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The Urban Lab of Europe !

# The Urban infra revolution project Journal N° 1

*Project led by the Municipality of Lappeenranta*



**CIRCULAR  
ECONOMY**

# The Urban infra revolution project

To mitigate the various risks posed by climate change, Urban infra revolution seeks to significantly reduce CO<sub>2</sub> emissions - 80% reduction of CO<sub>2</sub> emissions from 2007 level is the target for 2030 and completely eliminate waste is the target for 2050.

Urban infra revolution will test new solutions to reduce CO<sub>2</sub> emissions in urban construction development. Side streams from industry (ashes, green liquor dregs, tailings, construction waste) will be utilized in urban construction by combining them into a high-value material to replace concrete. Novel material formulas will be created containing suitable side streams to be used as geopolymer binder (replacing cement) and as inorganic aggregates in geocomposites. An innovative bio-fibre reinforced geo-composites will be developed to achieve the high standards of construction industry. Automated, on-site, fast and versatile additive manufacturing construction system, without molds, will be tested in comprehensive urban scale. The material and the piloted technology will be multifunctional and enable aesthetic design with revolutionary shapes with very low CO<sub>2</sub> emissions. Selected pilot structures will be manufactured within the urban infra and their properties are tested in real climate conditions. To implement and finally benefit locally the project results, a viable sustainable business ecosystem will be designed and environmental and socioeconomic impacts assessed.

**Partnership:**

- Municipality of Lappeenranta;

**4 SMEs:**

- Apila Group Ltd.;
- FIMATEC Finnish Intelligent Module Apartments Oy;
- Design Reform Ltd.;
- Totaldesign Ltd.;

**5 private enterprises:**

- UPM-Kymmene Oyj;
- Outotec Ltd.;
- Nordkalk Corporation;
- Metsäliitto Cooperative;
- Stora Enso International Oy;

**2 higher education and research institutes:**

- Lappeenranta University of Technology;
- Saimaa University of Applied Sciences;

**1 Region Development Company:**

- Imatra

# Table of Contents

<b>1. Executive summary</b>	<b>5</b>
<b>2. The context for the Urban infra revolution project</b>	<b>6</b>
2.1 Global & European context	6
2.2 Lappeenranta & green reality	7
<b>3. The Urban infra revolution concept</b>	<b>8</b>
3.1 The aims of the project	8
3.2 Key components	10
3.3 The consortium composition & key stakeholders	13
<b>4. Implementation status</b>	<b>15</b>
4.1 The main activities	15
4.2 Main challenges & risks	15
<b>5. Conclusions and next steps</b>	<b>20</b>

# 1. Executive summary

The journal presents the progress in implementation the Urban infra revolution project is an answer for important global challenges connected with circular economy. The second section of this journal presents the background for the project and the global, European and regional context for the undertaken planned activities. It stresses the importance of this project for European policy. This section also introduces into the main project idea and shows complementary activities for sustainable development that Lappeenranta was undertaken.

The next section is a short project presentation, including the main objectives and construction of the project. The project is very complex and there is a large number of organizations involved in the project activities. In the framework of the consortium the different organization collaborate together. On the one side it creates huge possibilities of innovative actions, but on the other side is great challenge for management. Additionally, the main stakeholders are included in this section.

The fourth section of the journal presents the implementation status of the project. The project started in November 2017. The first half year was a period of intense work not only for a material solutions and basement assumptions for additive technology, but also the creation of the management structure and the establishment of the proper procedures of communication between consortium members. In this part, it is also described the difficulties, barriers and challenges linked to the experimental nature of the project. This section presents the activities that are undertaken to create the right conditions and lowering the barriers. The most of risks in this period were connected with innovative character of the project. There were applied three main innovative area: material, production process and products. The project has an innovative nature. It is not only implementation of existing solutions, but also defining new standards and providing intense scientific research.

The last section summarises the state of the project and presents the steps that will be made in the near future.

## 2. The context for the Urban infra revolution project

### 2.1 Global & European context

This project is in line with the EU action plan for circular economy by finding new uses for recycled materials, increasing resource efficiency and lowering the carbon demand and achieve recycling level of C&D waste required by the European Union in 2020 (70%). The project also promotes the EU's 7th Environment Action Programme<sup>1</sup> with the priority objectives.

Present urban infrastructure consists mainly of steel reinforced concrete based solutions. Both these materials contain high energy, virgin raw materials and are intensive in CO<sub>2</sub> emissions. In the Lappeenranta area alone, CO<sub>2</sub> emissions from cement and lime production is ca. 393 000 ton/CO<sub>2</sub>. Current production methods are also time and labor intensive, and don't allow innovative shapes nor additional functions to the products. Recyclability of concrete is restricted: recycling of steel reinforced concrete elements is a complex and costly process. These difficulties usually lead to the situation, that construction waste remains landfilled and generates unwanted costs. Little attention is also paid into recyclability of modern composite materials. Except demolition waste, there are also other materials in industrial cities that are landfilled unnecessarily: tailings from mining, green liquor dreg and ashes from the forest industry and energy production. This project strives to create sustainable, fully recyclable solutions for these local side streams that are large in volume but also challenging to

reuse. In South Karelia, mining generated side streams and tailings are 884 000 ton/a. Tailing waste from partnering Nordkalk equals ca 170000 ton/a. Total amount of slags and ashes generated in the county is 21 507 t/a.

Today, most national research funding organisations and EU funding instruments support R&D projects improving the transition to circular economy. Development of alternative solutions to high energy consuming cementitious binders is one of the main concerns of the project. There is a need for new sustainable binders with lower CO<sub>2</sub> emissions and lower embodied energy of the binders used in the construction sector to design sustainable building envelopes. There is a world-wide demand for more efficient building products to significantly reduce energy and resource consumption. The EU legislation is promoting the idea of eco-design and its application in the building industry, so the idea of sustainable product development should be actively promoted.

