# Scientific report for Period 3

## PART 1 – INFORMATION ON PROGRAM

| | |
|---|---|
| **1.1. Title of the program** | **Innovative Materials and Smart Technologies for Environmental Safety** |
| **1.2. Program acronym:** | ***IMATEH*** |
| **1.3. Program web page address:** | http://imateh.rtu.lv |
| **1.4. Program manager** (name, surname, phone, e-mail)**:** | Dr.sc.ing. Andris Čate (Chate), +371 26416672, and_cate@latnet.lv |
| **1.5. Contact person** (name, surname, phone, e-mail)**:** | Dr.sc.ing. Diana Bajare, +371 29687085, diana.bajare@rtu.lv |
| **1.6. Report for a period** | from 02.01.2016 till 31.12.2016 |

**1.7. The aim of the program and objectives:**

**The aim of the National Research Programme:**
***Contribute to the creation of world class knowledge base, which would be wide and deep enough for innovation-based economic development involving innovative materials, smart technologies and safe human living environment, by using interdisciplinary approach in solving of scientific, technologic and social problems.***

National Research Programme (NRP) has a practical orientation; each of its tasks will contribute to the important sectors of the Latvian economy - Construction, Transport, Material Processing. In the same time, the main target of the research programme is to create new knowledge about use of innovative materials to ensure safe living environment, to facilitate technology transfer to the economy by contributing to the restructuration of the national economy according to the smart specialisation strategy for the long-term development in Latvia. In the framework of this programme innovative materials, technologies, recommendations and guidelines will be developed in order to build higher safety level of living environments and to raise competency of the scientists in this area as well as to improve normative acts and standards.

**The following tasks have been set to achieve the target:**
1. *Create and investigate multifunctional materials and composites, including composite materials for sustainable buildings, and bio-materials such as $CO_2$ neutral or negative fibre composite;*
2. *Create and investigate multifunctional materials and composites, including modified materials for plywood sandwich panels;*
3. *Develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation.*
4. *Create a layered wood composite with rational structure that provides increased specific bending load-carrying capacity, reduced cost of materials and energy consumption compared to traditional wood-based materials used.*
5. *Develop methods for materials, micro-, nano-scale features and improve the quality of diagnosis;*

6. *Develop a methodology and criteria for optimization of metallic material properties to improve the surface treatment and coating to reduce friction and wear of friction pairs including interaction with metal surfaces and ice.*

The accumulated knowledge in a form of publications, recommendations, technologies, methodology and other scientific documents will be available to producers of construction materials, civil engineers, planners, as well as legislative and supervisory institutions resulting in economic development and direct improvement of human living environment safety for the existing and future infrastructure.

Highly qualified scientific staff from the Riga Technical University (RTU) and the Latvian University (LU) is involved in the NRP. High qualifications of the Programme executors are attested by scientific publications (CVs of the main executors were included in Programme proposal, Annex 1), previous, active and submitted projects (were included in Programme proposal, Annex 2), as well as membership in professional associations and other professional activities (were included in Programme proposal).

Interdisciplinary research is included in the Programme. Main executors come from various scientific directions, such as: Construction Science (Construction Materials and Technologies, Structures); Mechanics (Construction Mechanics); Material Engineering and Mechatronics, Transport (Land Transport and Infrastructure); Material Science (Wood Materials and Technology, High Temperature Materials); Mechanics of Solids, Mechanical Engineering, Chemical Engineering (High Temperature Materials and Plasma Technology).

In order to facilitate development and sustainability of the sector, 11 young scientists, 11 doctoral students and 6 master's students are involved in the NRP, the total number of young scientists being up to 70%. Part of the young researchers has performed their research in the scientific institutions abroad.

In order to increase scientific capacity of the NRP, highly qualified scientific personnel of SIA „D un D centrs” and SIA „Evopipes” is attracted. "D un D centrs" was founded by scientists and engineers coming from the former Riga Aviation University specializing in monitoring and diagnosis systems for civil aviation. The approach of "D un D centrs" to R&D includes three main components: advanced investigation techniques, integrated models of both vibration and other machine’s parameters and malfunction tests. Modern data processing techniques provide high effectiveness of measurement and analysis but the testing allows to adopt the diagnosis model and to determine the limits of measured parameters’ alterations. „Evopipes” was founded in 2005 for the implementation of the polymer pipe production project in Jelgava, Latvia. At the end of 2008 the company began mass production offering wide range of products. „Evopipes” is the most advanced polymer pipe production complex in Europe, which uses the latest technology achievements, with annual production capacity of 14,000 tons of pipes. The products are tested and verification of their conformity to certain criteria is done in the laboratories of the Riga Technical University and Lithuanian Institute of Power Engineering. Company collaborates with the Riga Technical University, Faculty of Civil Engineering, Institute of Heat, Gas and Water Technology.

Strategic Management Group is established for the scientific monitoring of the Programme. Strategic Management Group consists of the Programme leader and project leaders and at least two internationally renowned scientists who are assessed according to h-index, WoS, SCOPUS or publications in journals of the respective sector validated by the ministry as well as two experts from the respective industry. Two scientists (Professor and Head of Department of Bridges and Special Structures **Gintaris Kaklauskas** from the Vilnius Gediminas Technical University (VGTU) and Director of the Institute of Materials Science, Professor of the Physics Department **Sigitas Tamulevicius**, Kaunas University of Technology (KTU)) and two experts (**Raimonds Eizensmits** Chairman of the LIKA (Latvian Association of Consulting Engineers) Board (Latvia) and **Renars Spade**, Expert of the Ministry of Economics (Latvia) have agreed to be included in the group and their CVs are included in Annex 4 of programme proposal.

The main responsibilities of the Programme leader and project leaders are to plan the cash flow and prepare progress reports and payment requests as well as to demand accounting documents and to summarise data on the activities and results. An option of mutual replacement among the project members is foreseen. Regular communication among the project members is planned to achieve this, especially with the cooperation partners, as well as regular control of the execution of tasks.

Programme leader and project leaders are responsible for time frame completion control, analysis of reasons causing delay and suggestions for improvement, corrections in time frame if necessary as well as timely planning of tenders, monitoring of the document exchange system.

Programme leader is responsible for conclusion of detailed Cooperation agreement with the cooperation partners, coordination and control of performance of the contract as well as respecting of work plan and time frame, timely preparation of progress reports.

Projects leaders (Programme consists of 6 projects) are responsible for achievement of the project targets, development of relevant methodology, detailed assessment of the experimental and theoretical data and corrections in work plan if necessary. Projects leaders are also responsible for timely planning of equipment maintenance and repair works as well as purchases of spare parts.

Executors of the NRP have modern and well equipped laboratories with the exploitation period of equipment being up to 7 years, for example, some of the project executors have participated in the project "Infrastructure Development in the National Research Centre for Nanostructured and Multifunctional Materials, Structures and Technologies", where one of the activities was purchase and installation of the scientific equipment in the Riga Technical University. Involvement of the executors of the Programme in various projects with national and international funding as well as research volume and publications in scientific journals points out the suitability of the existing infrastructure for needs of the NRP. To be able to ensure research sustainability, participants of the NRP have submitted several project proposals to the EU funded project Horizon 2020 *(Apvārsnis 2020)*, for example, in call H2020-COMPET-2014, COMPET-02-2014, activity RIA, project No. SEP-210135862, acronym FUCOLAS; in call H2020-COMPET-2014, COMPET-11-2014, activity CSA, project No. SEP-210137040, acronym COSMOS2020 etc. Currently information is being gathered and possible partners being identified for submitting proposals to the new Calls for proposals, such as M-ERA.NET, which are open every year, etc.

## 1.8. Executive summary of the Programme

*(max. two A4 pages. Summary of scientific results achieved during reporting period, their scientific and application significance)*

The planned targets of the NRP IMATEH in general as well as for each project in the framework of the programme were fully achieved in the reporting period from 02.01.2016. till 31.12.2016. The planned tasks are completed and the main results obtained. Detailed information on the scientific achievements of each Project is given in the Section 2 of this Report,

In the framework of this Programme 28 full length scientific papers were accepted during the Period 3 (performance indicators for Project 1 are 6 full length papers, for Project 3 − 12 papers or abstracts, for Project 4 – 5 full length paper or abstracts, performance indicators for Project 5 are 4 full length papers, for Project 6 – 1 full length paper). **All published papers in full length are included in report ANNEXES.**

Participants of NRP IMATEH took part in **41 international conferences** with oral or poster presentations and presented newest achievements of their research.

In that time period are submitted and approved **13 abstracts** or full length scientific papers for international conferences which will be organised in 2017**. 8 manuscripts of scientific papers are submitted in well citied journals (SNIP>1).**

In that time period of programme IMATEH a new study programme for Masters between Vilnius Gediminas Technical University and Riga Technical University are established. Title of programme: "***Innovative Road and Bridge Engineering***", duration 1.5 year, language – English, involved academically staff from both Universities.

**In the framework of programme 17 master's thesis and 12 bachelor's thesis have been defended in the Period 3.**

As planned, **doctoral researchers are involved** in the Period 3 of NRP IMATEH. The following theses were prepared in addition to the research planned in the Period 3:

1. J. Justs „Ultra high performance concrete with diminished autogenous shrinkage technology", supervisor Dr.sc.ing. D. Bajare, planned to defend in 2017
2. J. Tihonovs „Asphalt concrete mixes from the local mineral material with high exploitation properties", supervisor Dr.sc.ing. J. Smirnovs, Dr.sc.ing. V. Haritonovs, planned to defend in 2017
3. M. Shinka „Natural fibre insulation materials", supervisor Dr.sc.ing. G. Shahmenko, planned to defend in 2017
4. N. Toropovs „Fire resistance of high performance concrete", supervisor Dr.sc.ing. G. Shahmenko, planned to defend in 2017
5. I. Paeglite "Impact of moving load on the dynamic properties of bridges", supervisor professor, Dr.sc.ing. J. Smirnovs, planned to defend in 2017;
6. A. Freimanis „Risk assessment of secure, efficient and sustainable bridge constructions", supervisor professor Dr.sc.ing. A. Paeglitis, planned to defend in 2018;
7. R. Janeliukshtis „Development of damage identification method for the monitoring of technical condition of constructions", supervisor professor Dr.sc.ing. A. Cate, planned to defend in 2018.
8. Vilguts "Rational structures of multistorey buildings made of layered glued wood composite", supervisor professor Dr.sc.ing. D. Serdjuks, planned to defend in 2018
9. G. Frolovs "Calculations of rational structures and elements of structures from wood composite materials", supervisor professor Dr.sc.ing. K.Rocens, planned to defend in 2017;
10. A. Kukule "Work of plywood board ribs in the conditions with humidity changes", supervisor, professor Dr.sc.ing. K.Rocens, planned to defend in 2017;
11. O. Bulderberga "Function of mechanical damage detection in polymer composite material: development and study of properties", supervisor Dr.sc.ing. A. Aniskevics, planned to defend in 2017
12. M. Kirpluks "Bio-based rigid polyurethane foam and nano size filler composite properties", scientific supervisor Dr.sc.ing. U. Cabulis, planned to defend in 2018;
13. J. Lungevics "A method for predicting tribological properties of materials used in mechanical engineering" scientific supervisor Dr.sc.ing. J. Rudzitis, planned to defend in 2019;
14. E. Jansons "Development of criterion that determine the slidability of metal on ice" scientific supervisor Dr.sc.ing. J. Rudzitis, planned to defend in 2019.

**E. Labans defended the doctoral thesis** „ Development and improvement of multifunctional properties for sandwich structures with plywood components" (supervisor Dr.sc.ing. K. Kalnins) and obtained PhD in engineering (6.04.2016.).

**Patents which are maintain:**

1. Rocens K., Kukule A., Frolovs G., Sliseris J., Berzins G., LV14979 „Method for producing ribbed plates" – The Official Gazette of the Patent Office of the Republic of Latvia 20.06.2015, pp 785 – http://www.lrpv.gov.lv/sites/default/files/20150620.pdf
2. Rocens K., Frolovs G., Kukule A., Sliseris J., LV15083 "Method and equipment of production for ribbed composite plate with goffered wood-based core". – The Official Gazette of the Patent Office of the Republic of Latvia 20.12.2015, pp. 1749. – http://www.lrpv.gov.lv/sites/default/files/20151220.pdf

**Popular-science publications:**

1. Paeglitis A., Glulam timber pedestrian overpass over road P103 Dobele-Bauska 17.44 km in Tervete, Construction in Latvia, Nr.3, 2016, 79-85 pp. ISSN 1691-4058.
2. Gross A.K., A new method to help improve safety on ice. Slippery conditions are reproduced in the laboratory for testing the slidability of different materials on ice, Ilustrētā zinātne (in Latvian), December 2016.
3. Haritonovs V., Tihonovs J., Local resources for the asphalt concrete compositions (Asfaltbetona sastāviem vietējie materiāli, in Latvian) „Būvinženieris", No 52, October 2016.

**The submitted H2020 projects that are in the evaluation stage:**

1. Call H2020-EE-2016-CSA, Type of action CSA Draft proposal ID SEP-210360903, Deep_Renov. Target of the Project - promote and guide building owners/tenants in deep renovation through clear information, databases of qualified actors and reachable to a large number of owners/consumers (e.g. supported by municipalities) and also by adapting existing financial mechanisms, instruments and innovative business models to address market failures, in particular split incentives.
2. Call H2020-NMBP-2017-two-stage, Type of action RIA, Draft proposal ID SEP-210400265, SMARTmat. The main idea of the SMARTmat proposal is to create software for an adequate choice of concrete mix design and/or primary protection considering environmental and anthropogenic impacts according to construction region, typically used concrete mix composition and local raw materials' base.

**Participation in the international cooperation projects:**

1. COST Action Programme TU1301 NORM for Building materials (NORM4BUILDING), Action duration 08.07.2013-15.05.2017
2. COST Action Programme TU1404 "Towards the next generation of standards for service life of cement-based materials and structures", Action duration 14.05.2014.-13.05.2018
3. COST Action Programme CA15202 "Self-healing as preventive Repair of Concrete Structures", Action duration 30.09.2016.-29.09.2020
4. COST Action MP1105 FLARETEX: Sustainable flame retardancy for textiles and related materials based on nanoparticles substituting conventional chemicals action (2012-2016).
5. COST Action TU1406 Transport and Urban Development. Quality specifications for roadway bridges, standardization at a European level (BridgeSpec) (2014-2018)
6. FP7 SCP3-GA-2013-605404-DURABROADS „Cost effective DURABLE ROADS by green optimizes construction and maintenance" 2013 – 2016.

**New research projects, preparation of project proposals and participation:**

Based on the results of the NRP and the cooperation activates, IMATEH team submitted 8 project proposals in the first round of ERDF project tender with the specific objective "To increase the research and innovation capacity of scientific institutions of Latvia and their ability to attract external funding by investing in human resources and infrastructure" (Measure "Industry-Driven Research") and one M-Eranet project. After an international scientific assessment of the projects the following project proposals (duration of the project - 36 months) related to the target of the programme were confirmed:

1. Development, optimisation and sustainability evaluation of smart solutions for nearly zero energy buildings in real climate conditions", (2016-2018), total **Euro 580 000**.
2. „Innovative use of reclaimed asphalt pavement for sustainable road construction layers", (2016-2018), total **Euro 648 000**.
3. "A New Concept for Sustainable and Nearly Zero-Energy Buildings", (2016-2018), total **Euro 648 000**
4. "Zero Energy Solutions for Special Purpose Buildings", (2016-2018), total **Euro 634 615.**

5. Rigid polyurethane polyisocyanurate foam thermal insulation material reinforced with nano/micro cellulose, (2016-2020), total **Euro 630 000**.
6. “The quest for disclosing how surface characteristics affect slideability”, (2016-2018), total **Euro 594054**.

