**PRECAST SANDWICH PANEL – INNOVATIVE WAY OF CONSTRUCTION**

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**Summary**

In the period of Global crisis, construction industry is one of sectors that have suffered the most. It is evident that new ideas, new approach in design of structures and the use of “green” construction materials together with environmental awareness will result with revival of construction market and economic recovery.

Existing buildings are responsible for more than 40% of global energy use, i.e. in Croatia 83% of buildings consume from 150 to 200 kWh/m\(^2\)/a just for heating. It’s obvious that future of civil engineering are, not only low-energy buildings, but whole low-energy cities.

The construction sector consumes vast amount of natural resources and produces significant quantity of construction and demolition waste (CDW). A proper CDW use leads to efficient and effective use of natural resources and helps mitigate the environmental impacts to the Planet. The Waste Framework Directive requires Member States to take necessary measures to achieve a minimum target of 70% (by weight) of recycling CDW by 2020. The fact that in most European countries disappointingly small percentage of CDW is being reused, illustrates the possibility of expanding a construction market in Europe by reusing CDW for new “green” materials. Concrete, as one of the most used construction materials, can be used to produce energy and resource efficient products.

Based on these facts, this paper represents one solution for the Period of Economic Recovery: ECO-SANDWICH\(^{®}\) - an innovative ventilated prefabricated concrete wall panel with integrated Ecose\(^®\) mineral wool insulation. It allows very low energy design and retrofit of buildings, reuse and recycling of CDW (all in accordance with 6th and 7th Basic Requirement for Construction Works). It resulted from collaboration between academic community and construction industry and on principles of “turnkey” construction provides user a high quality, affordable, energy saving and aesthetically attractive concrete building.

**Keywords:** CDW, Prefabricated concrete wall panel, Energy efficiency, Economic recovery, ECO-SANDWICH\(^{®}\)

1 **Introduction**

In 2008, the European economy was marked by the growing global financial and economic crisis which entered a critical phase during September. The direct result of the global economic crisis has been a fall in the Gross Domestic Product (GDP), trade, and employment. The construction industry is an important source of income and brings a significant percentage in the GDP of any European country and therefore was among first industry to be hit by financial crises [1].
According to Eurostat, construction output in the EU (European Union) area dropped sharply in the second half of 2008 and was slightly dropping till second quarter of 2013 (Figure 1). The construction sector is facing with a considerable drop in the consumer and investment demand. In the third quarter of 2013 construction sector showed slightly grow and entered in Period of Recovery.

An answer to the economic crisis of construction sector have proved to be continued Research and Development (R&D) together with Innovation in order to provide a solid basis for recovery from the effects of economic downturn [3]. According to Schumpeter [4], the introduction of innovation in the form of new consumer goods, new methods of production or transportation, new forms of industrial organisation, or new services provides the impulse that sets and keeps the capitalist engine in motion. Also further development of the construction materials and technologies in the construction sector will help to decrease global problems of climate change and problem with population growth. As a largest industrial employer and a major source of revenue from exports, the construction sector is an evident contributor to the quality of life for all citizens.

The financial crisis is not the only challenge for the construction sector. Construction sector is also trying to compete in the ‘‘green’’ market while tackling challenging economic, regulatory and environmental issues. In recent years the construction sector has faced increasing pressure to reduce the carbon impact of materials and water use in the built environment by embedding resource efficiency principles in the design and construction of new buildings, infrastructure and refurbishment projects. One possible solution for construction sector that was impacted during Global financial crisis is investment in low-energy buildings. This possible solution is given by European Commission (EC) as a long term potential output [1]. A study published by Kats [5] shows that if the initial investments for the construction of a building would increase by 2% to cover more elements of sustainability, the savings for operating costs, for the entire cycle of the building’s existence, would be ten times the initial investment, or 20% of the total construction costs.

Another challenge that the construction sector is dealing with is construction and demolition waste (CDW). CDW is one of the heaviest and most voluminous waste streams
generated in the EU. There is a high potential for reuse and recycling embodied in CDW and it has been identified by the European Commission (EC) as a one of the priority stream.

By taking into account that sustainability of the structures, energy efficiency of the building and the EU’s 20-20-20 targets by 2020 together with renewable energy sources and reuse of CDW are the key areas of the development of the construction sector, this paper represents one solution for the Period of the Economic Recovery – innovative prefabricated concrete wall panel ECO-SANDWICH®. Also, this paper will show the problematic of construction and demolition waste (CDW) and its reuse, the reorientation to the energy efficiency of the existing buildings and possibility of precast construction through energy efficient precast innovative wall panels suitable for, beside others, energy efficient residential and public buildings affordable to the general public.