Another EU challenge is awareness about natural resources and efficiency in waste management. The project faces this challenge through the taking under consideration different waste materials as a raw products. A lot of mineral deposits in Europe are mostly depleted and, due to economic growth construction and demolition waste (CDW), it has become a serious problem.

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<sup>1</sup> <http://ec.europa.eu/environment/action-programme/>

In the EU, CDW accounts for approximately 25% - 30% of all generated waste, and it consists of numerous materials, many of which can be recycled. The EC Waste Directive says, in Art 11-2b, that: *"...by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material (...) shall be increased to a minimum of 70 % by weight."* The project will reuse debris generated during construction, renovation, and demolition of buildings but also other waste materials and by-products, like fly ash, bottom ash, biomass ash, mining wastes and other aluminosilicates waste minerals. Reuse of waste in making innovative materials

for urban architecture. The additional value for this topic is to change the way of thinking about these materials and, by recycling those complex products that contain a lot of valuable raw materials, creating more sustainable future products. The actions in the area of Recycling of products and buildings are linked to the European Priority Area "Improving Europe's waste management regulatory framework conditions and excellence" in terms of standardisation, including a classification of construction waste as construction materials; as well as of recycling complex products and buildings containing a lot of valuable raw materials in a cost-effective, resource and energy efficient and environmentally sound way in order to increase domestic EU production of raw materials.

## 2.2 Lappeenranta & green reality

Lappeenranta is a city founded in 1649 on the shore of the lake Saimaa in south-eastern Finland, about 30 kilometres from the Russian border. It belongs to the region of South Karelia. The city has approximately 73,000 inhabitants. Lappeenranta has undertaken a lot of activities for sustainable development. The city was the only Finnish city among the 14 finalists in the international Earth Hour City Challenge 2014, organized by WWF. Nowadays, Lappeenranta is the largest Finnish city to join of the HINKU carbon reduction initiative. The main aim of the initiative is reduce emissions by 80% by 2030 through the increasing the use of renewable energy and improving energy efficiency. The city is a pioneer of environmentally friendly energy production.

The Urban infra revolution project is fully in line with this strategy and goes even further. One of the city's strategic objectives is to establish Lappeenranta as a model city for sustainability, where growth is generated from

a clean environment and a waste-free world. In 2050, the city would like to have no landfill waste, no greenhouse gas emissions and no overconsumption.

The new solution (material, method, products, business models) enhances business in variety of industries, and employment is addressed. The project interlinks experiments to normed, regulated industry and supervisory authorities by novel material and methods, aiming to new innovative approaches in construction industry. Additive manufactured, technically improved urban structures strive for more versatile urban space usage exemplary new possibilities for outdoor recreation.

# 3. The Urban infra revolution concept

## 3.1 The aims of the project

The main aims of the project are:

- Enhancing sustainable construction in cities.
- Developing revolutionary urban design.
- Enhancing circular economy in local urban construction businesses.
- Developing climate change adaptation and mitigation.

Enhancing sustainable construction in the cities will be developed through the integrated approach and complementary partnerships of the project providing a platform for sustainable urban building development by enabling novel, high quality solutions for the urban construction value chain. The project strives for the integration of environmental, economic, social and cultural dimensions of urban development. In this project the closed loop of materials and faster, safer, more versatile industrial scale production methods that minimize negative externalities of construction are experimented.

Implementation of the other aim - developing revolutionary urban design - will be based on interaction of urban authorities, citizens, urban design experts, material R&D expertise and advanced additive manufacturing technology. Applicable manufacturing technology and developed novel bio-fibre reinforced geocomposite material allow for designing revolutionary urban structures about unique aesthetic value that will contribute to urban safety and welfare by demonstrating multifunctionality and innovative use of space.

Enhancing circular economy in local urban construction businesses is also an important project aim. The object is to develop scalable and transferable circular economy demonstrating business models based on added value of local industrial symbiosis. Through the project, business for local SMEs in technology development and construction as well as large industries will be enhanced. Novel, recyclable and industrial specifications meeting products have considerable industry relevance with international markets.

The project aims are holistic solutions for developing climate change adaptation and mitigation that enhance the storage of carbon in process of raw material sourcing, manufacturing, transportation, installation and assembly. The project allows to introduce the circular economy through closing the loop with 3D printable, recyclable geopolymer composites made of side-streams (Figure 1).

The project's main implementation activities will include a lot of linked activities. Firstly, converting the industrial side streams into recyclable materials than can be utilized in arctic condition construction including the comprehensive physical and chemical characterisation of various side streams considered in the project and tailoring of these materials to achieve the desired properties. Next tasks will be to develop suitable material technology and simultaneously manufacturing methods. These elements are connected and required perfect feedback between each other. The important element is also scaling the technologies developed to



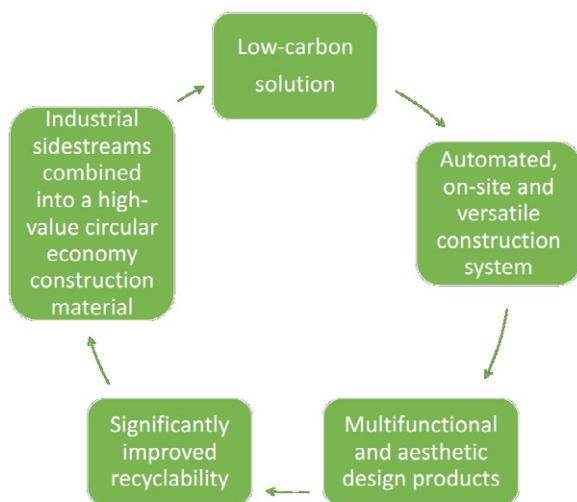


Figure 1. Closing the loop with 3D printable, recyclable geopolymer composites made of sidestreams.