During 3. time period the ERA-Net project “Development of eco-friendly composite materials based on geopolymer matrix and reinforced with waste fibres” was accepted, (2016-2018), total **Euro 69 960**

**Deliverables under following titles are included in Annexes:**

1. Recommendation on increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement (1. project);
2. Recommendation for parameter optimisation of mixing process for asphalt concrete mixes (1. project);
3. Method for production of ecological composite materials from fibre plants and local mineral binders (1. project);
4. Method for life-cycle assessment of natural fibre composite materials (1. project);
5. Design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method, including experimental check of developed design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method (3. project).
6. Methodology for determination of bending strength and conceptual experimental investigations of plates with cell type hollow ribs (4. project);
7. Methodology for determination of specific bending strength for plates with cell type hollow ribs and determination of values for the most typical geometrical parameters (4. project);
8. Method for diagnostics of early destruction of surface of polymer composite materials using *in situ* electron emission spectroscopy (5. project);
9. Method for diagnostics of early destruction of surface of polymer composite materials using destruction-induced staining (5. project);

**The new technologies, methods, prototypes or services that have been elaborated in the framework of the programme and approbated in enterprises:**

1. “Production method for high performance asphalt concrete mixes from low quality components”, approbated in enterprise “Ceļi un Tilti” Ltd, confirmed at 16.09.2016. (1.project);
2. “Production method of innovative and advanced cement composite with microfillers materials for infrastructure projects and public buildings” approbated in enterprise “Warm House” Ltd, confirmed at 20.09.2016., (1.project);
3. “Method for production of ecological composite materials from fiber plants and local mineral binders”, approbated in enterprise “ESCO būves” Ltd, confirmed at 21.10.2016. (1.project).
4. “A method to test the slidability of long rails on a longer ice track”, approbated in the infrastructure of Federation of Latvian Bobsleigh and Skeleton, confirmed at 5.10.2016. (6. project).
5. “Method for diagnostics of early destruction of surface of polymer composite materials using destruction-induced staining” approbated in enterprise Aviatest Ltd, confirmed from 7.11.2016. (5.project).
6. “Method for diagnostics of early destruction of surface of polymer composite materials using *in situ* electron emission spectroscopy” approbated in enterprise Evopipes Ltd, confirmed at 8.11.2016. (5.project).

**The new technologies, methods, prototypes, products or services that have been submitted for implementation (signed contracts on transfer of intellectual property):**

1. Licence Agreement between Latvian state Institute of Wood chemistry and SME (start-up) PolyLabs about industrialization of technologies developed in LS IWC about polyol synthesis from rape seed oil and tall oil by amidisation and esterification methods (2.project).
2. Contract between LS IWC and JSC Latvijas Finieris about following series of experiments about playwood tests in cryogenic conditions (liquefied nitrogen t = 77 K) (2.project).
3. Contract between LS IWC and SME Latvani about experimental production of insulated external walls of buildings using rigid polyurethane foams and tests of obtained sandwich-type constructions (2.project).
4. Contract of Riga Technical University, Institute of Materials and Structures and A/S "Latvijas Finieris" for tests of the plywood productsin 2nd phase of MNKC program. (2.project).

In addition programme members were working actively on organising two scientific conferences taking place in 2016 and 2017 - **IMST „3rd Innovative Materials, Structures and Technologies" 2017** (27.09.-29.09.2017), as well as **57 the Scientific and Technical Conference** (14.-18.10.2016.) and **Students Scientific and Technical conference** 27.04.2016 (more information on: http://imateh.rtu.lv/konferences/).

Project representatives have participated in the NRP IMATEH meeting on project progress and implementation on 14.10.2016. and 16.11.2016.

Several seminars were organised on implementation of the programme tasks in the framework of IMATEH (more information is presented in the scientific reports of all projects).

During the Riga Technical University 57th International Scientific Conference (14.-18.10.2016) the conference guests (scientists from Latvia and abroad, students and representatives from industries as well as members of the scientific commission) have been informed about the project achievements and the obtained scientific results.

On 10.11.2016 information on the project achievements and the obtained scientific results has been reported on the scientific conference of the Latvian Concrete Association. Students and representatives of the industry from Latvia as well as scientific staff from the Riga Technical University and the Latvian University of Agriculture were among the conference participants.

To promote the programme, Concrete Contest (Stage 1, concrete preparation competition) will take place on 13.04.2016. Teams of 3 participants will prepare concrete specimens, which will be tested on compression strength after 28 days, determining teams having the strongest specimens. Aim of the concrete contest is to encourage students to practical application of the knowledge obtained in the university and technological development.

Stage 2 of Concrete competition will take place on 12.05.2015, when the winner will be determined among 7 teams testing the specimens on compression strength.

Upon launching the NRP programme IMATEH website was created, where information on programme achievements and activities is constantly updated. On IMATEH website http://imateh.rtu.lv/ detailed information on projects 1-6 is available as well as information on NRP IMATEH activities and updates.

Co-funding of the private sector for the projects included in the programmes reaches EUR **59 002** in the Period 3. (01.01.2016 - 31.12.201516) as well as agreements for realization of 7 scientific projects corresponding to the NRP objectives with total income **Euro 3 804 629** were signed in 2016.

### 1.9. Results of the programme

| | Results | | | | | |
|---|---|---|---|---|---|---|
| | Planned | Achieved | | | | |
| | | year | | | | |
| | 2014.–2017. | 2014 | 2015 | 2016 | Total in period | 2017 |
| **Scientific performance indicators** | | | | | | |
| **1. Scientific publications:** | **51** | **3** | **25** | **28** | **56** | |
| number of original scientific articles (*SCOPUS*)(SNIP>1) | 17 | 0 | 1 | 5 | 6 | |
| number of original scientific articles enclosed in magazines of the database *ERIH (A and B)* or in proceeding of conference articles | 34 | 3 | 24 | 23 | 50 | |
| number of reviewed scientific monographs | 0 | 0 | 0 | 0 | 0 | |
| **2. In the framework of the programme:** | **51** | **11** | **30** | **30** | **71** | |
| number of defended doctoral thesis | 10 | 0 | 2 | 1 | 3 | |
| number of defended master's thesis | 41 | 6 | 13 | 17 | 36 | |
| number of defended bachelors' | 0 | 5 | 15 | 12 | 32 | |
| **Performance indicators of the promotion of the programme** | | | | | | |
| **1. Interactive events to promote the process and results of the programme. Target groups should include students and the number of:** | **86** | **6** | **52** | **64** | **122** | |
| conferences | 35 | 1 | 27 | 39 | 67 | |
| seminars | 20 | 1 | 11 | 12 | 24 | |
| organized seminars | 18 | 2 | 10 | 8 | 20 | |
| popular-science publications | 8 | 1 | 2 | 3 | 6 | |
| exhibitions | 2 | 1 | 1 | 2 | 4 | |
| Concrete contests | 3 | 0 | 1 | 1 | 2 | |
| **2. Press releases** | **143** | **43** | **30** | **33** | **106** | |
| **Economic performance indicators** | | | | | | |
| **1. Amount of private funding attracted to the scientific institution in the framework of the programme, including:** | **540 000** | **180 526** | **231 397** | **59 002** | **470925** | |
| 1.1. co-funding from the private sector to implement the projects of the programme | 295 000 | 37 321 | 0 | 50 930 | 73 251 | |
| 1.2. income from commercializing the intellectual property created in the framework of the programme (alienation of industrial property rights, licensing, conferring exclusive rights or rights to use on a fee) | 0 | 0 | 0 | 0 | 0 | |
| 1.3. income from contractual jobs that are based on results and experience acquired in the framework of the | 245 000 | 143 205 | 231 397 | 8 072 | 397 674 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| programme | | | | | | |
| **2. Number of applied for, registered, and valid patents or plant varieties in the framework of the programme:** | **7** | **1** | **1** | **0** | **2** | |
| in the territory of Latvia | 7 | 1 | 1 | 0 | 2 | |
| abroad | 0 | 0 | 0 | 0 | 0 | |
| **3. Number of new technologies, methods, prototypes or services that have been elaborated in the framework of the programme and approbated in enterprises** | **19** | **0** | **0** | **12** | **12** | |
| **4. Number of new technologies, methods, prototypes, products or services that have been submitted for implementation (signed contracts on transfer of intellectual property)** | **8** | **0** | **0** | **4** | **4** | |
| **5. Signed agreements for realization of scientific projects corresponding to the NRP objectives (total amount, Euro)** | **0** | **0** | **0** | **3 804 629** | **3 804 629** | |

***In case of deviation from planned justification of deviation and planned activities to mitigate deviation.***

The planned targets of the NRP IMATEH in general as well as for each project in the framework of the programme were fully achieved in the reporting period from 01.01.2016. till 31.12.2016. The planned tasks are completed and the main results obtained. Detailed information on the scientific achievements of each Project is given in the Section 2 of this Report. Nine new methods have been elaborated in the framework of the programme (Annexes), and six (6) of them are approbated in enterprises and 4 contracts on transfer of intellectual property services are signed with enterprises.

## 1.10. List of results of the programme

(*List of publications, conference thesis, etc.*)

**Following papers have been published (full length papers are included in Annexes):**

1. Bumanis G., Bajare D., Korjakin, A., Durability of High Strength Self Compacting Concrete with Metakaolin Containing Waste, Key Engineering Materials, vol. 674, 2016, 65-70; http://www.scopus.com/record/display.uri?eid=2-s2.0-84958213606&origin=resultslist&sort=plf-f&src=s&st1=bajare&st2=&sid=825680C2EBD50EF96A423542C8B86583.Vdktg6RVtMfaQJ4pNTCQ%3a210&sot=b&sdt=b&sl=19&s=AUTHOR-NAME%28bajare%29&relpos=0&citeCnt=0&searchTerm=
2. Bajare D., Bumanis G., Chloride Penetration and Freeze-Thaw Durability Testing of High Strength Self Compacting Concrete. Proceedings of the International RILEM Conference Materials, Systems and Structures in Civil Engineering 2016 Segment on Service Life of Cement-Based Materials and Structures, Service Life of Cement-Based Materials and Structures, Technical University of Denmark, vol. 2, 2016, 435-442;
3. Bumanis G., Goljandin D., Bajare D., The Properties of Mineral Additives Obtained by Collision Milling in Disintegrator, Key Engineering Materials, vol. 721, 2017, 327-331 (accepted);

4. Dembovska L., Bajare D., Pundiene I., Vitola L., Effect of Pozzolanic Additives on the Strength Development of High Performance Concrete, Procedia Engineering 00 (2016) 000–000 (accepted);
5. Bumanis G., Bajare D., Compressive strength of cement mortar affected by sand microfiller obtained with collision milling in disintegrator, Procedia Engineering 00 (2016) 000–000 (accepted);
6. Haritonovs V., Tihonovs J., Smirnovs J., High Modulus Asphalt Concrete with Dolomite Aggregates J. Transportation, Research Procedia, vol. 14, 2016, 3485-3492;
   https://www.scopus.com/record/display.uri?eid=2-s2.0-84991268433&origin=resultslist&sort=plf-f&src=s&st1=haritonovs&st2=&sid=58CFA54CB8994A281AED6E4EB9703B6C.wsnAw8kcdt7IPYLO0V48gA%3a30&sot=b&sdt=b&sl=23&s=AUTHOR-NAME%28haritonovs
7. Paeglitis A., Freimanis A., Comparison of constant-span and influence line methods for long-span bridge load calculations, The Baltic Journal of Road and Bridge Engineering, vol.11, 1, 2016, 84–91;
   https://www.scopus.com/record/display.uri?eid=2-s2.0-84964311654&origin=resultslist&sort=plf-f&src=s&st1=paeglitis&st2=&sid=BC0D23A70D5B278815D4B1F4E6F4ACE2.wsnAw8kcdt7IPYLO0V48gA%3a10&sot=b&sdt=b&sl=22&s=AUTHOR-NAME%28paeglitis%29&relpos=0&citeCnt=0&searchTerm=.
8. Paeglite I., Smirnovs J., Paeglitis A., Dynamic behaviour of pre-stressed slab bridges, Procedia Engineering 00 (2016) 000–000 (accepted);
9. Freimanis A., Paeglitis A., Mesh sensitivity analysis for quasi-static simulations, Procedia Engineering 00 (2016) 000–000 (accepted);
10. Paeglite I., Smirnovs J., Paeglitis A., Traffic load effects on dynamic bridge performance // Proceedings of the Eight International IABMAS Conference (IABMAS 2016) Bridge Maintenance, Safety, Management, Resilience and Sustainability , Brazil, Foz do Iguacu, 26.-30. June, 2016, pp. 2364-2369
    https://www.scopus.com/record/display.uri?eid=2-s2.0-85000925934&origin=resultslist&sort=plf-f&src=s&st1=paeglitis&st2=&sid=BC0D23A70D5B278815D4B1F4E6F4ACE2.wsnAw8kcdt7IPYLO0V48gA%3a10&sot=b&sdt=b&sl=22&s=AUTHOR-NAME%28paeglitis%29&relpos=1&citeCnt=0&searchTerm=
11. Rucevskis S., Janeliukstis R., Akishin P., Chate A., Mode shape-based damage detection in plate structure without baseline data (2016) Structural Control and Health Monitoring, vol. 23, 9, 1180-1193, (SNIP>1);
    http://onlinelibrary.wiley.com/doi/10.1002/stc.1838/abstract;jsessionid=5415D140388699A27A3163581B086C65.f01t04
12. Janeliukstis R., Rucevskis S., Wesolowski M., Kovalovs A., Chate A., Damage Identification in Polymer Composite Beams Based on Spatial Continuous Wavelet Transform, IOP Conference Series: Materials Science and Engineering, vol. 111, 1, 2016, 1-12.
    http://iopscience.iop.org/article/10.1088/1757-899X/111/1/012005/meta
13. Rucevskis S., Janeliukstis R., Akishin P., Chate A., Vibration-based approach for structural damage detection, 23rd International Congress on Sound and Vibration: From Ancient to Modern Acoustics, 2016, 1-6;
    https://www.scopus.com/record/display.uri?eid=2-s2.0-84987922684&origin=resultslist&sort=plf-f&src=s&sid=65A5B84061915A7510FB3A88D485205C.wsnAw8kcdt7IPYLO0V48gA%3a230&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2816310397700%29&relpos=4&citeCnt=0&searchTerm=

