sandwich panel is 4.09 W/m^2. Adding external and internal temperature according to the climate, -5°C and +20°C. COMSOL 5.2 gives U-vale of 0.16 W/m^{2}K.

Precast sandwich panel has similar U-value and heat transmittance through the wall. Both walls are designed for Finnish building code regulation where it has limitation for U-value 0.17 W/m^{2}K for residential building outer walls.

4 Cast-in-situ wall load bearing

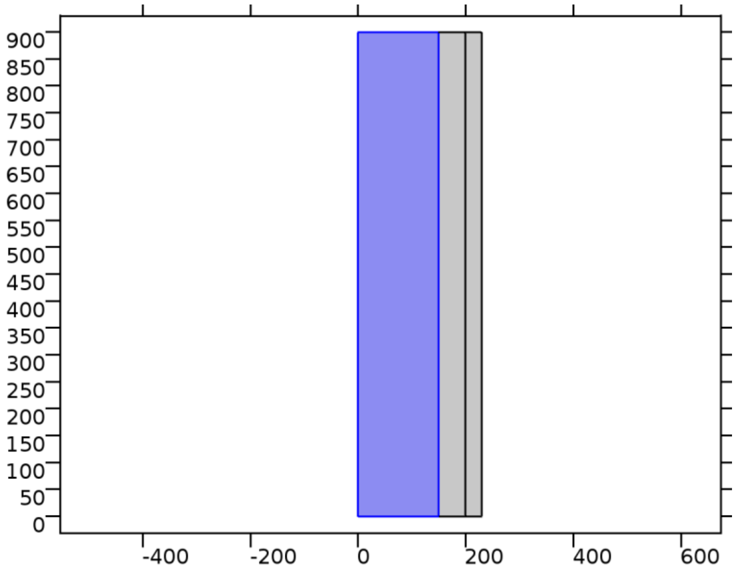
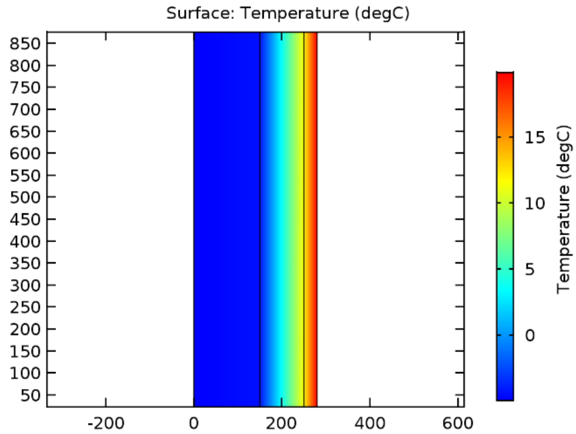


Figure 5 Cast-in-situ wall (load bearing) linear model on COMSOL 5.2

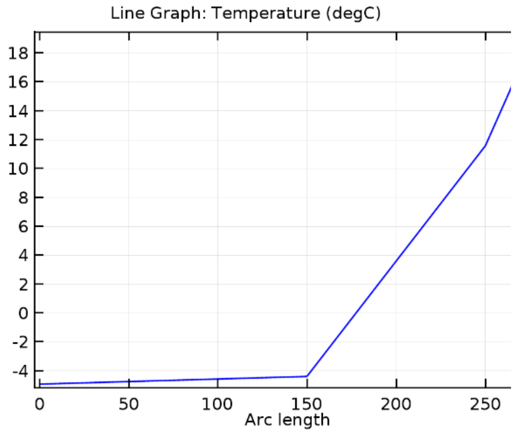
4.1 Definition

Cast-in-situ concrete wall for load-bearing purpose and the most common wall structure is designed. The simulated model consists of three layers and the blue part shows a concrete layer. From the left side of the layers, external layer concrete is 150mm of thickness. Expanded polystyrene (EPS) is the most common thermal insulation in Korea, it has assumed for the capital area from Korean building code, the thickness of 50mm. The internal layer is gypsum board from 10 to 30mm and in this model thickness of the internal layer gypsum board is assumed as 30mm.

4.2 Result



Internal temperature through the wall



Internal temperature difference linear graph

Figure 6 Temperature changes inside of the Cast-in-situ (load bearing)

Figure 6 shows temperature change inside of the Cast-in-situ wall. Thermal insulation prevents sudden drop however in this case, concrete has the same temperature as outside. In this paper, thermal bridges or moisture contents are neglected but it is not difficult to see the possible damage. Compare to the previous precast sandwich panel temperature changes inside of the wall is abrupt. Table 3 is the result of the simulation from COLSON 5.2

Table 3COMSOL result (Cast-in-situ wall load bearing)

Normal total energy flux (W/m^2)	**abs(ht2.nteflux)/(Ti-Te) (W/(m^2*K))**
8.9204	0.35682

Heat flux through the load bearing sandwich panel is 8.92 w/m^2. Adding external and internal temperature according to the climate, -5°C and +20°C. COMSOL 5.2 gives U-vale of 0.35 W/m^{2}K.

5 Conclusion

The following table 4 shows the comparison of each wall. The difference of pre-cast sandwich panel and cast-in-situ is easy to point out.

Table 4 COMSOL RESULT of Three linear model

	Total Heat flux **Normal total heat flux (W/m^2)**	**U-value** **abs(ht.ntflux)/(Ti-Te) (W/(m^2*K))**
Precast Sandwich panel Load-bearing	4.0662	0.16265
Precast sandwich panel Non-load bearing	4.0920	0.16368
Cast-in-situ wall **Load bearing**	**8.9204**	**0.35682**

According to finish building code D3, building energy calculation is based on U-value. Equation 1 is direct quotation from Finnish building code D3. The formula proves that cast-in-situ wall allows approximately 50% more heat through the wall than precast sandwich panels.

Equation 1 Finnish building code D3 (2.5 thermal loos of the building)

$$\sum \mathrm{H}_{der} = \sum(U_{exteranl\ wall} \times A_{exteranl\ wall}) + \sum(U_{upper\ floor} \times A_{upper\ floor}) + \sum(U_{base\ floor} \times A_{base\ floor}) + \sum(U_{window} \times A_{window}) + \sum(U_{door} \times A_{door})$$

$\sum \mathrm{H}_{der}$ the total sum of the specific thermal loss of the building components, [W/K]

U the thermal transmittance coefficient of the building component, [W/(m^2·K)]

A the area of the building component, [m^2]

This simulation may not have valid claims because of lack of the information and different conditions. However the energy efficiency of the building regulation has been more strict and detailed in recent year, and Korean market may need a solution to fulfil the regulation.

The design of the external wall considers many different aspects according to building code and regulations. Economics cannot be neglected. Possible applications to the new market need to be studied carefully with local climate and construction conditions for optimising the system.

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