Source: Matilainen M., 2018, Urban Infra Revolution UIR Developing a clean, safe and renewable city, <https://geopolymer.org/fichiers/?dir=gpcamp-2018>

industrial scale. This will include designing, building and testing a new additive manufacturing device that will be used for manufacturing the final functional structures made of industrial side streams. It helps with reforming the methods of urban building, creating a vision of “urban city 2050” with designers, policy-makers, citizens and other participants. Final activities will be designing the implementation of the proposed innovation, additive manufacturing construction elements from geocomposites utilising industrial side streams, conjointly from business and environmental perspectives. As a result, a viable sustainable business ecosystem is designed and environmental impacts are assessed (Figure 2).

The outcomes contribute directly to the ambitious goal on carbon free and waste free cities by reduced amount of unutilised waste from local industries and lower CO<sub>2</sub> emissions. New innovative products and new industrial scale technology enhance the local industry business and accelerate the employment possibilities in circular economy. Developed materials and technology improve the safety of construction areas and enhance construction

industry sustainability and productivity. Industrial symbiosis created adds bilateral value for project partners and local construction industry creating improved possibilities to operate in South Karelia region. Aesthetic urban scenery upgrades the living convenience in the city whereas multifunctional and technically improved urban structures strive for improved citizen welfare in the city by a holistic approach by enabling for example better noise control, more versatile urban space usage and new possibilities for outdoor recreation and light traffic in extreme conditions.

As an outcome of the project, the following results will be achieved:

- Closed loop in construction demonstrated: recyclable products of recycled materials for urban construction.
- Unutilised side streams/recycled materials used as raw materials to avoid the use of virgin materials.
- Technically improved new materials in closed loop urban structures applicable for extreme climates.
- Revolutionary, aesthetic, safe multifunctional urban structures solving real urban issues for example neighbourhood noise control and safety protection.
- Product acceptance procedures and criteria created.
- Enhanced value-generating circular economy business for local industries.
- Existing international mMarkets for the solution.
- Lower carbon emissions by replacing use of cement with circular materials and by use of recycled raw materials from local sources to reduce logistics CO<sub>2</sub> production and transportation energy consumption.

## 3.2 Key components

New generation urban development is focusing a lot on smart technologies, but modern construction engineering is a more important role when creating smart cities. The main conception is that the side-streams from industry will be utilized in urban construction by combining them into a high-value material to replace concrete. Thanks to it the CO<sub>2</sub> emissions will reduce by avoiding the use of cement and preferring local material sources. During the project the side-streams will be analysed, characterized and modified by activation. In the same time the method to pre-treat and activate tailings will be developed separately. Novel material formulas will be created, containing suitable

side-streams that will be used as a geopolymer binder (replacing cement) and as inorganic aggregates in geocomposites. The next step will be a fibre additive. An innovative fibre reinforced geocomposites will be developed to achieve the high standards of construction industry. Owing to this, a method to recycle the products directly after crushing can be developed and unnecessary dumping of constructional waste can be avoided. In the laboratory scale items will be prepared to test the material combinations (Figure 3), before they are used and tested in full scale piloting, to ensure the quality, technical performance, safety and appearance of the materials and products in arctic climate conditions. Multifunctional and