14. Janeliukstis R., Rucevskis S., Akisins P., Cate A., Wavelet Transform Based Damage Detection in a Plate Structure, Procedia Engineering, vol.161, 2016, 127-132;
http://www.sciencedirect.com/science/article/pii/S1877705816327175
15. Janeliukstis R., Rucevskis S., Wesolowski M., Cate A., Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares, Journal of Physics: Conference Series, vol. 744, 1, 2016, 1-12;
http://iopscience.iop.org/article/10.1088/1742-6596/744/1/012054/meta;jsessionid=E4BB7A397DBB62D5B904A2DD24B7CA9C.c4.iopscience.cld.iop.org
16. Buka-Vaivade K., Serdjuks D., Goremikins V., Vilguts A., Pakrastins L., Experimental Verification of Design Procedure for Elements from Cross-Laminated Timber, Procedia Engineering 00(2016) 000-000 (accepted);
17. Saknite T., Serdjuks D., Goremikins V., Pakrastins L., and Vatin N., Fire Design of Arche-type Timber Roof, Magazine of Civil Engineering, vol. 6, 4, 2016, 26-39;
https://www.scopus.com/record/display.uri?eid=2-s2.0-84994651633&origin=resultslist&sort=plf-f&src=s&st1=saknite&st2=&sid=BC0D23A70D5B278815D4B1F4E6F4ACE2.wsnAw8kcdt7IPYLO0V48gA%3a10&sot=b&sdt=b&sl=20&s=AUTHOR-NAME%28saknite%29&relpos=2&citeCnt=0&searchTerm=
18. Gusevs E., Serdjuks D., Artebjakina G., Afanasjeva E., Goremikins V., Behaviour of Load-Carrying Members of Velodromes Long-span Steel Roof, Magazine of Civil Engineering, vol. 5, 2016, 13-16;
http://engstroy.spbstu.ru/eng/index_2016_05/01.html
19. Sliseris J., Andrä H., Kabel M., Dix B., Plinke B., Virtual characterization of MDF fiber network, European Journal of Wood and Wood Products, 2016, 1-11 (SNIP 0,930);
https://www.scopus.com/record/display.uri?eid=2-s2.0-84976318982&origin=resultslist&sort=plf-f&src=s&sid=2E1B286D405845C34D49E9CBF83C7457.wsnAw8kcdt7IPYLO0V48gA%3a70&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=1&citeCnt=0&searchTerm=#
20. Frolovs G., Rocens K., Sliseris J., Shear and tensile strength of narrow glued joint depending on orientation of plywood, Procedia Engineering 00 (2016) 000–000 (accepted);
21. Kukule A., Rocens K., Lukasenoks A., Frolovs G., Change of Moisture Distribution in Ribbed Plate with Different Opposite Surface Temperatures, Procedia Engineering 00 (2016) 000–000 (accepted);
22. Sliseris J., Gaile L., Pakrastins L., Deformation process numerical analysis of T-stub flanges with pre-loaded bolts, Procedia Engineering 00 (2016) 000–000 (accepted);
23. Sliseris J., Gaile L., Pakrastins L., Non-linear buckling analysis of steel frames Proceedings of the 5th international conference Advanced Construction 2016. ISSN 2029–1213;
http://ktu.edu/uploads/files/fakultetai/Statybos%20ir%20architekt%C5%ABros%20fakultetas/files/PROCEEDINGS%282%29.pdf
24. Ivanov D.S., Le Chain Y.M., Arafati S., Dattin A., Ivanov S.G., Aniskevich A., Novel method for functionalising and patterning textile composites: liquid resin print, Composites Part A: Applied Science and Manufacturing, vol. 84, 2016, 175-185 (SNIP 2015 2.055);
http://www.sciencedirect.com/science/article/pii/S1359835X16000336
25. Glaskova-Kuzmina T., Aniskevich A., Martone A., Giordano M., Zarrelli M., Effect of moisture on elastic and viscoelastic properties of epoxy and epoxy-based carbon fibre reinforced plastic filled with multiwall carbon nanotubes, Composites Part A: Applied Science and Manufacturing, vol. 90, 2016, 522-527 (SNIP 2015 2.055);
http://www.sciencedirect.com/science/article/pii/S1359835X16302822

26. Bulderberga O., Aniskevich A., Vidinejevs S., A glass-fiber-reinforced composite with a damage indication function, Mechanics of Composite Materials, vol. 52, 2016, 155-162; https://link.springer.com/article/10.1007/s11029-016-9568-1
27. Zeleniakiene D., Leisis V., Griskevicius P., Bulderberga O., Aniskevich A., A Numerical Simulation of Mechanical Properties of Smart Polymer Composite with Microcapsules for Damage Sensing Applications, Proceedings of 17th European Conference on Composite Materials (ECCM17), 2016, 1-8, ISBN 978-3-00-053387-7.
28. Jansons E., Lungevics J., Gross K.A., A surface roughness measure that best correlates to ease of sliding. Engineering for Rural Development, 2016, 687– 695. https://www.scopus.com/record/display.uri?eid=2-s2.0-84976556593&origin=resultslist&sort=plf-f&src=s&st1=+surface+roughness+measure+that+best+correlates+to+ease+of+sliding&st2=&sid=BC0D23A70D5B278815D4B1F4E6F4ACE2.wsnAw8kcdt7IPYLO0V48gA%3a530&sot=b&sdt=b&sl=73&s=TITLE%28+surface+roughness+measure+that+best+correlates+to+ease+of+sliding%29&relpos=0&citeCnt=0&searchTerm=

**Programme IMATEH members have participated in the following conferences:**

1. Vitola L., Bajare D., Bumanis G., Sahmenko G., Evaluation of Puzzolanic Properties of Micro- and Nanofillers Made from Waste Products, 18th International Conference on Concrete, Structural and Geotechnical Engineering, 25.-26.01.2016, Istanbul, Turkey..
2. Bajare D., Bumanis G., Chloride Penetration and Freeze-Thaw Durability Testing of High Strength Self Compacting Concrete. Materials, Systems and Structures in Civil Engineering – 19-22.08.2016, Copenhagen, Denmark.
3. Dembovska L., Bajare D., Pundiene I., Vitola L., Effect of Pozzolanic Additives on the Strength Development of High Performance Concrete. 12th International Conference "Modern Building Materials, Structures and Techniques MBMST 2016", 26.05-27.05.2016, Vilnius, Lithuania.
4. Bumani G., Bajare D., Compressive strength of cement mortar affected by sand microfiller obtained with collision milling in disintegrator, 12th International Conference "Modern Building Materials, Structures and Techniques MBMST 2016", 26.05-27.05.2016, Vilnius, Lithuania.
5. Bumanis G., Goljandin D., Bajare D., The Properties of Mineral Additives Obtained by Collision Milling in Disintegrator, "The 25th International Baltic Conference of Engineering Materials & Tribology"– BALTMATTRIB 2016 3-4.11.2016. Riga, Latvia.
6. Bumanis G., Bajare D, Sahmenko G., Dembovska L., Vitola L., Korjakins A., High performance concrete with microfillers; their production methods, strength and durability, 57th International conference, Riga Technical University, 14.-18. 10.2016, Riga, Latvia.
7. Haritonovs V., Tihonovs J., Smirnovs J., High Modulus Asphalt Concrete with Dolomite Aggregates. Transport Research Arena Conference -TRA 18.-21.04. 2016., Warsaw, Poland.
8. Haritonovs V., Tihonovs J., Sustainable bitumen composites for road constructions, 57th International conference, Riga Technical University, 14.-18.10.2016, Riga, Latvia.
9. Sahmenko G., Sinka M., Bajare D., Energy-efficient and $CO_2$ neutral building materials from natural fibers, 57th International Scientific Conference, Riga Technical University, 14-18.10.2016., Riga, Latvia.
10. Sahmenko G., Sinka M., Building materials with natural fiber for sustainable construction, Concrete Association, XXV Scientific Technical conference, 10.11.2016, Riga, Latvia.
11. Kalnins K., Jekabsons G., Labans E., Optimisation for scaling up of plywood sandwich panels with rigid PU foam-cores, In proceedings of the 11th ASMO UK, ISSMO conference on Engineering Design Optimization Product and Process Improvement, NOED2016, TU. 18-20. 2016. July, Munich, Germany.

12. Kirpluks M., Kalnbunde D., Benes H., Cabulis U., Rapeseed Oil as Feedstock for High Functionality Polyol Synthesis, 7th Workshop on Green Chemistry and Nanotechnologies in Polymer Chemistry, 21-23.09. 2016, San Jose, Costa Rica.
13. Ivdre A., Abolins A., Cabulis U., Thermal Insulation Based on Polyols from Tall Oil and/or Rapeseed Oil in Combination with PET, 7th Workshop on Green Chemistry and Nanotechnologies in Polymer Chemistry, 21-23.09.2016, San Jose, Costa Rica.
14. Kalnins K., Overview of research towards multifunctional plywood sandwich panels, in proceedings of the 12th meeting of the Northern European Network for Wood Science and Engineering (WSE) 12-13.09.2016, Riga, Latvia.
15. Kirpluks M., Labans E., Kalnins K., Japins G., Plywood rib stiffened sandwich panels filled with bio-based rigid polyurethane foams, In proceedings of the 12th meeting of the Northern European Network for Wood Science and Engineering (WSE) 12-13.09.2016., Riga, Latvia.
16. Paeglite I., Smirnovs J., Paeglitis A., Traffic load effects on dynamic bridge performance, 8th International IABMAS Conference (IABMAS 2016) Bridge Maintenance, Safety, Management, Resilience and Sustainability, 26.-30.06.2016, Foz do Iguacu, Brazil.
17. Paeglite I., Smirnovs J., Paeglitis A., Dynamic behaviour of pre-stressed slab bridges, 12th International conference "Modern Building Materials, Structures and Techniques", (MBMST 2016), 26.-27.05.2016, Vilnius, Lithuania.
18. Freimanis A., Paeglitis A., Mesh sensitivity analysis for quasi-static simulations, 12th International conference "Modern Building Materials, Structures and Techniques", (MBMST 2016), 26.-27.05.2016, Vilnius, Lithuania.
19. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares, MoViC & RASD 2016 – „Joint International Conference: Motion and Vibration Control & Recent Advances in Structural Dynamics", 3.–6. 07.2016, Southampton, England.
20. Janeliukstis R., Rucevskis S., Akishin P., Chate A., Wavelet Transform Based Damage Detection in a Plate Structure, WMCAUS – „World Multidisciplinary Civil Engineering Architecture Urban Planning Symposium" 13.–16. 07.2016., Praha, Czech Republic.
21. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Multiple Damage Identification in Beam structure Using Wavelet Transform Technique, MBMST 16 – 12th International Conference „Modern Building Materials, Structures and Techniques", 26.-27.05.2016., Vilnius, Lithuania.
22. Rucevskis S., Janeliukstis R., Akisins P., Cate A., Vibration-Based Approach for Structural Damage Detection, 23rd International Congress on Sound and Vibration, 10.-14.07.2016, Athens, Greece.
23. Buka-Vaivade K., Serdjuks D., Goremikins V., Vilguts A., Experimental Verification of Design Procedure for Elements from Cross-Laminated Timber, 12th International Conference „Modern Building Materials, Structures and Techniques", 26.-27.05.2016, Vilnius, Lithuania.
24. Serdjuks D., Goremikins V., Buka-Vaivade K., Development of Innovative Smart Structures with Using of Renewable Natural Resources for Structural and Infrastructural Purposes, Riga Technical University International Scientific Conference, 14–18.10.2016., Riga, Latvia.
25. Serdjuks D., Design of Timber Structures by EN 1995-1-1, International scientific seminar "Design of Timber Structures by EN 1995-1-1", 24.02.2016, Petersburg, Russia.
26. Serdjuks D., Fire Design of Timber Structures by EN 1995-1-2, International scientific seminar "Fire Design of Timber Structures by EN 1995-1-2", 24.02.2016, Petersburg, Russia.
27. Serdjuks D., Design of Timber Structures by EN 1995-1-1, International scientific seminar „Design of Timber Structures by EN 1995-1-1" 224.02.2016, Petersburg, Russia.

28. Frolovs G., Rocens K., Sliseris J., Shear and tensile strength of narrow glued joint depending on orientation of plywood, 12th international conference "Modern Building Materials, Structures and Techniques", 26.-27.05.2016, Vilnius, Lithuania.
29. Kukule A., Rocens K., Lukasenoks A., Frolovs G., Change of Moisture Distribution in Ribbed Plate with Different Opposite Surface Temperatures 12th international conference "Modern Building Materials, Structures and Techniques", 26.-27.05.2016, Vilnius, Lithuania.
30. Sliseris J., Gaile L., Pakrastins L., Deformation process numerical analysis of T-stub flanges with pre-loaded bolts 12th international conference "Modern Building Materials, Structures and Techniques", 26.-27.05.2016, Vilnius, Lithuania.
31. Frolovs G., Rocens K., Sliseris J., Stress state analysis of plates with cell type ribs under loading, International Conference "Advanced Construction", 6-7.10.2016 Kaunas, Lithuania.
32. Kukule A., Rocens K., Lukasenoks A., Determination of moisture distribution in ribbed plate used as building envelope, 5th International Conference "Advanced Construction", 6-7.10.2016 Kaunas, Lithuania.
33. Sliseris J., Gaile L., Pakrastins L., Non-linear buckling analysis of steel frames 5th International Conference "Advanced Construction", 6-7.10.2016 Kaunas, Lithuania.
34. Aniskevich A., Bulderberga O., Dekhtyar Yu., Korvena-Kosakovska A., Kozak I., Romanova M., Electron emission of the carbon nanotube-reinforced epoxy surface nano layer towards detection of its destruction induced by elastic deformation. International Nanotechnology Conference & Expo (Nanotech-2016), 4-60.04.2016, Baltimore, USA.
35. Zeleniakiene D., Leisis V., Griskevicius P., Bulderberga O., Aniskevich A., A Numerical Simulation of Mechanical Properties of Smart Polymer Composite with Microcapsules for Damage Sensing Applications. Poster No. PO-3-02, ECCM17 – 17th European Conference on Composite Materials, 26-3006.2016, Munich, Germany.
36. Chimbars E., Dekhtyar Yu., Kozaks I., Aniskevich A., Influence of high-frequency radiation on early collapse of composite material with embedded nanotubes. Riga Technical University 57th International Scientific Conference, 17.10.2016, Riga, Latvia.
37. Dehtjars J., Aniskevics A., Bulderberga O., Romanova M., Gruskevica K., Balodis A., Material mechanical micro- nano- scaled features and their impact on human safety. Riga Technical University 57th International Scientific Conference, 17.10.2016, Riga, Latvia.
38. Zeleniakiene D., Leisis V., Griskevicius P., Bulderberga O., Aniskevich A., A Numerical Simulation of Mechanical Properties of Smart Polymer Composite with Microcapsules for Damage Sensing Applications. Proceedings of 17th European Conference on Composite Materials (ECCM17), 2016.
39. Jansons E., Lungevics J., Gross K.A., Surface roughness measure that best correlates to ease of sliding, 15th International Scientific Conference Engineering for Rural Development, 25-27. 05.2016., Jelgava, Latvia.
40. Lungevics J., Jansons E., Rudzitis J., Gross K.A., Use of an inclined plane with additional time measurements to investigate surface slidability on ice, 12th International Conf. Mechatronic Systems & Matls. 3-8. 07.2016., Bialystok, Poland.
41. Lungevics J., Gross K.A., Modification of metal surfaces for achieving a lower friction and wear, 57$^{th}$ International conference, Riga Technical University, 14.-18. 10.2016, Riga, Latvia.

**List of accepted abstracts or full text papers for conferences organised in 2017:**

1. Bumanis G., Sahmenko G., Korjakins A., Bajare D., Influence of curing conditions on the durability of high performance concrete, IMST 2017, September 27-29, Riga, 2017
2. Rieksts K., Haritonovs V., Izaks R., Tihonovs J., Investigation of filler properties using Dynamic Shear Rheometer, IMST 2017, September 27-29, Riga, 2017.