2 Construction Demolition Waste - CDW

The increasing activities in the construction sector influence on the environment by overuse of natural resources and also thus on upgrowth of the CDW. CDW arises from activities such as the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning and maintenance. According to Eurostat (Figure 2), CDW accounts for over 34% of all waste generated in the EU in the year 2010, which makes it dominated EU waste. As shown on Figure 3, generation of CDW is slightly arising every year in EU. In the year 2010 there was drop of CDW generation but it can be related with economical crises in the construction sector.

Traditionally most CDW was landfilled. In order to minimize the use of the non-renewable natural resources and to minimize the negative impact of the production and management of CDW, EC established legislative framework for the handling the waste in the Member States (MS) with CDW included. The Waste Framework Directive [8] regulates general aspects of European waste legislation and it defines the term “waste” and outlines the essential requirements waste management measures. It also establishes major principles such of handling the waste in a way that does not have a negative impact on the environment or human health. According to The Waste Framework Directive [8], MS have to take any necessary measures to achieve a minimum target of 70% (by weight) of CDW by 2020 for preparation for reuse, recycling and other material recovery, including backfilling operations using non-hazardous CDW waste to substitute other materials. One
of the main recommendations given by Waste Framework Directive is CDW recycling that offers important opportunities:

- To reduce land disposal requirements for landfilling
- To avoid overconsumption of natural non-renewable aggregate resources, by introducing alternative and supplementary materials in the aggregate market
- To create new business opportunities from waste recycling [9].

Even thought, the data about generation, composition and recycling of CDW waste are very limited, some data shows that the level of recycling and reusing of CDW varies greatly across the EU [10] as seen in Figure 4.

![Figure 4 Recycled rate of the CDW for some countries in the EU [10]](image)

Mainly CDW is used as a by-product for low-value-added applications such as landscape restoration, despite the quality of the recycled aggregate. A large proportion of CDW has the potential to be reused or recycled within the construction sector in order to contribute to saving natural resources and energy. Most of CDW’s components have a high resource value. Except landscaping, recycled aggregate derived from CDW can be reused in the road construction (unbound sub-base and base layers, hydraulically bound layers, bituminous surface pavements), cementitious mortars and concrete [11].

In order to reach a minimum target of 70% (by weight) of CDW for reusing, innovative ways of reuse and recycling strategies are needed. Therefore, in cooperation between academic community and construction industry, concrete mixtures with several different amounts of CDW were optimized in order to maximise usage of recycled CDW without the reduction of mechanical and durability properties of concrete. This new concrete was used in new innovative precast energy efficient concrete product – ECO-SANDWICH®.

3 Energy efficiency of buildings

Existing buildings are responsible for more than 40% of global energy use, e.g. in Croatia 83% of buildings consume from 150 to 200 kWh/m²/a just for heating, and therefore sustainability and energy efficiency are not a question of choice any more, they are the inevitable way of life. The ones who are still not aware of that, in close future will be „forced” to embrace it, „forced” by national strategies and natural environment itself.

On 28th June 2013, the EC published a report on progress made by MS towards Nearly Zero Energy Buildings (NZEB), which are to become the standard for all new buildings in the EU by the end of 2020, and two years earlier for public buildings [12].
Construction industry, as one of the main indicators of country’s development and welfare, is already being „forced” to reorient to the sustainability. One significant cause of reorientation of construction industry toward sustainability is present Global crisis. Only the most quality and innovative projects will overcome crisis. There will always be investors interested in attractive projects and there will always be customers (with high purchasing power and low purchasing power) ready to invest in real estates that are in some aspect different from common ones, and from that point of view energy efficient buildings are interesting segment of stock market.

Johnson Controls Inc. [13] defines energy efficiency as the first step toward achieving sustainability in buildings. Energy efficiency helps control rising energy costs, reduce environmental footprints, and increase the value and competitiveness of buildings. The first priority in the designing green buildings is energy efficiency. Energy efficiency of buildings must be observed as a whole, and it implies understanding of technical products that deliver the best outcome, the performance requirements of the building, and the goals and needs of the people inside the building.

There are also important co-benefits from making buildings more energy efficient, including job creation, fuel poverty alleviation, health improvements, and better energy security and industrial competitiveness [14].