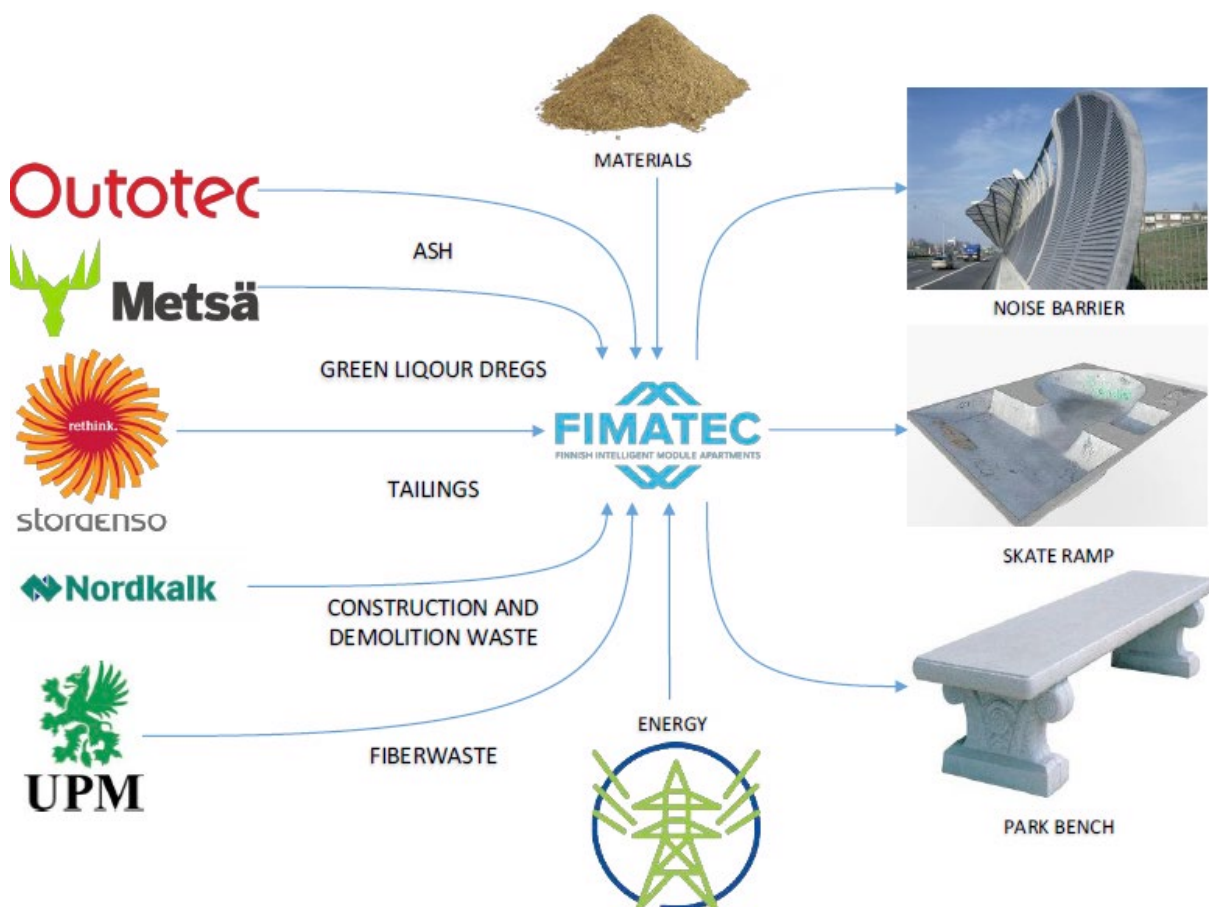


Figure 2. The project conception, including involved organizations.

Source: Matilainen M., 2018, Urban Infra Revolution UIR Developing a clean, safe and renewable city, <https://geopolymer.org/fichiers/?dir=gpcamp-2018>

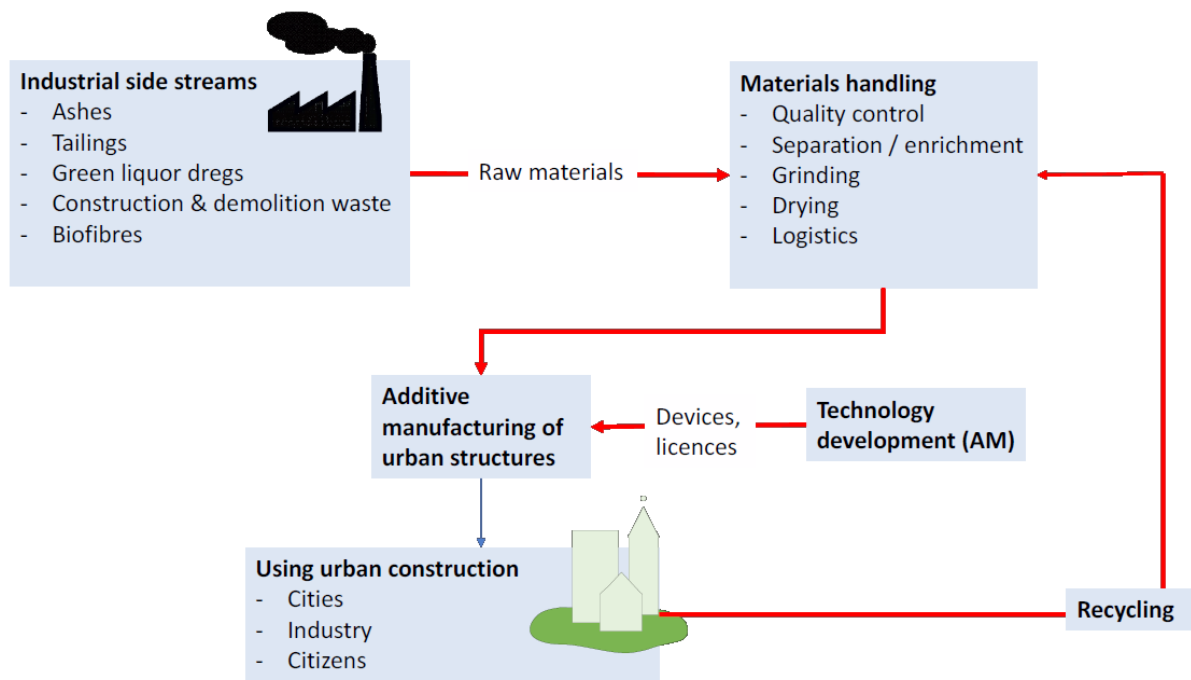


Figure 3. The scheme of the activities in the project.

Source: Matilainen M., 2018, Urban Infra Revolution UIR Developing a clean, safe and renewable city, <https://geopolymer.org/fichiers/?dir=gpcamp-2018>

aesthetic products, that cannot to be prepared with conservative construction methods, will be designed to create a novel urban environment. The innovative future vision, Urban City 2050, will be created and visualized in a Virtual environment, in cooperation with designers and stakeholders. Novel construction solutions for the urban environment will be designed. Multifunctionality of the products will be ensured with innovative shapes. Design restricted product methods will replace with an IT-directed device, and time and labor intensive methods with automated, additive manufacturing method. This allows a low-carbon and safe on-site building, avoiding disposable moulds and unnecessary transportation. Selected pilot structures will be manufactured within the urban infra and their properties are tested in arctic climate conditions (Lappeenranta). Industrial piloting for more demanding conditions will be piloted in the same way. To implement and finally benefit locally the project results, a viable sustainable business

ecosystem will be designed and environmental and socioeconomic impacts will be assessed. The final implementation of the results demands the creation of the circular economy business model. Social and technical acceptance of the materials is crucial; this requires both chemical, physical and sociologic testing, and life cycle analysis. The final revolution and enhance in local business is possible, transferrable and replicable globally, when the acceptance procedure and incorporation of product specifications are prepared (Figure 4).