3. Sinka M., Sahmenko G., Bajare D., Lime-hemp concrete (LHC) enhancement using magnesium based binders, International Conference on Bio-Based Building Materials, June 21st - 23rd 2017, Clermont-Ferrand, France.
4. Sinka M., Sahmenko G., Bajare D., Hydrothermal properties of lime-hemp concrete (LHC) measured on site, IMST 2017, September 27-29, Riga, 2017.
5. Ivdre A., Cabulis U., Abolins A., Thermal Insulation Based on Polyols from Tall Oil and/or Rapeseed Oil in Combination with PET, 7th Workshop on Green Chemistry and Nanotechnologies in Polymer Chemistry, September 2017, San José, Costa Rica.
6. Janeliukstis R., Rucevskis S., Kovalovs A., Chate A., Numerical Investigation on Multiclass Probabilistic Classification of Damage Location in a Plate Structure, ICEDyn 2017 – "International Conference on Structural Engineering Dynamics", 3.-5.07.2017., Ericeira, Portuguese.
7. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Algorithm of damage identification in beam structure based on thresholded variance of normalized wavelet scalogram, IMST 2017, „Innovative Materials, Structures and Technologies" 27. 29.09.2017, Riga, Latvia.
8. Janeliukstis R., Rucevskis S., Chate A., Hybrid localization of damage in a plate structure exploiting classification and wavelet transform, SMAR 2017 – "4th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures", 13.-15. 09.2017., Zurich, Switzerland.
9. Kovalovs A., Rucevskis S., Chate A., Numerical Investigation on Damage Detection in a Prestressed Concrete Beam by modal analysis, IMST 2017, „Innovative Materials, Structures and Technologies" 27. 29.09.2017, Riga, Latvia.
10. Sliseris J., Gaile L., Pakrastins L., Rocens K., Development of beam finite element based on extended-multiscale method for modelling of complex structures, IMST 2017, „Innovative Materials, Structures and Technologies" 27. 29.09.2017, Riga, Latvia.
11. Frolovs G., Sliseris J., Rocens K., Stress state analysis of plates with cell type hollow core for typical load cases, IMST 2017, „Innovative Materials, Structures and Technologies" 27. 29.09.2017, Riga, Latvia.
12. Sliseris J., Gaile L., Pakrastins L., Rocens K., Non-Linear beam finite element based on extended-multiscale method for modelling of complex natural fiber reinforced breams, "Environment. Technology. Resources.", 15-17.06.2017., Rezekne, Latvia.
13. Frolovs G., Sliseris J., Rocens K., Optimal design of plate with cell type hollow core "Environment. Technology. Resources.", 15-17.06.2017., Rezekne, Latvia.

**Papers submitted in well citied journals:**

1. Bumanis G., Vitola L., Dembovska L., Bajare D., Comparison of the freeze resistance assessment methods for high performance cement composite durability assessment, submitted in the journal "Building and Construction", (SNIP 2.124).
2. Rieksts K., Haritonovs V., Izaks R., The influence of filler type and gradation on the rheological performance of mastics, submitted in the journal "Road Materials and Pavement Design" (SNIPS 1.3).
3. Sinka M., Sahmenko G., Bajare D., Life cycle analysis of pre-fabricated and in-situ made lime-hemp concrete, measuring of carbon footprint, submitted in the journal "Renewable and Sustainable Energy Reviews" (SNIP 3.109).
4. Kirpluks M., Kalnbunde D., Walterova Z., Cabulis U., Rapeseed Oil as Feedstock for High Functionality Polyol Synthesis, submitted in the journal "Journal of Renewable Materials", (SNIP 1.122).
5. Kirpluks M., Cabulis U., Andersons J., Japins G., Kalnins K., Modelling the effect of foam density and strain rate on the compressive response of polyurethane foams, submitted in the journal "International Journal of Materials and Manufacturing", (SNIP 0.767).

6. Labans E., Kalnins K., Bisagni, Flexural behaviour of sandwich panels with cellular wood, plywood and thermoplastic composite core, submitted in the journal "Journal of Sandwich Structures and Materials" (SNIP 0.994 ).
7. Lungevics J., Jansons E., Gross K.A., Rudzitis J., A measurement method for surface slidability on ice using an inclined plane equipped with motion detection sensors, submitted in the journal "Journal of the International Measurement Confederation" (SNIP 1.401 ).
8. Gross K.A., Zavickis J., Pluduma L., Lungevics J., Evaluation of visual examination methods for the quality control of polished surface, submitted in the journal "Journal of the International Measurement Confederation" (SNIP 1.401 ).

Leader of the programme IMATEH ________________________A. Chate __________________

*(signature and transcript)* *(date)*

## PART 2: PROGRAMME PROJECT INFORMATION

### 2.1. Project No. 1

| | |
|---|---|
| Title | ***Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures*** |
| Project leader's name, surname | Diana Bajare |
| Degree | Dr.sc.ing. |
| Institution | Riga Technical University, Institute of Materials and Structures |
| Position | Professor |
| Contacts – *Phone number* | +371 29687085 |
| Contacts – *E-mail* | diana.bajare@rtu.lv |

### 2.2. Tasks and deliverables

*(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)*

**Target:** ***Create and investigate multifunctional materials and composites, including composite materials for sustainable buildings, and bio-materials such as $CO_2$ neutral or negative fibre composite.***

**The Project consists of research divided in three parts each having its own core task to be completed in the framework of NRP IMATEH:**

| No. | Tasks | Deliverable | Responsible partner | Status |
|---|---|---|---|---|
| **1/2.6.** | **To develop recommendation on increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement.** | Recommendation on increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement (31.12.2016) Annex 1-A | D. Bajare, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU | Finished |
| **2/2.3.** | **To develop recommendations for parameter optimisation of mixing process for asphalt concrete mixes** | Recommendation for parameter optimisation of mixing process for asphalt concrete mixes (30.12.2016) Annex 1-B | V. Haritonovs, Centre of Construction Science, RTU | Finished |
| **3/1.3.** | **To develop method for production of ecological composite materials from fiber plants and local mineral binders.** | Method for production of ecological composite materials from fiber plants and local mineral binders (30.03.2016) Annex 1-C | G. Sahmenko, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU | Finished |
| **3/2.5** | **To develop and write guidelines for data collection system, which is suitable for heat and humidity migration control in energy-efficient buildings.** | Guidelines for data collection system (30.12.2017) Annex 1-C | G. Sahmenko, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU | In progress |
| **3/3.2.** | **Life-cycle assessment of natural fibre composite** | Method for life-cycle assessment of natural fibre | G. Sahmenko, Department of | Finished |

| | | | | |
|---|---|---|---|---|
| | **materials** | composite materials (30.12.2016.)<br>Annex 1-C | Building Materials and Technologies, Institute of Materials and Structures, RTU | |

***Core task 1:*** *To develop high performance concrete composite materials for infrastructure projects and public buildings, focusing on their permanence (freeze resistance, corrosion resistance, etc.) and sustainability in the local climate in Latvia, which differs from the climate in other European countries with high level of relative humidity and swift temperature fluctuations around 0 $^{o}$C in winter and autumn, etc.;*

***Core task 2:*** *To develop compositions of bitumen composites characterised by economy, environmental friendliness and permanence using lower quality local aggregates, recycled asphalt concrete as well as warm-mix asphalt concrete technologies;*

***Core task 3:*** *To develop $CO_2$ neutral composite materials made from fiber plants for use in energy-efficient buildings, thus contributing to a comfortable and healthy climate inside the building***.**

**Time frame for the core tasks is given in Annexes 1-A, 1-B and 1-C.**

In addition, specific tasks related to completing core tasks of each Project parts are defined in every Period of the Project corresponding to the calendar year.

*In case of non-fulfilment provide justification and describe further steps planned to achieve set targets and results*

**The planned targets of the NRP IMATEH Project 1 „*Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures”* were fully achieved in the reporting period from 01.01.2016 till 31.12.2016. The planned tasks are completed and the main results obtained.**

### 2.3. Description of gained scientific results

*(Describe scientific results achieved during reporting period, give their scientific importance)*

**Target of the Project 1: *Create and investigate multifunctional materials and composites, including composite materials for sustainable buildings, and bio-materials such as CO2 neutral or negative fibre composite.***

Target of the Project 1 within the National programme IMATEH is to create innovative and sustainable materials (cement, bitumen and fibrous composites) by using local raw materials. Targets set for this reporting period are fully achieved.

***Core task 1:*** *To conduct research on the high performance cement composite materials for use in infrastructure and public buildings stressing their durability in the Latvian climate.*

**Time frame for the Core task 1 is given in Appendix 1-A.**

***Task for the Period 3:*** *To perform a research on high performance cement composite materials intended for infrastructure and public buildings, which is focused on their durability in the Latvian climate.*

The climate in Latvia promotes increased corrosion of the concrete structures. High relative humidity per year (the average relative humidity in Latvia is 81%) as well as fluctuations in temperature around 0°C accelerates intensity of all kinds of corrosion. Unlike the concrete of the class C50/60, which is widely used in the civil engineering, the high performance cement composites (HPCC) (concrete with the compressive strength exceeding 70 MPa) do not have approved methods for assessing their durability (freeze resistance, chloride migration, alkali-silica corrosion), which are described in the corresponding standards.

According to the latest research, high performance cement composites are considered as a separate concrete group, which needs different methods for testing and data interpretation. The importance of the above mentioned problem is demonstrated by the activities of the RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures), which are related to the research and efforts to create new standards and methods for durability assessment of the materials, such as Technical Committee 246-TDC "Test methods to determine durability of concrete under combined environmental actions and mechanical load", Technical Committee 251-SRT "Sulphate resistance testing", etc.

Durability of the conventional concrete (C50/60) mainly depends on the environmental aggression and its structural properties, which are mainly defined by the water/cement ratio (w/c 0.4-0.5), filler particle packing, casting of concrete and its curing during the initial hardening period. High performance concrete typically has lower w/c ratio - between 0.3 and 0.4 - and higher corrosion resistance compared to the conventional concrete. This is due to the lower porosity of the HPCC, where pores with relatively smaller size dominate, the capillary pores are not interconnected but the structure in general is denser. These structural characteristics are related to the high amount of cement in the composition (usually up to 500kg/m$^3$) and use of pozzolana or inert microfillers as well as low w/c ratio and use of efficient plasticisers. Therefore the structure of concrete is more compact, with lower water and steam permeability as well as lower rate of penetration of aggressive substances. Due to the compositional characteristics it is highly important to ensure maintenance of the high performance concrete during the initial hardening period in order to maximise its hydration.

As has already been mentioned, it is possible to produce high performance concrete by increasing the proportion of cement in the composition on by partly replacing it with the pozzolana microfillers (for example, microsilica, fly ash, metakaolin, granulated blast furnace slag, etc.). Ternary systems have several advantages, which result from the synergy process involving cement materials and pozzolana microfillers. It improves the properties of both fresh and hardened concrete including its durability, as well as the created composition is more sustainable from both economical and ecological point of view.

It is possible to assess the real durability for the high performance concrete only over time (for example, in 25 years) exposing it in an aggressive natural environment. Unfortunately, the necessary data have not been accumulated and the durability of high performance concrete is difficult to predict, because it is not possible to draw conclusions based on the data gathered from the research on the durability of conventional concrete, because these cement composites are different in their nature, properties and application.

It is important to raise awareness of the stakeholders, such as producers, users and legislators with regard to the properties of cement composites including its durability. For example, in the standards of several countries it is defined that the freeze resistance of the concrete is linked to certain amount of air voids; this is used as an indicator for predicting the concrete freeze resistance. Namely, determining of air volume in the concrete can be considered as an indirect method for predicting its freeze resistance. In contrast, the studies performed in last years have demonstrated that high performance cement composites can reach F500 class without use of the air-entraining admixtures, if their composition is proper and optimal conditions are ensured during the initial hardening period. The freeze resistance class for this concrete is considerably higher than in average. It shows that it is necessary to update the existing national standards removing the requirements for the mandatory use of air-entraining admixtures in order to reach certain freeze resistance class as well as considering air volume as an indirect method for predicting the concrete freeze resistance. Second most important aspect is to choose the most appropriate method for determining the high strength cement composite freeze resistance; it should be rapid and unambiguous, when interpreted. The existing standards do not fulfil these requirements. Therefore it is necessary to edit and change these standards. The same applies to other durability testing methods: resistance against the destructive impact of chlorides, alkali-silica reactions, carbonising, sulphate resistance, etc.

In order to complete the task set for the Period 3 of the Project, high performance cement composites (HPCC) with compressive strength >70 MPa have been prepared by using various microfillers (microsilica, metakaolin, cenospheres, fly ash), which replaced 5, 10 un 15% of cement in the concrete compositions. After the hardening stage (after 28 days) resistance against the destructive impact of chlorides as well of freeze resistance of the specimens were tested. Impact of various microfillers on the freeze resistance of the HPCC was also tested during the research. In order to reach the goal of the project - to create composite materials for sustainable buildings from the local resources - cement produced by SIA "Cemex" (Latvia) has been used in the HPCC.

***Core task 2:*** *To conduct a research on compositions of bitumen composites, where lower quality local mineral materials, recycled asphalt concrete as well as warm-mix asphalt concrete technologies were used.*

**Time frame for the Core task 2 activities is given in Appendix 1-B.**

***Task for the Period 3:*** *To develop formulations of the high performance bitumen composites using reclaimed asphalt pavement (RAP) and to continue developing bitumen composites from lower quality local aggregates.*

Asphalt industry in the world is constantly seeking for new solutions in order to improve the durability of asphalt concrete, to increase the stability of structures as well as to save resources and to contribute to the successful environment management. Successful environment management means lower CO2 emissions during the production, improved work conditions for the people working with asphalt concrete and fossil fuel savings. One of the solutions leading to these improvements is to introduce the technology called warm mix asphalt.

In the Latvian climate it is recommended to build the conventional asphalt wearing courses between April 15 and October 15. The unconventional warm mix asphalt belongs to a group of technologies, which can be used for the asphalt production in lower temperatures. These technologies allow to reduce the viscosity of bitumen and ensure more even covering of the fillers with bitumen layer, to lower the production temperature to 80° - 90°C without compromising the exploitation properties of the asphalt concrete.

**Benefits from using the warm mix asphalt:**

1. Ecological aspect:
    a. $CO_2$ emissions are reduced,
    b. working conditions are improved.
2. Production aspects:
    a. it is possible to increase the proportion of reclaimed asphalt pavement by increasing the viscosity of old bitumen,
    b. longer period of asphalt concrete exploitation (bitumen is less aged during the production),
    c. due to lower emissions it is possible to obtain authorization for producing asphalt concrete closer to cities.
3. Construction:
    a. easily compacted (easily workable),

   b. construction in lower temperatures leads to longer period, when construction works are possible,
   c. shorter cooling down period of the new surfaces,
   d. longer distances of the WMA are possible.
4. Economical aspects:
   a. lower energy consumption,
   b. lower wear of the production facilities.

Use of the warm mix asphalt technologies in the production of asphaltic concrete is in its development stage in Latvia, therefore the warm mix asphalt technologies, asphalt concrete production principles and their economic benefits are analysed in this research. In the framework of this research it is planned to develop a bitumen composite material with lower production and workability temperatures. It is planned to determine the exploitation properties (rutting resistance, fatigue and thermal cracking resistance) and to prepare economic assessment.

The importance of the research is demonstrated by the activities of the RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures) and activities of F. Caster "Bituminous Materials and Polymers", which are related not only to the development of innovative bitumen materials and systems, for example, Technical Committee 237-SIB "Testing and characterization of sustainable innovative bituminous materials and systems" but also to the recycling, for example, Technical Committee 264-RAP "Asphalt Pavement Recycling".

It is important to note that, according to the EC requirements for the greenhouse gas emission reduction, the CO2 reduction should reach 20% by 2020. Use of warm asphalt mix, reclaimed asphalt pavement (RAP) and local resources will contribute significantly to reaching this goal.

***Core task 3:*** *To develop $CO_2$ neutral composite materials made from textile plants for use in energy-efficient buildings, thus contributing to a comfortable and healthy climate inside the building.*

**Time frame of the Core task 3 activities is included in Appendix 1-C.**

***Task for the Period 3:*** *To develop method for natural fiber composite material life-cycle assessment.*

One of the goals for this Period of the Project is to develop a method for natural fiber composite material life-cycle assessment (LCA), which refers to the core task of the project: "*To develop $CO_2$ neutral composite materials made from fiber plants for use in energy efficient buildings*". $CO_2$ neutral construction materials are especially important now, when a growing number of agreements are concluded in order to tackle the problem of global warming by reducing the $CO_2$ levels, for example, the Paris Agreement signed by the ES and other global actors in 2015 as well as various ES directives, for example 2010/31/EU, are aimed at reducing the $CO_2$ emission level by 2020 by 20% compared to the levels of 1990.