It is necessary to emphasize, that it’s not enough to retain only on individual low or zero energy buildings. Mankind need to think broadly and aspirre to completely low or zero energy neighbourhoods and cities, in order to achieve „efficient” energy efficiency.

4 Precast construction

To achieve energy efficient buildings, engineers must observe construction as a whole, not only focus to the energy efficient materials.

Building with precast construction elements is familiar way of construction and in today’s era of energy efficiency it has great capability. Constructing with precast elements offers great advantages such as safer, quicker and cheaper building. With precast way of construction, construction is practically moved to the factory into controlled conditions. Precast buildings have to satisfy all requirements of mechanical resistance and stability - Ultimate Limit State (ULS) and Serviceability Limit State (SLS) as „traditionally built buildings” and they can be at least equally energy efficient as „traditionally built buildings”. So the main difference is in the construction technology. It can be said that energy efficient buildings built with precast panels (and other precast construction elements) are structural revolution if we observe final product (energy efficient building) in terms of time, money, natural resources, sustainability and achieved level of energy efficiency of the building.

Precast construction decreases time needed for construction, which reflects with lower construction cost. Also, with producing as much as it is possible in factory, the safer and less wasteful construction process becomes. On construction site, precast panels are embedded into load bearing frame of the building. Precast panels (and other precast construction elements) are expanding the construction market and creating new jobs.

Today’s precast construction sets new limits and challenges. One example of real construction challenge and architecturally attractive project is Dubai Rotating Tower with 420-meters height and 80 moving floors in Dubai, United Arab Emirates, designed by architect David Fisher. Each floor will be able to rotate independently. This will result in a constantly changing shape of the tower (Figure 5). The Dynamic Tower in Dubai will be the first skyscraper to be entirely constructed in a factory from precast parts (Figure 5). The
Dynamic Tower in Dubai utilises wind turbines to generate electricity for itself, making it the first designed to be self–powered [15].

![Figure 5: Left – Different shapes of Dubai Rotating Tower ; Right – Construction of Dubai Rotating Tower with precast segments [15]](image)

### 4.1 Sandwich Panel Walls

Precast sandwich panels, also called Structural Concrete Insulated Panel (SCIP), are construction elements completely made in the factory in the controlled conditions. They provide an energy efficient solution for building envelope and fulfil requirements of exterior membrane, thermal insulation, moisture barrier and interior finish.

Precast sandwich panels are typically made of an external concrete layer (non-load bearing), an insulation layer and an internal concrete layer (load bearing). Special connectors placed during casting are connecting those three layers. Some of the connecting systems in use today are plastic pin systems, carbon - fiber truss systems, solid concrete sections and various bent steel - shaped systems.

During the selection of the connectors’ material, it is important to consider conductivity of the material being selected. The highly conductive material can cause the connecting system act as a thermal bridge allowing unwanted heat to pass through the thermal insulation layer. This will result with the increase of overall heat transfer coefficient (U – value) of the insulated precast concrete panel to increase. The thicker layer of thermal insulation and the lower energy building it is, the higher influence on building will have thermal bridges.

Three types of thermal insulation are commonly used in SCIP. The common types of insulation in precast insulated wall panels are:

- Expanded polystyrene (EPS)
- Extruded polystyrene (XPS)
- Polyisocyanurate (PIR)

Great advantage of SCIP comparing to other less - massive Structural Insulated Panel (SIP, e.g. metal sandwich panel) is a very high thermal mass. Thermal mass describes the ability of a material to absorb, store and later release heat at a rate roughly in step with a building's daily heating and cooling cycle. Concrete and masonry products, being dense material, can absorb and store a lot of heat, thereby can delay and reduce peak HVAC
(heat, ventilation and air conditioning) loads. This may allow for initial building cost decreases in the form of a smaller-capacity HVAC system.

The use of connectors with very low thermal conductivity, along with the extremely tight building envelope that is created by the use of precast concrete insulated wall panels, creates a energy very efficient building. Connectors with low thermal conductivity will minimize heat transfer from the exterior concrete layer to the interior concrete layer and vice versa.

SCIP building envelope will require very little maintenance over the life span of the structure. Standard maintenance on this type of construction includes only occasional cleaning as aesthetically desired, and maintenance of the caulking and waterproofing systems. The insulated concrete wall panel system will deliver a service life of more than 75 years [16]. In Table 1 are shown main advantages and possible applications of SCIP.