In the project, it is possible to specify the key components:

- Material- the materials developed can be utilized widely in different applications in urban infra and industry, also in arctic, extreme weather and chemical conditions, to replace concrete. As similar raw materials/ side streams are produced nationally (millions of tons annually) and internationally, the

solution is easily transferable and scalable. It is also possible to scale-up the solution internationally through the internationally operating industrial partners. Because of that demand for these new materials is stated internationally.

- Products - designed products replace common, widely used structures in urban environment. The global concrete market size 2015 was USD 492.2 billion. Better performance makes them more attractive and popular, enhancing business potential. The durability in extreme climate and recyclability provide sustainable solutions for international markets.
- Method - additive manufacturing technology is a mobile application that can also be utilized by SMEs, and will be commercialized internationally (by 2020).
- Business - defined business models are adjustable to enhance local businesses

globally. Solutions provide new possibilities for variety industrial sectors (waste origin raw material preparation, urban design, technology developing and manufacturing, construction industry) and sizes. Only in Finland, annual building construction markets are 22 billion EUR.

Resources needed - legal acceptance of the solutions is mandatory for scaling-up. The operators in the local sector are contacted in the project, to find suitable/willing actors to start full-scale production. If needed, additional national operators will be contacted to scale-up the solution. Final responsible operators are obliged to invest in the technology and licenses, to utilize the solution. Local administrative support (also financial) will be needed. Project partners are internationally operating corporations, creating a base for international markets for the solution.



Figure 4. The project team working on materials compositions.



### 3.3 The consortium composition & key stakeholders

Construction has been one of the slowly growing industries in the area: there are over 1000 offices and it employs over 3,800 people. Mining and forest industry employs altogether 3,500 people. Unemployment (2016) rate in Lappeenranta area is ca. 14,6% and in the Imatra area 16,4% as average unemployment rate in Finland is 13,2%. Partnering Outotec, Norkalk, UPM-Kymmene, Metsä Fibre are among the biggest employing companies in Lappeenranta. Stora Enso is one of the biggest employers in Imatra. This project facilitates practical circular economy business affecting widely to the socio-economic-environmental welfare of the area.

The project is implemented by grate consortium that include different organizations representing different sectors of the economy. The vertical

integration of waste producing industries (mining, forestry), research, R&D, technology producers and end users enables efficient process from idea towards commercialised products, as the cooperation of big organization and SME's create complementary horizontal integrations (Figure 5). Lappeenranta University of Technology contributes comprehensive knowledge about industrial side stream processing and simultaneous economic-technical-environmental examination of the solutions developed in the project. R&D SMEs provide required expertise in material formulation, urban design and procedures for ad hoc solution building and prompt piloting. Technology producers ensure the constructability of the aimed solution and vice versa. Cities providing a live urban piloting platform and dialogue with local society ensure

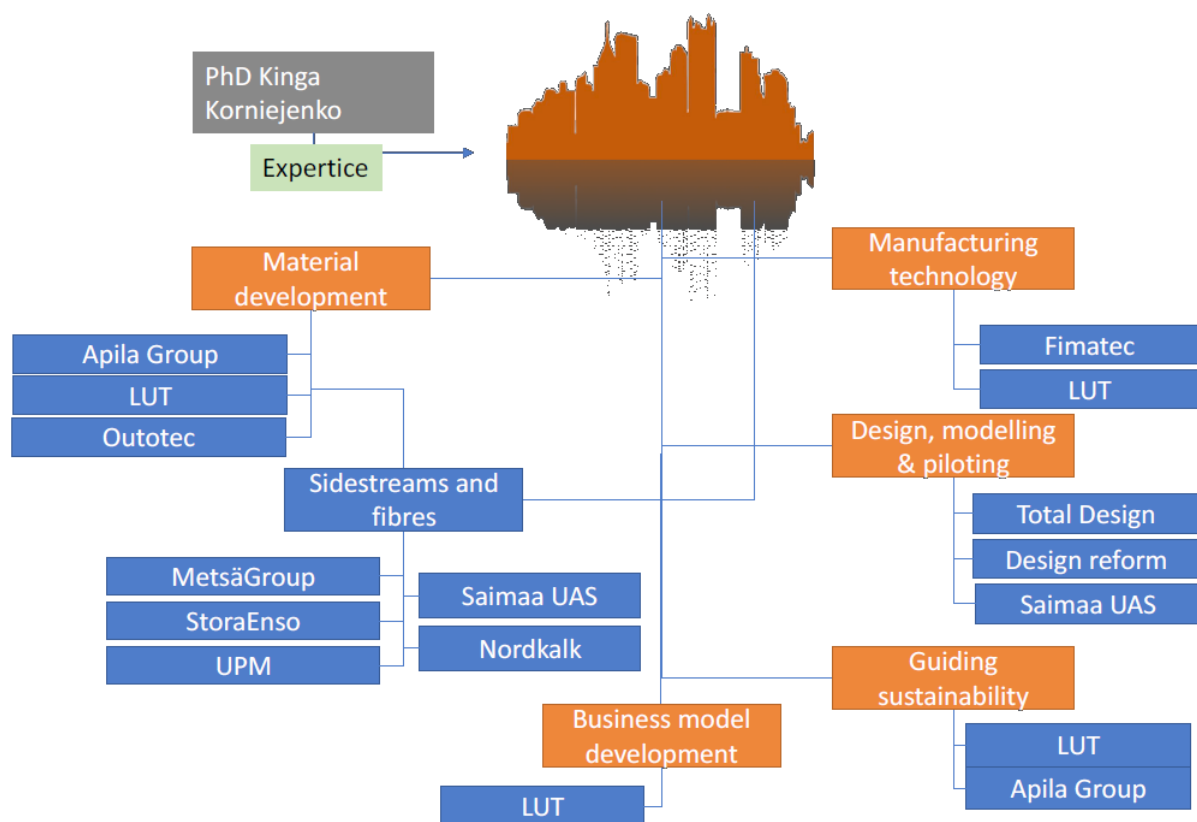


Figure 5. Consortium composition.