In order to fulfil these requirements the construction industry, which is among the industries with the biggest amount of greenhouse gas emissions, has to focus on new types of construction materials, which are $CO_2$ neutral or even negative. Among these materials are natural fiber composite materials which take up more $CO_2$ during their life-cycle than are generated during their production and exploitation. In order to fulfil the requirements of the above mentioned agreements and directives as well as to implement them in the national economy, a method for the production of natural fiber composite materials from the local resources have been developed and approved in the company SIA "Ekobūve" during the Period 3 of the Project.

For the fair assessment of the ecological benefits, a method for the natural fiber composite material life-cycle assessment has been developed in the framework of this Project. In order to develop this method, data from the separate technological processes of the natural fiber composites have been processed with the software SimaPro using Ecoinvent life-cycle data base. Life-cycle assessment and $CO_2$ balance calculations have been performed for the hemp fiber / lime binder panels, which are industrially produced in the company plant and assembled on the construction site. By using this method, the producers have an alternative for the traditional methods with lower environmental impact.

Second goal for this period is to obtain and assess the data from the heat and moisture migration collection system related to the following part of core task: "*... for use in energy-efficient buildings, thus contributing to a comfortable and healthy climate inside the building*". Analysis of this data shows that the natural fiber composites ensure relatively constant value of the relative humidity (40-60% RH) reducing fungi and mould formation as well as indoor temperature fluctuations in the changeable weather conditions.

During the tests the material showed humidity accumulation capacity allowing ensuring an indoor climate, which is stable and favourable for the human health; it absorbed the excessive humidity and released it, when the indoor humidity levels decreased. The test results show that the internal surface temperature for the 200 mm thick panel without plastering reaches its maximum in approximately 6 hours after the external temperature has reached its maximum, while for the 350 mm thick panel — in approximately 10 hours. It indicates that the thermal inertia of this material under real-life conditions is higher compared to the conventional wall materials (brick, aerated concrete) with similar thickness, which is related to the high proportion of hemp fibres having similar chemical composition and structure as wood.

In the next Period of the Project the obtained results will be updated and used to draw proposals for the standard LBN 002-15 “Thermotechnics of Building Envelopes” in order to include the thermophysical properties of the natural fibre composites in the respective standard. The updated standard would ensure wider application of the materials due to the fact that objective and reliable information about materials would be available to the producers and building planners.

| Tasks for Period 3 | Main results |
|---|---|
| ***1 To develop methods for increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement.*** | ***Recommendations for the increase of the corrosion and freeze resistance properties of the high performance cement composite (HPCC), 1 scientific publication*** |
| The testing results show significant difference in the freeze resistance of various high performance cement composites (HPCC) with the compressive strength exceeding 70MPa (after 28 days of hardening) depending on the microfillers used for partly replacing cement. The specimens with microsilica (5-15% of the amount of cement), show the highest compressive strength (94MPa after 180 days of hardening); however the compressive strength of these specimens reduced significantly after 110 freeze-thaw cycles in brine (16-33%) (LVS 156 Annex C) (Image 1). The compressive strength of the reference mix (without microfillers) did not change or even increased slightly after 110 freeze-thaw cycles in brine indicating that the hardening process continued in brine. While using metakaolin microfiller (10% of the amount of cement) the obtained concrete mix withstands 150 freeze-thaw cycles according to the LVS 156 Annex C without significant strength loss, which corresponds to 500 freeze-thaw cycles in water (Image 2). Relatively low freeze resistance of the high performance cement composites with microsilica microfiller can be explained by the fact that their increased strength and dense structure do not tolerate well the temperature fluctuations (from -20°C to +20°C), which possibly leads to the inner deformation and appearing of microcracks. The cracks in their turn contribute to the negative consequences of freezing resulting in low freeze resistance of these mixes, which needs to be increased by adding air-entraining admixtures etc. Interpretation of the freeze resistance results as well as calculation methodology could also have significant impact on the freeze resistance results. Therefore an additional research would be necessary to develop methodology for the high performance cement composite freeze resistance assessment based on the obtained results. | |

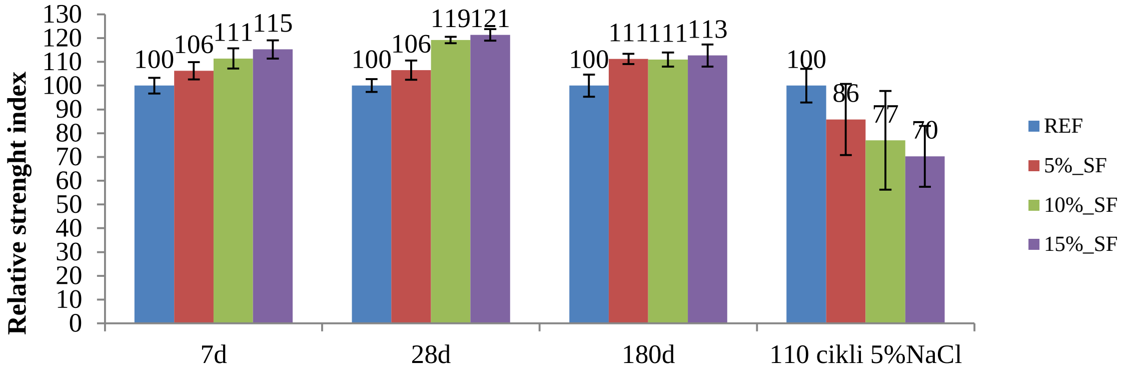



**Image 1. Relative strength index of the high performance concrete with microsilica (SF) aged 7, 28 and 180 d and after 110 freeze-thaw cycles.**

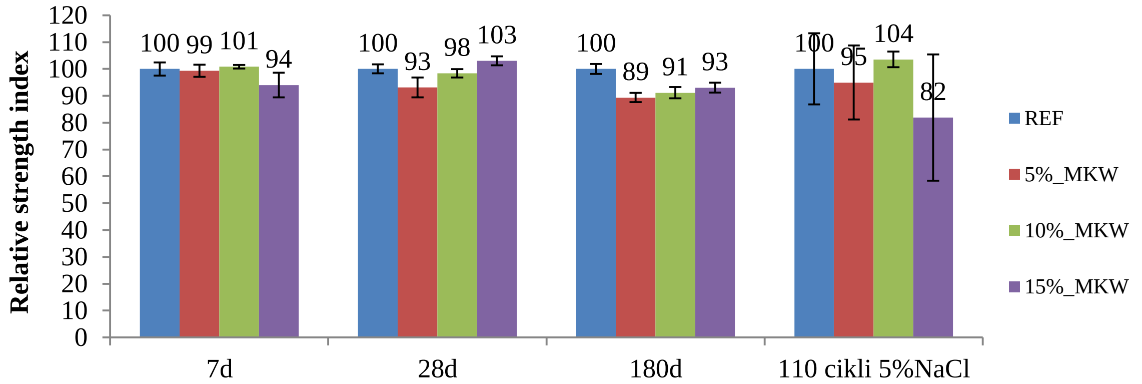



**Image 2. Relative strength index of the high performance concrete with metakaolin (MKW) aged 7, 28 and 180 d and after 110 freeze-thaw cycles.**

As the properties of the concrete (C50/60), which is currently widely used for various purposes, depend, to a huge extent, from the initial curing conditions, the research has been conducted 24 hours after casting of the high performance cement composite. The specimens have been exposed to various curing conditions for 28 days (specimens immersed in the water media, kept in the room temperature (60% RH) without additional wetting, in the +2$^{o}$C temperature (60% RH) without additional wetting). Then the specimens were stored in the room temperature until they reached 180 days. The research has been conducted in order to find out, what impact does the curing conditions have on the mixes with metakaolin, cenospheres (10% of the cement mass) as well as reference mix (100% cement) on the concrete properties including its freeze resistance.

Changes in the compressive strength of the concrete depending on the composition and curing conditions are given in Image 3. Lower temperature (2$^{o}$C) or relative humidity of the hardening environment has significant impact on the initial hardening dynamics (up to 28 days of hardening) of the high performance cement composites. The compressive strength of the specimens immersed in the water media increases more rapidly with the time. The concrete composition, in this case, type and amount of the microfillers, is more important with regard to the mechanical properties and durability of the concrete. The aim of using cenospheres (CS) was to accumulate additional moisture (in a similar way as by adding superabsorbent polymers), which possibly could ensure optimal moisture levels in the structure of composite during its hardening, this approach worked only in case, if the initial curing was in the water media. In addition, significant strength increase compared to the compressive strength after 28 days has been observed only after 180 days. In contrast, partial replacement of the cement with metakaolin (MKW) in the composition of the HPCC not only increases its mechanical properties compared to the reference composition but also ensures significant strength increase regardless of the initial curing conditions (air temperature and humidity).

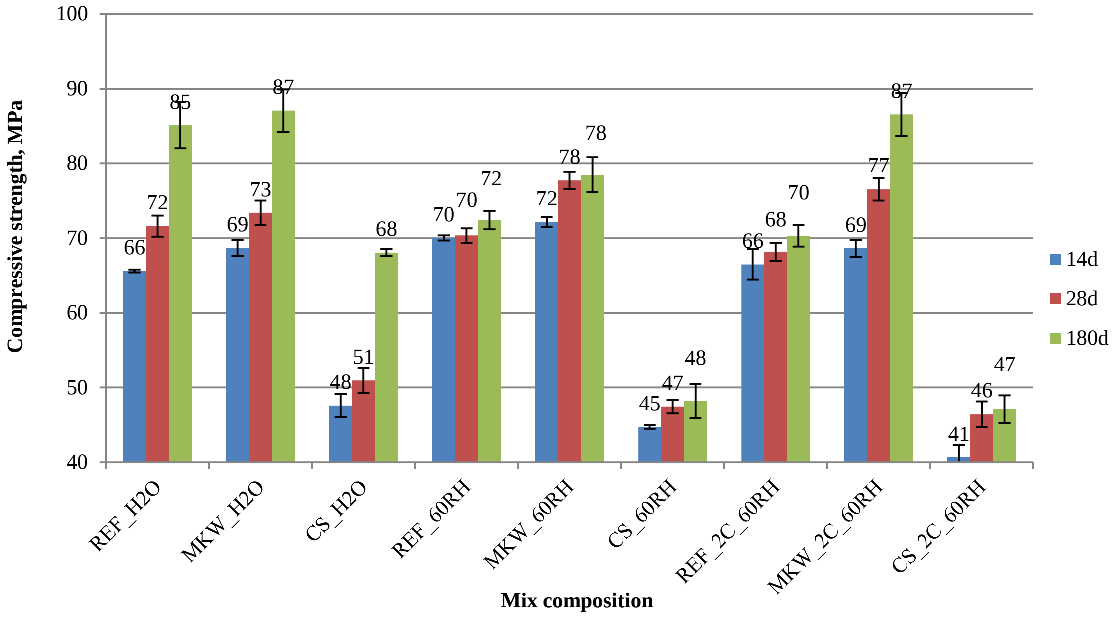
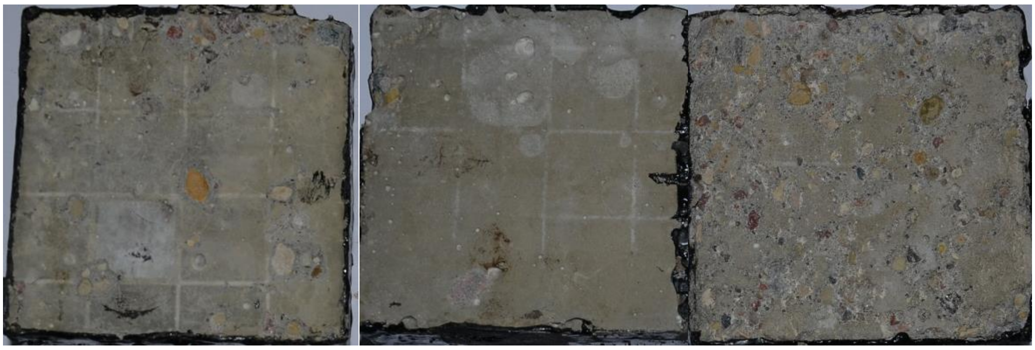



**Image 3. The compressive strength of the concrete depending on the type of microfillers and curing conditions: REF_H2O, MKW_H2O and CS_H2O – reference mix with 100% cement (REF), metakaolin (MKW) and cenospheres (CS), which are cured under normal curing conditions (water media, +20°C); REF_60RH, MKW_60RH, CS_60RH – reference mix, mix with metakaolin and cenospheres, which are cured in air (+20°C, 60% RH); REF_2C_60RH, MKW_2C_60RH and CS_2C_60RH – specimens, which are cured in air and lower temperature (+2°C, 60%RH).**

The surface resistance of the above mentioned HPCC has been measured in order to assess the destruction caused by frost after 52 freeze-thaw cycles with 3% NaCl (CDF test - RILEM TC 117-FDC) (Image 4). Surface loss after 52 freeze-thaw cycles is given in Table 1. For the HPCC specimens, who are cured in the water media, the crushing of the surface resulting from the freeze-thaw cycles is 1.5-3.3 kg/m$^2$. Crushing of the surface has been formed mainly in the contact area between the cement stone and aggregates. The HPCC specimens which are cured in the room temperature (REF_60RH) have lower resistance to the impact of freeze-thaw cycles compared to the specimens who are cured in lower temperature or in the water media. However, the microfillers have major impact on the freeze resistance parameters. HPCC with metakaolin have higher freeze resistance, which is similar to the results of previous research. Therefor it can be concluded that the low temperature does not have significant impact on the resistance to the freeze-thaw cycles and the surface loss is relatively insignificant (Table 1).

REF_H2O MKW_H2O CS_H2O

REF_60RH MKW_60RH CS_60RH



REF_2C_60RH MKW_2C_60RH CS_2C_60RH

**Image 4. Surface resistance of the specimens to the freeze-thaw cycles and the destruction it has caused.**

**Table 1. Surface deterioration caused by the impact of freeze-thaw cycles**.

| **Composition** | **Surface loss [kg/m$^3$]** | |
|---|---|---|
| | **44 cycles** | **52 cycles** |
| REF_H2O | 3.1 | 3.3 |
| MKW_H2O | 1.2 | 1.9 |
| CS_H2O | 1.0 | 1.5 |
| REF_60RH | 32.4 | 65.0 |
| MKW_60RH | 0.4 | 0.7 |
| CS_60RH | 0.3 | 2.6 |
| REF_2C_60RH | 0.2 | 0.4 |
| MKW_2C_60RH | 0.2 | 0.3 |
| CS_2C_60RH | 0.3 | 1.6 |

Chloride penetration depth depending on the type and volume of disintegrated sand (Table 2). The results show that the reference mix (REF) with the highest cement content shows the chloride penetration depth (migration coefficient $D_{nssm}$ 9.2 x 10-12m$^2$/s. By replacing 5-15% of the cement mass with disintegrated limestone-quartz sand the chloride migration coefficient increases from 12.2 to 15.5 x 10-12m$^2$/s (mixes QD5, QD10, QD15). Replacing 5% of the cement mass with disintegrated sand decreases the $D_{nssm}$ to 6.3 x 10-12m$^2$/s (Q5) but replacing 10 un 15% of the cement mass with disintegrated sand increases the $D_{nssm}$ to 10.0-11.2 x 10-12m$^2$/s (Q10 un Q15). It has been concluded that the disintegrated limestone-quartz sand does not show any activity in the concrete hardening process and the hydrated cement paste with decreased amount of cement loses its impermeability leading to lower resistance to the chloride migration in the structure of concrete. While the disintegrated quartz sand (5% of the cement mass) improves the resistance to the chloride migration in the structure of concrete, which can be related to the improvement of the hydrated cement paste density but by increasing the amount of the disintegrated sand the cement stone loses its permeability.