Table 1: Advantages and possible applications of SCIP

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>APPLICATIONS</th>
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<tbody>
<tr>
<td>Low U – values</td>
<td>Commercial offices</td>
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<tr>
<td>Excellent thermal mass properties</td>
<td>Hotels</td>
</tr>
<tr>
<td>Excellent acoustic properties</td>
<td>Retail and bulky goods</td>
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<tr>
<td>Faster construction time: quick installation by highly skilled crews; less weather dependent</td>
<td>Industrial – warehouses and factories</td>
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<tr>
<td>Simplified and safer construction process: less trades on site; less waste; less materials handling</td>
<td>Multi – unit residential, housing</td>
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<tr>
<td>Controlled conditions in factory</td>
<td>Airports</td>
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<td>Quality product: off-site manufacture means high quality</td>
<td>Railways</td>
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<td>Minimal site disturbance</td>
<td>Education</td>
</tr>
<tr>
<td>Fire resistant</td>
<td>Correctional facilities</td>
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<tr>
<td>Design flexibility: many surface finishes and patterns available</td>
<td>Health and aged care</td>
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<tr>
<td>Durable: high strength; factory produced, precast concrete offers the ultimate outcome with minimal maintenance</td>
<td>Cinemas and theatres</td>
</tr>
<tr>
<td>Decreased life costs (HVAC costs) during the exploitation of building</td>
<td>Clubs, libraries, churches and community centres</td>
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5 INNOVATIVE STRUCTURAL CONCRETE INSULATED PANEL

This paper presents an example of an innovative Structural Concrete Insulated Panel, called ECO - SANDWICH®. This innovative SCIP is a ventilated precast wall panel utilising recycled CDW and mineral wool produced using innovative and sustainable Ecose® technology for reduction of primary energy consumption in the building stock. It is applicable for very low energy design and retrofit of buildings. Innovative SCIP represents
a significant improvement over the existing precast wall panel products due to development of a ventilated precast concrete wall panel that uses mineral wool as core insulation and recycled aggregates as a replacement of a natural aggregates in concrete layers, aligning itself with the mandatory targets of the EU Energy Performance of Buildings Directive – EPBD, its Recast EPBD II and with Waste Framework Directive targets.

This innovative SCIP consist of two precast concrete layers interconnected through stainless lattice girders. 50 % of the total aggregate quantity needed for production of concrete layers has been replaced with recycled aggregate obtained from CDW. The inner (load bearing) layer of the ECO - SANDWICH® is made of recycled concrete aggregates while the outer façade layer is made of recycled brick aggregates. The Ecose® based mineral wool provides significant environmental advantages. It is manufactured from abundant recycled (glass bottles, plate glass, internal waste; up to 85 % of total content of resources) and naturally (silica) occurring materials; the technology is free from formaldehyde, phenols, pentanes, butanes and acryliics, it has lower embodied energy than traditional oil based binders (reduced up to 70 %), it improves the overall sustainability of buildings and it has no artificial colours or dyes. In addition, the performance of Ecose® based mineral wool does not deteriorate over time and is fully recyclable at the end of a building’s life. Between Ecose® Technology mineral wool and outer concrete layer a 4 cm ventilated layer is inserted to prevent damping of insulation material. Inner and outer layer of concrete are interconnected with a stainless steel lattice girders. The inner concrete layer is connected to the load bearing structure of the building (columns, walls) by the stainless steel connexion.

![Figure 6: Cross – section of ECO – SANDWICH® wall panel](image)

During the research, different concrete mixtures were prepared in which a thorough analysis of mechanical and durability properties was performed. The aim of testing was to optimize concrete mixture for innovative SCIP.

In the mixtures, proportions of the recycled aggregate of 40 %, 50 % and 60% were varied. All concrete mixtures were produced with cement CEM II A/S 42.5 R. As aggregate, natural sand of the nominal size 0-4 mm from two sources was used: river sand and crushed aggregate together with recycled concrete (RB) and recycled brick (RO) aggregates 4-8 mm and 8-16 mm. For concrete mixtures with 40 % of recycled aggregate, natural crushed aggregate 4-8 mm was also used. Recycled concrete aggregate was produced by crushing waste brick. Except aggregate, proportion of other components was the same in all mixtures: 400 kg of cement, w/c = 0.42 and air entraining plasticizer MELCRET SPA 0.7 % per weight of cement.
After mechanical and durability testing [17], it was decided that inner layer of innovative SCIP will be made with 50% of recycled concrete aggregates while the outer façade layer will be made with 50% recycled brick aggregates.