Source: Matilainen M., 2018, Urban Infra Revolution UIR Developing a clean, safe and renewable city, <https://geopolymer.org/fichiers/?dir=gpcamp-2018>

citizens and urban planning satisfying results. Globally operating industrial partners provide a sustainable base for international markets for the developed solutions. Throughout the project, competitive circular economy business models, value chains and cross sectoral cooperation will be created to develop a sustainable solution for market demand.

The project plan will engage the stakeholders at each step. Beginning at the creation of the idea, through the implementation, ending of the results promotion. The project idea was introduced first in Green Lappeenranta Imatra (GLI) development group meeting in November 2016. The idea was approved to initiative measure. GLI group consists of members from city of Lappeenranta and Imatra, Regional Council of South Karelia, Tekes – the Finnish Funding Agency for Innovation and regional company representatives. The wider stakeholder group include GLI group and various relevant stakeholders like Green Energy Showroom (GES), which is an active network of energy and environmental sector companies operating in South-Karelia, the members of which want to generate business through sustainable solutions. The wider stakeholders have contributed to project design with supportive actions in communication and seeking for appropriate actors to start project design. Consultation and co-design by wider stakeholders has started in mid-November 2016. Project design started with identifying the needs: widely used cement in concrete manufacturing is very valuable and there is a massive amount of tailings, fly ash, soda ash (green liquor dregs), industrial side streams of forest and limestone industry available in the area. The yearly amounts of side streams exceed three times the amount of household waste. Balancing, recycling and innovation is highly needed. Promotion of circulation economy is spearhead of City of Lappeenranta's strategy.

The resource wise road map has approved in 2015 for achieving carbon neutral air, ensuring pure water and getting rid of waste by 2050. The construction industry is in process of big changes concerning materials, construction techniques, management and design. The wider stakeholder group participated in co-creation of the solutions to be tested and experimented.

The wider group of stakeholders includes local, regional, national and EU institutions, agencies, organisations and associations: Green Lappeenranta Imatra development group, Tekes, Regional Council of South Karelia, Hinku (network of carbon neutral municipalities), Finnish Sustainable Communities network, Green Energy Showroom (active network of energy and environmental sector companies operating in South Karelia (SK), over 40 members, companies, SMEs, universities, cities, municipalities who want to generate business through sustainable solutions). Environmental, employment and other related authorities and associations: Chamber of commerce of SK, Entrepreneurs of SK belong to stakeholders. In the project implementation, the City of Lappeenranta maintains a participative approach, share tasks and responsibilities with the stakeholders in all WPs. Stakeholders will contribute in implementation by supportive and assisting tasks for activities. They will enable experimenting and testing of novel circulated material and printed products of the new material for urban environment. Infrastructure modification, city design, environmental testing are tasks where various actors and experts are needed. Citizens, students, schools are important stakeholders in spreading and adapting new innovations and future mind-set. Stakeholders are important in dissemination activities and deepen expertise with their networks and experiences. Contribution of environmental authorities is essential throughout the project.

## 4. Implementation status

### 4.1 The main activities

The project started in November 2017. The first half year was the period of intense work not only for a material solutions and basement assumptions for additive technology, but also the creation of the management structure and the establishment the proper procedures of communications between consortium members. In this time more than 20 raw materials has been carefully investigated and they are applied as a part of geopolymers composites. The some promising recipes have been developed. Now, they are tested for processing properties.

An important element for the consortium is also communication. The communication base on both traditional collaboration (team meetings, Figure 6.) and modern ways of communication (via the Internet). The good communication is ensured through the consortium leader. All project partners participate in the decision



Figure 6. The project team working together.

### 4.2 Main challenges & risks

The main challenges connected with project implementation on the first stage are connected with the innovative character of the project.

The first innovative element is material. Growing environmental awareness and importance of development of sustainable construction materials for decreasing environmental impact of construction industry are main motivators to research works on new, innovative materials' solutions. The production of the most important building material of the 20th century - Portland

cement that there is a main material used for urban architecture, is associated with significant environmental pollution. The process requires very high temperature and it is energy consuming. During the manufacturing there is the emission of significant amounts of carbon dioxide and highly toxic nitrogen oxides into the atmosphere. Moreover it has a lot of other disadvantages such as: energy- and non-renewable natural resource-intensity and questionable durability<sup>2</sup>. It is clearly incompatible with rationally "sustainable". These

making process. The management of the project is performed in a way to ensure the active role of each of the partners: management plan with milestones and clear tasks for each partner.

<sup>2</sup> Łach M., Korniejenko K., Hebdowska-Krupa M., Mikula J., 2018, *The Effect of Additives on the Properties of Metakaolin and Fly Ash Based Geopolymers*, MATEC Web of Conferences, vol. 06005, pp. 8.

factors show that new solution in this area is required. The most promising alternative is inorganic polymer (geopolymer) technology<sup>3</sup>.