The surface deterioration caused by the impact of freeze-thaw cycles (RILEM TC 117-FDC method) for the HPCC mixes with disintegrated sand has been assessed as well. The results show

(Table 3) that replacing 15% of the cement with disintegrated sand the surface loss increases significantly. 1.7-1.8 kg/m$^2$ of the concrete surface loss occurs only after 28 freeze-thaw cycles already and it increases to 9.6-10 kg/m$^2$ after 84 freeze-thaw cycles which results in complete exposure of the concrete structure and deterioration of microfillers. The concrete mix with 5-10% of disintegrated sand has the surface loss 0.3-1.5 kg/m$^2$ after 84 freeze-thaw cycles but for the reference mix with 100% cement it is 0.5 kg/m$^2$.

**Table 2. The coefficient of chloride penetration depth depends on the amount of disintegrated sand in the concrete.**

| Composition | $D_{nssm}$ [$10^{-12}m^2/s$] |
|---|---|
| REF | 9.2±0.1 |
| QD5 | 12.9±1.2 |
| QD10 | 15.5±1.4 |
| QD15 | 12.2±1.2 |
| Q5 | 6.3±0.9 |
| Q10 | 11.2±0.7 |
| Q15 | 10.0±0.2 |

**Table 3. The surface loss after exposure to freeze-thaw cycles depends on the amount of disintegrated sand in the concrete.**

| Number of cycles | Weight loss [kg/m$^2$] | | | | | | |
|---|---|---|---|---|---|---|---|
| | REF | Q5 | QD10 | QD15 | QD5 | QD10 | QD15 |
| 28 | 0.0 | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 | 1.7 |
| 42 | 0.2 | 0.0 | 0.0 | 4.2 | 0.2 | 0.2 | 4.3 |
| 56 | 0.3 | 0.1 | 0.1 | 7.1 | 0.3 | 0.3 | 7.0 |
| 70 | 0.3 | 0.1 | 0.6 | 8.2 | 0.5 | 1.2 | 8.4 |
| 84 | 0.5 | 0.3 | 0.8 | 10.0 | 0.7 | 1.5 | 9.6 |

Sulphate corrosion testing for the HPCC with various microfillers has been performed. The prepared concrete specimens were exposed to the impact of sodium sulphate, which could result in appearing of sulphate salt (ettringite, gypsum) and increased volume. It causes expansion of the concrete and can lead to appearing of microcracks and destruction of the concrete structure. Controlled changes in both concrete mass and length have been fixed during the testing. The results show that after 28-day immersion in the sulphate solution the mass of the reference mix has increased by 0.5%, which may indicate accumulation of the sulphate products in the concrete pore structure, while mass of the HPCC with metakaolin microfiller increased by 0.7 to 0.38%. Expansion of the concrete during deformation testing period has not been detected but the shrinkage by 0.11 to 0.07% has been observed, which is normal during the concrete hardening process.

***Recommendation for the increase of the corrosion and freeze resistance properties of the high performance cement composite (HPCC)*** has been developed based on this research.

| | |
|---|---|
| ***2 To develop formulations of the high performance bitumen composites using reclaimed asphalt pavement (RAP) and to continue developing bitumen composites from lower quality local aggregates.*** | ***Recommendation for optimisation of bitumen composites' mixing process parameters<br>Participation in international scientific conference with a report, 1 scientific publication*** |

Development of the asphalt concrete composition with high proportion of the reclaimed asphalt pavement (RAP) (over 25%) continues during this period. Renovation of the RAP bitumen is carried out in order to obtain the bitumen class (B50/70) that corresponds to the technical rules. Calculations of the granulometric composition aimed at decreasing the content of small particles (< 0,063mm) continues as well. Homogeneity assessment of the recycled material has been carried out using namogram (*Wirtgen Cold Milling Manual*). The methods for using RAP material in the production of High Moduls Asphalt Concrete (HMAC) mix have been analysed. Renovation of the aged RAP bitumen has been carried with the bitumen's corresponding to the class B70/100 in order to obtain the bitumen class B20/30, which is suitable for the creation of HMAC mixes. Calculations of the granulometric composition of the mix have been carried out in order to reach thresholds corresponding to the asphalt concrete ACb16 and ACb 22. Based on the *Wirtgen Cold Milling Manual* new proportion of the RAP bitumen's has been defined in order to obtain bitumen class B50/70.

Analysis of the High Modulus Asphalt Concrete (HMAC) mix properties has been continued during this period. Recommendations for the optimisation of the mixing parameters and transportation of this type of asphalt concrete have been developed according to the plan.

In this research Period of the Project the designed bitumen composite material compositions with RA have been checked in pilot tests of deformative properties by using testing methods intended for the concrete exploitation properties - wheel tracking test, stiffness test and fatigue test, thermocrack formation tests as well as water sensitivity (adhesion of the bitumen and aggregate). The results have been compared with the reference mixes, which were prepared with new components. Analysing the results it has been found out that the rutting resistance for the asphalt concrete with 30% RAP is higher (WTSair 0.1) compared to the rutting resistance class of the reference mixes (WTSair 0,3). The fatigue resistance class is the same for both reference mix and asphalt concrete with 30% RAP- $\varepsilon_6$-130 (10Hz, 10°C). By increasing the RAP content to 50% the high rutting resistance is maintained but the fatigue resistance decreases significantly. It has been concluded that the highest exploitation properties of the asphalt concrete with RAP (aged bitumen renovated with the bitumen B70/100 having lower viscosity) are achieved by adding 30% of the RAP.

Classification of the warm mix asphalt technologies as well as information collection about the aggregates and technologies related to the production and construction in lower temperatures have been carried out during this period. The principles of the warm mix asphalt production have been analysed. The disadvantages of this technology have been defined. The methodology for the estimating of production costs has been developed.

4 deliverables have been developed based on the research performed in this Period of the Project: Methodology for the use of recycled material, Economic assessment of the use of high performance bitumen composites, Proposals for improvement of technical specifications for the construction of roads and Recommendation on use of bitumen with high viscosity, when using warm asphalt concrete mix aggregates.

***Recommendation for parameter optimisation of mixing process for asphalt concrete*** mixes has been developed based on this research.

| | |
|---|---|
| ***3 To develop method for natural composite material life-cycle assessment.*** | ***Method for production of ecological composite materials from fiber plants and local mineral binders. Method for natural fiber composite material life-cycle assessment.***<br>***Participation in an international conference with the report.*** |

According to the time frame, during the Period 3 of the Project it was planned not only to develop the method for natural fiber composite material life-cycle assessment but also to continue obtain and analyse the data coming from the heat and moisture migration collection system as well as to start developing a model based on the obtained data. The initial collection of the experimental data on the heat and moisture from the wall panel has been done for assessing the processes taking place in the constant microclimate inside the building.

The wall panel, which has been produced in January 2016 in cooperation with the company SIA "ESCO Būve", has been integrated in the existing wall structure on the 4th day after production, therefore drying and hardening processes continued under the real-life conditions. The thickness of the panel is 200 mm, without plastering. The density of the panel is 400kg/m$^3$, thermal conductivity 0,075 W/m*K. 3 sensors have been integrated into the panel in various depths (50, 100 and 150 mm) for the humidity migration and temperature control as well as 2 sensors for the registration of indoor climate and 2 sensors for the registration of outdoor climate (to detect the environmental and surface relative humidity levels as well as to register temperatures), as well as heat flow sensor (plate-shaped) for the detection real thermal conductivity. The signals coming from the sensors were collected in the data collection module and via mobile network sent by e-mail in the form of data table. The results of data analysis show that the humidity stabilisation period in the panel lasts at least 70 days in under these conditions.

During the experiments the material showed humidity accumulation capacity allowing to ensure an indoor climate, which is stable and favourable for the human well-being; it absorbed the excessive humidity and released it, when the indoor humidity levels decreased. During the test it has been found out that using the panel without plastering having a density 400kg/m$^3$, the internal surface temperature reaches its maximum in approximately 6 hours after the external temperature has reached its maximum, indicating that the thermal inertia of this material under real-life conditions is higher compared to the conventional wall materials (brick, aerated concrete) with similar thickness, which is related to the high proportion of hemp fibres having similar chemical composition and structure as wood. The optimal time interval for the temperature gradient equalisation is about 10 hours and it can be achieved by increasing the thickness of the panel from 200 mm to 350 mm. It should be noted that the panel without inner and outer plastering has been used. It is planned to use a panel with inner and outer plastering in the further research.

Method for the production of ecological composite materials from fiber plants and local mineral binders has been developed in the Period 3 of the Project according to the plan (See annexes for the deliverables). This method is based on the results obtained during the previous stages of the research and its main sections are the following:

1) Impact of the hemp-lime composite material production technology on the final properties of the material;
2) Impact of the hemp shives on the properties of the material;
3) Impact of the technological processes of the production on the final properties of the material;
4) Fire resistance properties of the material.

This method has been developed for the existing and possible new producers of the $CO_2$ neutral hemp-lime composite, because it involves impact of several technological factors and components on the exploitation properties of the construction material. Studying the impact that the shives obtained from the hemp cultivated in Latvia have on the properties of the material, it can be concluded that higher compressive strength can be reached using the shives with high proportion of short shives – 0,63-10 mm, and the optimal proportion of shives is about 85%. The most efficient approach is to combine two different types of short shives. The specimens with higher compressive strength (0,340 MPa versus 0,218 MPa) have slightly lower thermal conductivity, however, the increase of the thermal conductivity is not important – only up to 0,004 W/m*K. It has been found out that the content of dust in the hemp shives has negative impact on the strength of the material, therefore the recommended amount of dust should not exceed 2% of the amount of hemp shives.

The results of the fire resistance tests show that the developed $CO_2$ neutral construction material for the buildings can be classified as C s1, d0 according to LVS EN 13823:2010. Classification s1 shows that very small quantity of smoke is generated in the burning process. It is considered as the highest possible indicator for building materials (except class A1). Classification d0 in its turn show that no flaming droplets are generated, which is also the highest possible indicator in the respective class. The class C s1, d0, which has been obtained in the tests, is close to the class B s1, d0. It can be concluded that the highest possible fire resistance class that could be assigned to these materials is B s1, d0 because the amount of binder and density should be increased up to 1000 kg/m$^3$ in order to correspond to the class A; therefore the thermal conductivity would be around 0,2 W/m*K, which does not correspond to the goals and tasks of this Project. Use of alternative binders (magnesium binders), additives consisting boron and aluminium as well as compacting of the concrete are offered as the main prospective solutions for increasing the fire resistance of the material.

In order to improve the properties of the developed composite, researches involving various alternative binders and their impact on the properties of the material have been conducted in the Period 3 of the Project.

Magnesium-based binders were studied in order to increase the fire resistance of the composites. The compressive strength of the developed composite reached 1,80 MPa and its density – 500 kg/m$^3$, which are considerably better results compared to the hemp-lime composites. The prospective application of these binders gives the opportunity to use natural fiber composites for the production of self-supporting structures (without using wooden frame) which can bear insignificant vertical loads (for 1-1,5 floor buildings). In order to put the obtained results and conclusions into practice, additional research is necessary, which is planned in the next Period of the Project.

The research on the use of sapropel and lime-sapropel binders in the production of $CO_2$ neutral construction materials is performed separately. The strength of this composite is similar to the strength of hemp-lime composites but its $CO_2$ balance is significantly better because the binder of organic origin - sapropel - is used instead of the $CO_2$ emission generating lime.

ALINA organoclays with encapsulated active substances slowing down the biodegradation of the materials were added to the composites. The accelerated ageing tests were performed with specimens consisting ALINA organoclays as well as reference specimens placing them into climatic camera under the impact of ultraviolet radiation and temperature fluctuations. In order to put the obtained results and conclusions into practice, additional research is necessary, which is planned in the next Period of the Project.

With regard to the technological processes of the production, forced action mixers are the most appropriate equipment for mixing of the components of hemp-lime composite materials because it allows to prepare more homogenous mass compared to the gravitation mixer, which ensures better mechanical properties of the cured material.

By testing the impact of drying conditions on the mechanical, physical and exploitation properties of the material it has been concluded that it is not recommended to expose it to the increased humidity because the presence of moisture produces increased amount of lignin, sugar and other organic compounds which prevents lime carbonating.

In addition, the method for natural fiber composite material life-cycle calculations has been developed according to the tasks for the Period 3 of the Project. For this purpose data on separate processes were obtained and processed with the software SimaPro using Ecoinvent life-cycle inventory data base.

The data on hemp cultivation and processing were adapted to the Latvian situation, using research on the hemp processing life-cycle analysis and updating them with the average values of the processes and resources obtained from the data coming from the main companies cultivating and processing hemp in Latvia. The functional unit was designed as a panel with the thickness 300 mm and dimensions 1000x1000mm consisting of 275 kg/m$^3$ hemp-lime concrete and two 100x50mm load-bearing columns. The life-cycle was calculated for a period of 100 years.

As one of the core tasks includes the task to develop $CO_2$ neutral construction materials, in the framework of this method various possible material compositions and possible life-cycles have been modelled according to the IPCC 2007 GWP 100 method, which is the most widely used method for this kind calculations. One of the schematic draw of the process for the functional unit is given in the Image 5 showing the scenario with recycling of all materials after the life-cycle period of 100 years.

Viewing the results on the generated/accumulated amount of $CO_2$ for various types of hemp-lime materials it can be seen that the majority are $CO_2$ negative (as on Image 5), which means that they have accumulated more $CO_2$ than they will generate during the entire life-cycle including production The accumulated amount ranges from 15 to 30 kg for a functional unit, which is 50 to

100 kg on 1m$^3$ of the material. This amount is possible because hemp has accumulated significant amount of $CO_2$ during the period of growth, which is about 1 kg for 1 kg of hemp shives, taking into account the amount released during the previous stages of their processing.