Thermal properties of the innovative SCIP are determined by the U-value. The U-value is calculated according to HRN EN ISO 6946:2008 and HRN EN ISO 13789:2008 for known material properties and thickness of every single layer of the precast wall system. The U-value of the innovative SCIP is ≤ 0.2 W/(m²K), which is less comparing to similar SCIPs (e.g. precast concrete wall panels with EPS core) with the same thermal insulation thickness and conventional concrete, but the innovative SCIP has higher U-value comparing to the other SIPs (e.g. metal sandwich panels) with the same thermal insulation thickness. It is necessary to emphasize the advantage of this innovative SCIP comparing to the metal SIPs, and it is higher thermal mass of the innovative SCIP. As a result of higher thermal mass, buildings built with presented innovative SCIPs need approximately 11% less energy for cooling and 22% less energy for heating compared to buildings built with metal SIPs with the same thermal insulation thickness.

Innovative SCIP as construction element and building built with these innovative SCIP as a whole, if designed and constructed properly, satisfy and guarantee ultimate limit state (ULS) defined by mechanical properties and serviceability limit state (SLS) defined by thermal and sound insulation properties.

Sound reduction index of presented innovative SCIP and similar products has been calculated according to national standard HRN EN 12354 based on known material properties and dimension (thickness) of every single layer of the sandwich wall panel. In computer programme, presented innovative SCIP was simulated as classic barrier without openings.

SCIP 1 consists of inner layer of conventional concrete (6 cm), EPS core (20 cm) and outer layer of conventional concrete (6 cm). SIP 1 consists of XPS core placed between aluminium layers (0.1 mm). SIP 2 consists of mineral wool core (20 cm) placed between steel layers (0.1 cm).

Sound reduction index of this innovative SCIP is $R = 53$ dB and it is significantly higher comparing to similar SCIP and similar metal SIPs with the same thermal insulation thickness, Figure 8. Higher sound reduction index $R$ is resulting with better sound insulation of buildings built with presented innovative SCIP.
Figure 8: Sound reduction index of ECO - SANDWICH® and other sandwich panels available on market

Precast construction offers a wide range of possibilities for architects and civil engineers to design aesthetically attractive low energy buildings, to combine precast elements with other construction materials and create new opus of modern passive architecture, as shown on Figure 9 (example of multifunctional hall).

Figure 9: Visualization of possible application of presented innovative SCIP (Author: Prof. Ljubomir Miščević, Arch; Faculty of Architecture, University of Zagreb)

6 CONCLUSION

Construction industry is facing with two main challenges: Global crisis and demands of protecting the environment. Both challenges can be met with the new innovative construction technologies, construction materials, construction elements and structures as a whole. Nowadays, innovation implicates energy efficiency and sustainability. Also architects and civil engineers are dealing with increasingly demanded construction market: better quality standards, fast construction and quality performance guarantee.

As familiar but not widely used, building with precast construction elements has great capability in the area of the energy efficiency of the building. Made in the controlled conditions with great thermal performance, precast sandwich panels represent better solution for high construction markets’ demands. As said, they provide an energy efficient solution for building envelope and fulfill requirements of exterior membrane, thermal insulation, moisture barrier and interior finish.
Therefore, investments in the precast construction, taking account high demands for the environment protection, reuse of material and energy efficiency of the buildings, can be one of the solutions for revival of construction sector and economic recovery.

Without collaboration among industry and academic community in R&D projects, progress of construction industry in this Global crisis is minute. In this paper this collaboration resulted with innovative SCIP called ECO - SANDWICH®. Contribution to innovation of the ECO - SANDWICH® wall panel is the development of a ventilated prefabricated concrete wall panel that uses mineral wool as core insulation. Additionally, this innovative SCIP is made with 50% of aggregates recycled from CDW (by total volume) while the Ecose® mineral wool uses bio-based materials free from formaldehyde, phenol and petrochemicals and its embodied energy is 70% lower than for conventional mineral wool. By using CDW in production of innovative precast panels, the Waste Framework Directive is being respected and global CDW problem is being dealt on a much effective way than when landfilling.

Construction with presented innovative SCIP provides user a high quality, affordable, energy saving and aesthetically attractive concrete building on principles of ‘‘turnkey’’ construction. ‘‘Turnkey’’ construction of precast energy efficient buildings with presented new SCIP extends construction market, sets new limits of quality in precast construction and fosters new jobs because presented innovative SCIP has the competitive advantage over the competing SCIPs available on market.

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