Geopolymers are a group of materials defining as inorganic aluminosilicate polymers with specific composition and properties. The name 'geopolymer' was first used by the French scientist Professor Joseph Davidovits in 1970. These materials have very high mechanical properties and excellent resistance to chemically aggressive environments, especially resistance to a variety of acids and salts<sup>4</sup>. They were initially developed as a fire resistant alternative to organic polymers. They have good fire resistance (up to 1000°C) and no emission of toxic fumes when heated<sup>5</sup>. Nowadays, the geopolymers are mainly applied in construction industry.

One of the expected result of the project is to design new materials for additive manufacturing, materials with tailored properties that are environmentally friendly and cost effective. The project will demonstrate the ability of new materials – geopolymers and processes to achieve finished components for construction industry with reduced life cycle costs. This composites should:

- closing the loop of construction material;
- be applicable for extreme (arctic) weather conditions;
- be reinforced with biofibres

- be based on local industry wastes is developed (Figure 7).

The project has undertaken the topic of biofibers for reinforcement the composites. The improvement the mechanical properties by reinforcing the matrix trough bio fibres addition is beneficial form the environmental point of view<sup>6</sup>. The replacement of the synthetic fibres with their natural counterparts reduces significantly the environmental impact (closing important life cycles, including CO<sub>2</sub>). The natural fibres have also other features such as<sup>7</sup>: low cost of production, low density, they are renewable in short time, non-toxic, and easy to process. It is also one of the most important innovative aspects in the project.



Figure 7. The raw materials invastigated in the project.

<sup>3</sup> Palomo A., Krivenko P., Garcia-Lodeiro I., Kavalerova E., Maltseva O., Fernández-Jiménez A., 2014, *A review on alkaline activation: new analytical perspectives*, Mater. Construcc., vol. 64, Iss. 315, pp. 22.

<sup>4</sup> Alomayri T., Shaikh F.U.A., Low I. M., 2013, *Thermal and mechanical properties of cotton fabric-reinforced geopolymer composites*, „Journal of Material Science”, vol. 48, p. 6746-6752.

<sup>5</sup> Vickers L., van Riessen A., Rickard W.D.A., 2015, *Fire-Resistant Geopolymers. Role of Fibres and Fillers to Enhance Thermal Properties*, Springer, Singapore - Heidelberg - New York - Dordrecht - London, pp. 129.

<sup>6</sup> Korniejenko K., Łach M., Hebdowska-Krupa M., Mikuta J., 2018, *The mechanical properties of flax and hemp fibres reinforced geopolymer composites*, IOP Conference Series: Materials Science and Engineering, vol 379, pp. 9.

<sup>7</sup> Natali A., Manzi S., Bignozzi M.C., 2011, *Novel fiber-reinforced composite materials based on sustainable geopolymer matrix*, Procedia Engineering, vol. 21, p. 1124-1131.



However the first public building with structural geopolymers concrete was built in 2013 in Australia and also the Russian company Renca has developed eco-friendly cement for additive manufacturing technology, still, there isn't formula for geocomposite or examples of construction products created being both additive manufactured in construction scale and achieve the properties to fill the highly regulated demands of materials in extreme conditions: strength, resistance to frost, dirt, moist, mould. In addition, there are no examples of geocomposites successfully reinforced with biofibres in industrial scale. Finland is one of the leading countries in the world in micro- and nano-scale cellulose composites. This technology is transferred to serve inorganic material technology and building industry. The innovation itself is potentially the first manufacturing method demonstrating fully closed loop construction: built on-site, local waste based and fully recyclable construction materials.

The second important innovative aspect in the project is additive manufacturing technology. The main challenge is not only development of zero-waste technology of 3D printing, but also use as a raw material waste products.

Additive Manufacturing is a rapidly developing industrial sector and, potentially, a disruptive technology. The project is an answer for new challenges such as resources saving and energy efficiency and sustainable compared to subtractive technologies. Unfortunately, the full exploitation of 3D AM processes is currently limited due to the in-process and in-service performance of the available materials'

sets, especially in application in construction industry: *'While 3D printing techniques have been successfully applied in a wide range of industries such as aerospace and automotive, its application in concrete construction industry is still in its infancy'*<sup>8</sup>. Contemporary only some prototype solution in the area of geopolymers material were designed in Australia, China and Russia<sup>9</sup>. They are based mainly for powder based technology and have a lot of limitations. The limitations are mainly connected with used materials. The further development of this technology required improvements to design new materials, to assess materials performance and to improve processing strategies.

The innovative material and manufacturing method create the innovative products for urban architecture. This project incorporates urban design, as the gained exquisite process of structures allows novel functionality with more flexible, unique design in infrastructure. Additionally, in the project there will be the development of a digital 3D model covering the city. This model is used in various ways, for example for urban mediation with citizens and urban development purposes such as sunshine simulation and noise modelling. This project utilizes 3D modelling to introduce new, not yet existing structures to different urban actors.

Available additive manufacturing technologies cannot yet meet the industrial scale needed for the construction industry. Also, the materials struggle in meeting the quality standards of arctic conditions. This project strives for high quality, multifunctional, industrial scale urban construction in extreme weather areas. We want

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<sup>8</sup> Nematollahi B. et al., 2017, *Current Progress of 3D Concrete Printing Technologies*, 34th International Symposium on Automation and Robotics in Construction (ISARC 2017), pp. 8.

<sup>9</sup> Xia M. and Sanjayan J., 2016, *Method of formulating geopolymer for 3D printing for construction applications*. Materials and Design, vol. 110, p. 382–390.

to bring the production close to the building site, use local raw materials and close the material loop in order to diminish the CO<sub>2</sub> emissions of urban building and enhance zero waste arctic cities. Traditional construction industry is very regulated and experimentally restricted but still a key player when moving from high energy society to circular economy, low-carbon society. Therefore we want to take initiatives to develop and provide a new platform to experiment sustainable urban innovations for vivid, modern, clean technology pioneering cities.