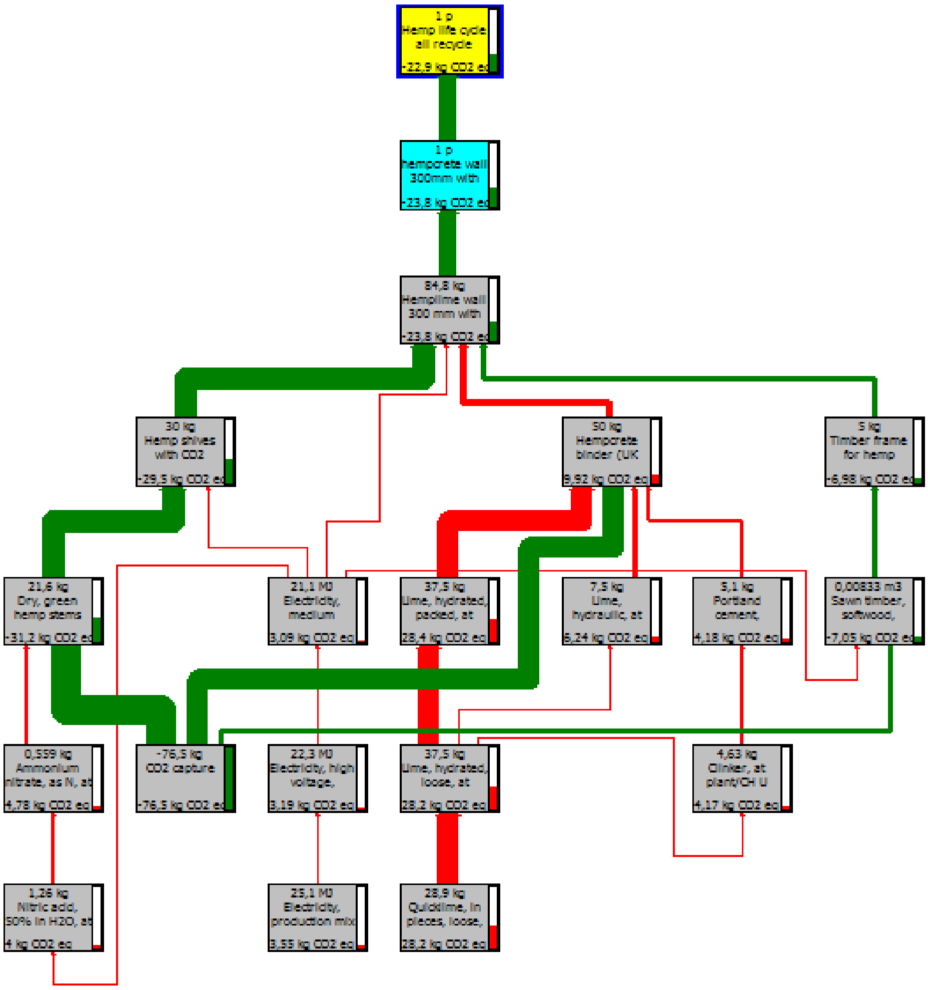
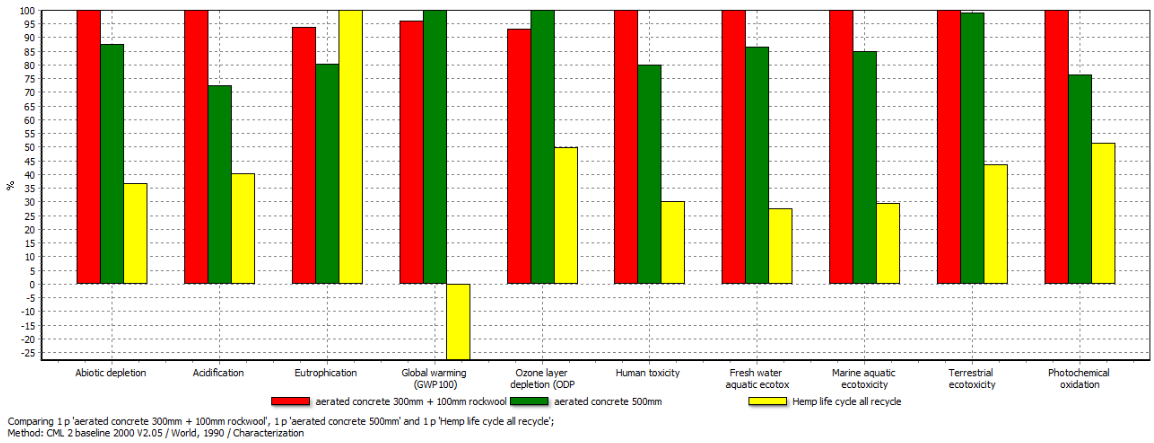



**Image 5. Hemp-lime functional unit $CO_2$ process tree**

Performing the life-cycle calculation of the material it has been compared to the alternative materials with analogue U value (0,19 W/m$^2$*K). Comparison with 500 mm aerated concrete wall (red) and 300 mm aerated concrete wall with 100 mm stone wall insulation (green) is shown on Image 6, calculations are made according to the CML2 Baseline method. The significant advantages of these materials can be seen in the graph – they show values, which are 65-75 % lower and even 125% for the $CO_2$. The only indicator, where the results of this material are lower, is eutrophication, which can be explained with the fact that hemp needs significant amount of phosphate fertilizer; however it is only 10-20% higher than for other materials.

***Method for production of ecological composite materials from fibre plants and local***



## 2.4. Further research and practical exploitation of the results

*(Describe further research activities that are planned, describe possibilities to practically exploit results)*

The goal of the state programme and this project is to create innovative and sustainable materials (cement, bitumen and textile plant composites) using local resources.

The planned goals for this reporting period are fully achieved.

The durability testing of the high performance cement composite materials were performed and well as the started durability testing of the high performance concrete specimens were continued in this reporting period. The following durability tests were performed: freeze resistance tests in 5% NaCl solution (150 cycles, 1 cycle per day, duration of the testing 7-8 months, LVS 156 Annex C), freeze resistance test – surface testing with CDF test), chloride penetration depth test (NT Build 492), alkali-silica (RILEM AA2) and sulphate resistance (SIA 262-1) tests. High performance cement composites with metakaolin-consisting waste products, microsilica and fly ash microfillers and cenospheres, which replace 5 to 15% of the cement in the composition of HPCC were tested. The freeze resistance testing is continued by freezing the specimens at -52.5°C and performing the test of surface crushing after the destructive impact of the frost (according to the LVS 156 Annex C and RILEM TC 117-FDC) in order to compare freeze resistance testing and determine the most appropriate method. The durability tests for the high performance cement composites produced with disintegrated sand (a method for the sand crushing) were continued. The dolomite and quartz sand (Saulkalne-S, fraction 0.3-2.5) and quartz sand (Saulkalne-S, fraction 0-1mm) was disintegrated.

By completing the tasks planned for this reporting period it has been concluded that the introduction of microfillers (e.g. waste products consisting metakaolin) significantly increases durability indicators of the concrete. The resistance of concrete structures to the chloride penetration depth increases up to 3.5 times, which is an important indicator for designing steel reinforced concrete structures, where the reinforcement has to be protected from the corrosion. Using of metakaolin microfiller limits alkali-silica reactions in the HPCC composition resulting in reduced crack formation risks as well as gas and water permeability of the concrete. It has been found out that it is possible to increase it to 500 freeze-thaw cycles, if the waste product containing metakaolin is included in the composition of the HPCC to replace 10% of the cement. The microsilica improves the compressive strength of the concrete considerably in its turn but the freeze resistance of the concrete decreases significantly, therefore it is necessary to apply traditional methods for the freeze resistance improvement (e.g. by adding air-entraining admixtures). The cenospheres decrease the compressive strength of the concrete due to their porous structure, however, in the long-term the compressive strength of the concrete cured under conditions of increased humidity is close to the compressive strength of the reference mix. Activity of the disintegrated sand and improvement of the compressive strength has been observed in the samples of cement mortar, however, significant increase of the compressive strength increase in the concrete has not been observed.

The scientific importance of the results is related to the increased knowledge and understanding of the testing involving physical, mechanical and durability properties of cement composites, selection of the most suitable methods and interpretation of the obtained data. The performed research allows understanding the role of microfillers, analysing their properties and their impact on the concrete freeze resistance, sulphate resistance, resistance to the chloride penetration in the structure of HPCC and alkali-silica reactions.

The practical importance of the results to the huge extent related to providing information and training to the specialists of the construction industry contributing to practical application of the innovative and high-quality concrete for the construction purposes. Use of new materials is related to prejudices, lack of knowledge and distrust to the huge extent. By understanding an impact that various microfillers have on the properties of HPCC (for example, its freeze resistance, resistance to the impact of sulphates or chlorides) allows to select the most suitable microfiller and the right amount. The efficient use of microfillers allows to decrease the cement consumption for the production of HPCC by maintaining and even increasing its mechanical properties and durability. The performed research, developed methods and recommendations will provide confidence and courage to use a new type of concrete, which allows to design new types of buildings by using innovative structural solutions. The method “High performance cement composite production method” tested and verified in the company SIA "Warm House" shows that the HPCC is suitable for the industrial production.

The further activities are related to the production and testing of innovative reinforced cement composite materials. Dispersed reinforcement (various types of glass fibre) will be added to the high performance concrete mixes with efficient microfillers, which have been developed in the framework of this project, and the physical and mechanical properties of these composite materials will be tested. Glass fibre and glass materials have a potential risk of producing alkali-silica reactions in the concrete structure, which is an undesirable effect and could create significant deterioration of the concrete structure. Impact of the microfillers and glass fibre alkali-silica reaction will be assessed and the deliverable about the obtained results will be prepared.

An important solution involving both economical and ecological aspects is use of the warm mix asphalt technology for the development of high performance asphalt concrete mixes. By introducing the warm mix asphalt technology in Latvia it would be possible to increase the proportion of black bitumen pavement on the roads with lower classification as well as to renovate longer distances on the main roads thus improving the overall road condition. It would be possible due to the decreased energy consumption related to the production of warm mix asphalt thus reducing the production costs and allowing to use these resources for the road maintenance, construction of new roads or reconstruction and renovation of the existing roads. It is important to note that the importance of this research is in the fact that the asphalt concrete producers do not have to modify significantly their plants in order to produce warm mix asphalt. The asphalt concrete mixes intended for the moderate and severely congested roads, which will be developed in the framework of this project using warm mix asphalt technology as well as local aggregates, will be tested and verified in the real-life production process by the company SIA "Ceļi un Tilti". It is planned to conclude an agreement with the state-owned company VAS "Latvijas Valsts ceļi" in 2017 in order to continue research on this important theme in order to develop specifications of these bitumen composite materials.

The scientific value of the results refers to the assessment of properties for the bitumen and aggregates as well as the impact of their interaction on the workability improvement in lower production and laying temperatures. In order to assess the workability in the laboratory settings, warm mix asphalt mixes have been developed and produced by using special aggregates and their compaction in lower temperatures has been tested. The lowest compaction temperature has been determined by comparing the compaction temperatures with the traditional warm asphalt concrete as well as the economical assessment and recommendations for the design of the bitumen composite created in the framework of this project have been prepared.

Two methods have been developed in order to achieve the goals of the Period 3 of the Project: "Method for production of ecological composite materials from fiber plants and local mineral binders" and "Method for natural fiber composite material life-cycle assessment". These methods are important for the achievement of the common goals of the project as well as they have practical application.

"Method for production of ecological composite materials from fiber plants and local mineral binders" is intended for the existing and possible new producers of the ecological building materials because it involves an impact of both components and technological processes on the mechanical, physical and exploitation properties. For example, the collected information about the impact that the shives obtained from the hemp cultivated in Latvia have on the properties of the material allows the producers to select the hemp shives or their combination, which are the most appropriate for their production goals. The offered possibilities to increase the fire resistance of the material are also important as they can be used depending on the requirements for the specific project.

The developed method "Method for production of ecological composite materials from fiber plants and local mineral binders" is submitted for examination to the company SIA “ESCO būve”, which is active in the hemp-lime composite wall panel production and construction of the buildings.

"Method for natural fiber composite material life-cycle assessment" is prepared in a form that allows representatives of the industry without essential and specific knowledge to compare the $CO_2$ balance of the hemp-lime composites produced with different technologies. By using this method the producers will have an opportunity to estimate the impact of the selected technology and combination of resources on the properties of the material as well as to choose alternative methods in order to reduce the impact on environment. "Method for natural fiber composite material life-cycle assessment" will be given to companies for approbation during the next Period of the Project.

In the Period 3 of the Project it was planned to obtain and analyse data coming from the heat and moisture migration collection system as well as to start developing a model based on the obtained data. The initial collection of the experimental data on the heat and moisture from the wall panel has been done for assessing the processes taking place in the constant microclimate inside the building.

**To achieve the project target, it is planned for the Period 4 of the Project:**

1. *Development of preparation method for innovative and reinforced cement composite materials or infrastructure projects and public buildings*
2. *Development of the methodology for the use of recycled asphalt; Economic assessment of the use of high performance bitumen composites;*
3. *To design and create data collection system, which is suitable for the heat and moisture control in the structures of energy efficient buildings. To prepare guidelines for the development of data collection system. To prepare proposals for updating of the LBN 002-01.*

To achieve the goals of the Core task 1, in the research Period 4 of the Project it is planned to produce and teste innovative reinforced cement composite materials. Dispersed reinforcement - various types of glass fibre (waste materials and commercially available materials) will be added to the high performance concrete mixes with efficient microfillers (cenospheres, metakaolin, microsilica, dust coming from the cement production), which have been developed in the framework of this project, and the physical and mechanical properties of these composite materials will be tested. The dispersed reinforcement limits the structural deformation of the HPCC under the impact of the internal stress, reduces concrete fragility and increases its tensile strength. However, the glass fibre and glass reinforcement can react with the cement minerals and reduce the HPCC durability due to the destructive impact of alkali-silica reaction. In this Period of the Project it is planned to determine the potential of the microfillers to limit the destructive impact on the alkali-silica reaction on the HPCC structure. The tests will be performed according to the RILEM AAR-2 methodology and the deliverable on the obtained results will be prepared.

To perform research on the bitumen composites, in the Period 4 of the Project it is planned to continue the experimental testing of deformative properties for the bitumen composite material (HMAC, RAP and warm mix asphalt) mixes by applying methods intended for the concrete exploitation properties - wheel tracking tests, stiffness tests and fatigue tests, thermocrack formation tests as well as water sensitivity (adhesion of the bitumen and aggregate).

It is planned to continue developing innovative bituminous composite mixes by using gravel shiver LA>20 and comparing their properties to the traditional types of asphalt concrete.

A high priority will be placed on the properties of bitumen mastic and polymer-modified bitumen as they define the exploitation properties of the asphalt concrete and its workability to the greatest extent. Bitumen mastic will be created by using various aggregates (lime, dolomite, granite). It is planned to determine the rheological properties of the bitumen mastic in order to assess the rutting resistance and fatigue resistance according to the SUPERPAVE methodology. Modified and unmodified bitumen will be used for the development of bitumen mastic as well.

Summarising the obtained results in the end of the Period of the Project it is planned to prepare economic assessment (asphalt concrete mixes from lower quality local aggregates), methodology (for the use of recycled material), recommendations (for the decrease of bitumen viscosity using warm mix asphalt technology) and proposals for improvement of local technical specifications as well as to submit one patent application.

In the framework of the Core task 3 temperature, humidity and heat flow measurements will be continued in the existing buildings and wall segments with the natural fiber construction materials, a model will be developed based on the obtained data and guidelines for the development of data collection system will be prepared in the Period 4 of the Project.

The data during winter/spring season will be mainly collected from the existing building with continuous presence of its inhabitants therefore ensuring the indoor climate which is required for the purposes of this research. Data collection will be performed in the cooperation with the company SIA "ESCO Būve", which is active in the hemp-lime wall panel building construction. These data are necessary for assessing the humidity accumulation capacity of the natural fibre construction materials ensuring stable climate, which is favourable for the human health and well-being. In the same time the data form the previously tested structures - the experimental wall panel and the part of the wall insulated from the inside, etc. - will be collected during this Period of the Project in order to compare them with the data form previous seasons.

During the summer/autumn period the data will be collected from two main sources - a building being exploited as well as a building, which is planned to build in the spring/summer season of 2017. The data from a building being exploited are necessary in order to verify the thermal inertia of this material under real-life conditions and to assess the time lag related to the thermal flywheel effect. The data from the newly erected building are necessary in order to check drying of the materials in the summer climate and compare these data to the previous results.

Heat and moisture migration control model will be developed as well as guidelines for the development of data collection system will be prepared based on these data.

It is also planned to draw proposals for the standard LBN 002-15 "Thermotechnics of Building Envelopes" in order to include the thermophysical properties of the natural fibre composites in the respective standard in the framework of the Period 4 of the Project. These proposals will include average density and the corresponding thermal conductivity, specific heat capacity and the water vapour resistance factor of the natural fibre construction materials, which are determined from the results of experiments as well as from the literature sources. This additional information in the LBN 002-15 would ensure wider application of these materials due to the fact that objective and reliable information about materials would be available to the building planners.

In order to improve the properties of the developed composite, research involving various alternative binders and their impact on the properties of the material will be conducted in the Period 4 of the Project. In parallel, research on the biopersistence of the hemp/lime, magnesium or sapropel binder / hemp shive composite material and its possible increase will be conducted.