The project also emphasizes on new products with a functionalized approach that will have strong societal and environmental impact. More important social and environmental benefits from the implementation of the project results will include in particular:

- Energy efficiency – lower energy consumption comparison with cementitious materials, especially because lower temperature of manufacturing.
- Reduction of carbon foot print - geopolymers during production emit much lower

greenhouse gases comparing to traditional construction materials such as Portland cement. It is estimated that the production of geopolymers produce 4–8 times less carbon dioxide than cement production, and in the same process the using of energy is limited (2–3 times).

- Waste reduction – manufacturing without waste.
- Circular economy – possibilities of using for manufacturing waste products as a raw materials such as fly ashes or clay bricks.

The most problematic for the project are delays connected with works on materials. According to the previously planned schedule there are some slight delays in the project, but there is crucial element that will be continued during the project and because of that it needs more time to be successfully finished. The other risks is connected with the implementation of a new material into additive technology. However the consortium is prepared for this challenge, it is still some risk that performance of the technology don't meet the expectations/demands.

**Table 1: Mapping urban infra revolution against the established uia challenges**

Challenge	Level	Observations
1. Leadership for implementation	Low	The project leader is involved in the projects and manage very professionally. All project partners participate in decision making process. The management of the project is performed in a way to ensure active role of each of the partners
2. Public procurement	Low	The public procurement procedures connected with tender procedures, predicted for the project, have been successfully finished.
3. Integrated cross-departmental working	Low	The actions delivered by other departments are in time. The cross-departmental is smooth.
4. Adopting a participative approach	Low	The consortium is characterized by effective coordination mechanisms.

Challenge	Level	Observations
5. Monitoring and evaluation	Medium	According the previously planned schedule there are some slight delayed in the project, but there is crucial element that will be continue during the project and because of that it needs more time to be successfully finished.
6. Communicating with target beneficiaries	Medium	<p>The communication with target beneficiaries is a great challenge, because each urban investment must be accepted by all inhabitants (local legislation). The communication with target beneficiaries is very important element for successful introduction.</p> <p>The communicating with the target users will be the most important challenge in the next period of the project implementation. The idea of using side streams in central city constructions may awake concerns about health and safety and environmental safety in public. This presumable resistance is overcome by the dialogue with authorities and by creating a transparent product acceptance procedure for the product including the physical and chemical properties of the material. Another approach for overcoming the obstacles mentioned is active dialogue with public and construction industry as part of project in piloting, sustainability assessment and circular economy business models assessment. Virtual showrooms are utilized in simulating the future applications and innovative structures that do not exist yet, but are enabled by the innovative solution created</p>
7. Upscaling	Medium	<p>The most important challenges are connected with upscaling according to technology as well as legislation. The solution represents new construction materials which existing product standardization and regulations cannot be directly applied. This possible regulatory obstacle is taken into consideration by clarifying the relevant standards and regulations in early phase of the project and open dialogue with respective authorities.</p> <p>The most important challenge in this stage is legislation. The solution represents new construction materials which existing product standardization and regulations cannot be directly applied to. This possible regulatory obstacle is taken into consideration by clarifying the relevant standards and regulations in this early phase of the project and open dialogue with respective authorities. The required material and product property testing is carried out in order to have an identified product acceptance procedure for the material developed in the project. Revolutionary materials and construction designs may also face lack of trust from the regulated, conservative construction industry. Familiar technologies are easily prioritized over modern initiatives.</p>

## 5. Conclusions and next steps

The project is a response for market and society needs, especially in the area of development technologies for circular economy. The main challenge is not only the development of zero-waste technology for 3D printing, but also use as a raw material waste products and produce the prototype solutions for urban architecture. Cities in Europe are in reformation due to urbanization and climate change. Novel space usage, multifunctionality of structures and material resistance in rapidly changing climate conditions are in demand. As the amount of construction increases in the cities, an increased amount of cement giving way to CO<sub>2</sub> emission (being 5.2 billion ton in 2015). According to calculations it's nearly 10% of all human CO<sub>2</sub> emissions. The project aims to develop procedures, technologies and business models that enable unutilized side streams to be converted into sustainable high-quality, low in CO<sub>2</sub> materials with improved properties.

However the project is very innovative and challenging, it is introduced by the strong consortium. Till the beginning of the project a lot of works has been done, especially in the area of material development: characterizing waste materials and for tailoring the properties of the waste streams to enable their suitability for the process and preparing suitable recaptures for further works. The next challenge is connected with preparing the techniques applied for manufacturing the novel composites, especially adjusted to meet the requirements of the materials as well as the target use.

The further steps are connected with the design urban structure using the new material and intensify the activities connected with project promoting between the citizens. The steps of consultation with the potential users is very important for the project, because the acceptance of society is key factor for the project implementation.

Urban Innovative Actions (UIA) is an Initiative of the European Union that provides urban areas throughout Europe with resources to test new and unproven solutions to address urban challenges. Based on article 8 of ERDF, the Initiative has a total ERDF budget of EUR 372 million for 2014-2020.

UIA projects will produce a wealth of knowledge stemming from the implementation of the innovative solutions for sustainable urban development that are of interest for city practitioners and stakeholders across the EU. This journal is a paper written by a UIA Expert that captures and disseminates the lessons learnt from the project implementation and the good practices identified. The journals will be structured around the main challenges of implementation identified and faced at local level by UIA projects. They will be published on a regular basis on the UIA website.



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