### 2.5. Dissemination and outreach activities

*(Describe activities that were performed during reporting period to disseminate project results)*

In the project Period 3 of the Project „Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures" **6 full conferences papers were published or accepted for publishing** (see Annex 7):

1. Bumanis G., Bajare D., Korjakins A., Durability of High Strength Self Compacting Concrete with Metakaolin Containing Waste, Key Engineering Materials, vol. 674, 2016, 65-70;

   http://www.scopus.com/record/display.uri?eid=2-s2.0-84958213606&origin=resultslist&sort=plf-f&src=s&st1=bajare&st2=&sid=825680C2EBD50EF96A423542C8B86583.Vdktg6

RVtMfaQJ4pNTCQ%3a210&sot=b&sdt=b&sl=19&s=AUTHOR-NAME%28bajare%29&relpos=0&citeCnt=0&searchTerm=

2. Bajare D., Bumanis G., Chloride Penetration and Freeze-Thaw Durability Testing of High Strength Self Compacting Concrete. Proceedings of the International RILEM Conference Materials, Systems and Structures in Civil Engineering 2016 Segment on Service Life of Cement-Based Materials and Structures, Service Life of Cement-Based Materials and Structures, Technical University of Denmark, vol. 2, 2016, 435-442;
3. Bumanis G., Goljandin D., Bajare D., The Properties of Mineral Additives Obtained by Collision Milling in Disintegrator, Key Engineering Materials, vol. 721, 2017, 327-331 (accepted for publishing);
4. Dembovska L., Bajare D., Pundiene I., Vitola L., Effect of Pozzolanic Additives on the Strength Development of High Performance Concrete, Procedia Engineering 00 (2016) 000–000 (accepted for publishing);
5. Bumanis G., Bajare D., Compressive strength of cement mortar affected by sand microfiller obtained with collision milling in disintegrator, Procedia Engineering 00 (2016) 000–000 (accepted for publishing).
6. Haritonovs V., Tihonovs J., Smirnovs J., High Modulus Asphalt Concrete with Dolomite Aggregates J. Transportation, Research Procedia, vol. 14, 2016, 3485-3492.
   https://www.scopus.com/record/display.uri?eid=2-s2.0-84991268433&origin=resultslist&sort=plf-f&src=s&st1=haritonovs&st2=&sid=58CFA54CB8994A281AED6E4EB9703B6C.wsnAw8kcdt7IPYLO0V48gA%3a30&sot=b&sdt=b&sl=23&s=AUTHOR-NAME%28haritonovs%29&relpos=2&citeCnt=0&searchTerm=

**Participation in conferences:**

1. Vitola L., Bajare D., Bumanis G., Sahmenko G., Evaluation of Pozzolanic Properties of Micro- and Nanofillers Made from Waste Products, 18th International Conference on Concrete, Structural and Geotechnical Engineering, 25.-26. 01. 2016, Istanbul, Turkey;
2. Bajare D., Bumanis G., Chloride Penetration and Freeze-Thaw Durability Testing of High Strength Self Compacting Concrete, Materials, Systems and Structures in Civil Engineering, 19-22.08.2016, Copenhagen, Denmark;
3. Dembovska L., Bajare D., Pundiene I., Vitola L., Effect of Pozzolanic Additives on the Strength Development of High Performance Concrete, 12th International Conference "Modern Building Materials, Structures and Techniques" MBMST 2016, 26.05-27.05.2016, Vilnius, Lithuania.
4. Bumanis G., Bajare D., Compressive strength of cement mortar affected by sand microfiller obtained with collision milling in disintegrator, 12th International Conference "Modern Building Materials, Structures and Techniques" MBMST 2016, 26.05-27.05.2016, Vilnius, Lithuania.
5. Bumanis G., Goljandin D., Bajare D., The Properties of Mineral Additives Obtained by Collision Milling in Disintegrator, The 25th International Baltic Conference of Engineering Materials & Tribology, BALTMATTRIB 2016, 3-4.11.2016, Riga, Latvia.
6. Bumanis G., Bajare D, Sahmenko G., Dembovska L., Vitola L., Korjakins A., High performance concrete with microfillers; their production methods, strength and durability, Riga Technical University, 57th International Scientific Conference, 14.-18.10.2016, Riga, Latvia.
7. Haritonovs V., Tihonovs J., Smirnovs J., High Modulus Asphalt Concrete with Dolomite Aggregates. Transport Research Arena Conference, TRA 2016, 18. -21.04.2016, Warsaw.
8. Haritonovs V., Tihonovs J., Sustainable bitumen composites for road constructions, Riga Technical University, 57th International Scientific Conference, 14.-18. 10.2016, Riga, Latvia.

9. Sahmenko G., Sinka M., Energy-efficient and $CO_2$ neutral building materials from natural fibers, Riga Technical University, 57th International Scientific Conference, 14-18.10.16, Riga, Latvia;
10. Sahmenko G., Sinka M., Building materials with natural fiber for sustainable construction, Concrete Association, XXV Scientific Technical conference, 10.11.2016, Riga, Latvia.

In the project Period 3 of the Project „Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures" **4 conference abstracts or full papers have been prepared and submitted for 2017**:

1. Bumanis G., Sahmenko G., Korjakins A., Bajare D., Influence of curing conditions on the durability of high performance concrete, IMST 2017, September 27-29, Riga, 2017
2. Rieksts K., Haritonovs V., Izaks R., Tihonovs J., Investigation of filler properties using Dynamic Shear Rheometer, IMST 2017, September 27-29, Riga, 2017.
3. Sinka M., Sahmenko G., Bajare D., Lime-hemp concrete (LHC) enhancement using magnesium based binders, International Conference on Bio-Based Building Materials, June 21st - 23rd 2017, Clermont-Ferrand, France.
4. Sinka M., Sahmenko G., Bajare D., Hydrothermal properties of lime-hemp concrete (LHC) measured on site, IMST 2017, September 27-29, Riga, 2017.

**Full papers have been prepared for submission to the journals with SNIP>1:**

1. Bumanis G., Vitola L., Dembovska L., Bajare D., Comparison of the freeze resistance assessment methods for high performance cement composite durability assessment, submitted in the journal "Building and Construction" (SNIP 2.124).
2. Rieksts K., Haritonovs V., Izaks R., The influence of filler type and gradation on the rheological performance of mastics, submitted in the journal "Road Materials and Pavement Design" (SNIP 1.3).
3. Sinka M., Sahmenko G., Bajare D., Life cycle analysis of pre-fabricated and in-situ made lime-hemp concrete, measuring of carbon footprint, submitted in the journal "Renewable and Sustainable Energy Reviews" (SNIP 3.109).

**2 master's thesis and 3 bachelor's thesis have been prepared and defended within Project 1.**
**Master's thesis:**

1. Edgars Zelcs "Prefabricated concrete building stiffening element calculation method comparison", supervisor Dr.sc.ing. A.Korjakins;
2. Maris Jansons "Road Pavement Maintenance, Pothole Repair with Bitumen Emulsion and Crushed Stone", supervisor Dr.sc.ing. V. Haritonovs.

**Bachelor's thesis:**

1. Kristaps Juska "Wooden beam intermediate floor types, their optimal choice", supervisor Dr.sc.ing. A.Korjakins;
2. Aleksejs Novikovs "Optimization of reinforced solid slab", supervisor Dr.sc.ing. A.Korjakins;
3. Julija Sadijeva "The ecological insulation materials", supervisor Dr.sc.ing. A.Korjakins.

**The following doctoral theses are developed:**

1. J. Justs „Ultra high performance concrete with diminished autogenous shrinkage technology", supervisor Dr.sc.ing. D. Bajare, planned to defend in 2017
2. J. Tihonovs „Asphalt concrete mixes from the local mineral material with high exploitation properties" supervisor Dr.sc.ing. J. Smirnovs, Dr.sc.ing. V. Haritonovs, planned to defend in 2017
3. M. Sinka „Natural fibre insulation materials", supervisor Dr.sc.ing. G. Shahmenko, planned to defend in 2017

4. N. Toropovs „Fire resistance of high performance concrete”, supervisor Dr.sc.ing. G. Shahmenko, planned to defend in 2017

**Number of the new methods that have been tested and verified in various companies:**

1. Preparation of production methods for high performance asphalt concrete mixes from low quality components, tested and verified in the company SIA “Ceļi un Tilti”, acknowledgement dated with 16.09.2016.
2. Preparation of production method for high performance cement composite by partly replacing cement with microfillers, tested and verified in the company SIA “Warm House”, acknowledgement dated with 20.09.2016.
3. Method for the production of ecological composite materials form fiber plants and local mineral binders, tested and verified in the company SIA “ESCO būves”, acknowledgement dated with 21.10.2016.

**Increase of the qualification and obtaining of new knowledge, promotion of the international cooperation:**

1. **Maris Sinka**, researcher, Department of Building Materials and Products, 21. -27.11.2016 University of Ghent, Ghent, Belgium - basic training on the use of SimiPro life-cycle analysis software. Task - to learn the basics as well as data input and processing mechanism for being able to use this software without further assistance. (Funded from different budget)
2. **Diana Bajare**, prof. Department of Building Materials and Products 3-7.07.2016, Technical University of Denmark, Lyngby, Denmark - meeting on the preparation of a new Horizon2020 project on the development of innovative structural solutions for the sustainable construction. The meeting was organised in the Technical University of Denmark with participation of 5 representatives from 3 different universities in Europe. Opportunities of the new project proposal preparation for the planned new project tenders and possible student exchange have been discussed in this meeting. Possible project themes and the results to be achieved have been discussed during the visit. It has been decided to start the preparation of the project for the submission in the autumn of this year. (Funded from different budget)
3. **Laura Vitola**, assistant, Department of Building Materials and Products, 26.02.16.-30.04.16. Eduardo Torroja Institute for Construction Sciences, Madrid, Spain - during the visit several series of specimens have been prepared in order to study an impact of the metakaolin and fly ash on the structure of alkali activated cement. Methods for the macro and microstructure investigation (SEM, etc.) as well as several methods of the chemical and thermal analysis (XRD, FTIR, DTA) have been acquired. (Partial funding)
4. **Diana Bajare**, prof. Department of Building Materials and Products, 17-19.06.2016 Warsaw, Poland - was meeting with the colleagues of the project COST TU1404 on the preparation of new Horizon 2020 project proposal on the development of innovative structural solutions for the sustainable construction. 12 representatives form 6 different universities in Europe as well as industry representatives participated in the meeting. Opportunities of the new project proposal preparation for the planned new project tenders. Possible project themes and the results to be achieved have been discussed during the visit. Before the meeting prof. D.Bajare visited Lafarge cement factory in Poland including demonstration of the new cement production line on a special visit organised for the participants of the meeting and potential project partners. It has been decided to start the preparation of the project for the submission in the autumn of this year. (Funded from different budget)
5. **Laura Dembovska**, Slovenia, researcher Department of Building Materials and Products, Slovenian national building and civil engineering institute, Ljubljana, Slovenia,18.-29.01.2016 During the visit several series of cement-based composites have been prepared in order to perform the microstructural analysis with the microtomography method and

DTA/TG as well as to acquire the above mentioned methods, their principles and result interpretation. An additional goal of this visit was to strengthen the cooperation between the scientific institutions.

6. **Diana Bajare**, prof. Department of Building Materials and Products, 02-05.03.2016, University of Zagreb, Zagreb, Croatia - Participation on the event "Phosphor gypsum brainstorm", where new project ideas for next Horizon 2020 project tenders have been discussed. 17 participants from 10 different countries attended this event. (From the project budget)

**New research projects, preparation of project proposals and participation:**

Based on the results of the Project 1 and the cooperation activates in 2016, project team submitted 4 project proposals in the first round of ERDF project tender with the specific objective "To increase the research and innovation capacity of scientific institutions of Latvia and their ability to attract external funding by investing in human resources and infrastructure" (Measure "Industry-Driven Research"). After an international scientific assessment of the projects the following project proposals (duration of the project - 36 months) related to the target of the Project 1 were confirmed:

1. „Development, optimisation and sustainability evaluation of smart solutions for nearly zero energy buildings in real climate conditions", in cooperation with the University of Latvia, (2016-2018), total project funding **EUR 580 000**.
2. „Innovative use of reclaimed asphalt pavement for sustainable road construction layers", (2016-2018), total project funding **EUR 648000**.
3. "A New Concept for Sustainable and Nearly Zero-Energy Buildings", (2016-2018), total project funding **EUR 648 648.00**.
4. "Zero Energy Solutions for Special Purpose Buildings", (2016-2018), total project funding **EUR 634 615.**

**The submitted H2020 projects that are in the evaluation stage:**

1. Call H2020-EE-2016-CSA, Type of action CSA Draft proposal ID SEP-210360903, Deep_Renov. Target of the Project - promote and guide building owners/tenants in deep renovation through clear information, databases of qualified actors and reachable to a large number of owners/consumers (e.g. supported by municipalities) and also by adapting existing financial mechanisms, instruments and innovative business models to address market failures, in particular split incentives.
2. Call H2020-NMBP-2017-two-stage, Type of action RIA, Draft proposal ID SEP-210400265, SMARTmat. The main idea of the SMARTmat proposal is to create software for an adequate choice of concrete mix design and/or primary protection considering environmental and anthropogenic impacts according to construction region, typically used concrete mix composition and local raw materials' base.

**Participation in the international cooperation projects:**

1. COST Action Programme TU1301 NORM for Building materials (NORM4BUILDING), Action duration 08.07.2013-15.05.2017
2. COST Action Programme TU1404 "Towards the next generation of standards for service life of cement-based materials and structures", Action duration 14.05.2014.-13.05.2018
3. COST Action Programme CA15202 "Self-healing as preventive Repair of Concrete Structures", Action duration 30.09.2016.-29.09.2020

**The performance indicators of the programme and project promotion**

Project representatives participated in the NRP IMATEH meetings on the Project progress and implementation on 14.10.2016 and 16.11.2016.

Popular scientific article was published in the journal „Būvinženieris” titled "Local resources for the asphalt concrete compositions" („Asfaltbetona sastāviem vietējie materiāli”), October 2016, No 52 (authors - V.Haritonovs, J. Tihonovs).

In order to promote the project M. Shinka and G. Shahmenko participated on the scientific discussion "Eco materials in the construction" on 19.04.2016, where they presented the latest trends in the ecological construction industry as well as the results achieved in the first periods of the research programme.

The preparation for the international conference IMST „Innovative Materials, Structures and Technologies 2017", 27.09.-29.09.2017 has been started (initial information and web page have been prepared, information about the topics, location and time of the conference has been prepared and distributed).

Scientific conference for students has been organised on 27.04.2016.

During the Riga Technical University 57th International Scientific Conference (14.-18.10.2016) the conference guests (scientists from Latvia and abroad, students and representatives from industries as well as members of the scientific commission) have been informed about the project achievements and the obtained scientific results.

On 10.11.2016 information on the project achievements and the obtained scientific results has been reported on the scientific conference of the Latvian Concrete Association. Students and representatives of the industry from Latvia as well as scientific staff from the Riga Technical University and the Latvian University of Agriculture were among the conference participants.

To promote the programme, Concrete Contest (Stage 1, concrete preparation competition) took place on 13.04.2016. Teams of 3 participants prepared concrete specimens, which were tested on the compression strength after 28 days, determining teams having the strongest specimens. Aim of the concrete contest is to encourage students to practical application of the knowledge obtained in the university and technological development.

Stage 2 of the Concrete Contest took place on 12.05.2016., when the winner has been determined among 7 teams by testing the specimens on the compression strength.

Upon launching the NRP programme IMATEH website has been created, where information on programme achievements and activities is constantly updated. On IMATEH website http://imateh.rtu.lv/ detailed information on Project 1 is available as well as information on NRP IMATEH activities and updates.

The co-financing coming from the private sector and income from contract work based on the results of the Project 1 constitute EUR 16 449 in the Period 3.

## PART 2.– INFORMATION ABOUT PROJECT

### 2.1. Project Nr.2

| | | |
|---|---|---|
| Title | ***Innovative and multifunctional composite materials for sustainable buildings*** | |
| Project leader's name, surname | Kaspars Kalnins | |
| Degree | Dr.sc.ing. | |
| Institution | Riga Technical University, Institute of Materials and Structures | |
| Position | Leading researcher | |
| Contacts | *Phone* | +371 26751614 |
| | *E-mail* | Kaspars.kalnins@sigmanet.lv |

### 2.2. Tasks and deliverables

*(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)*

**Goal of the project:** ***Development of sandwich panels from raw resources available in Latvia – birch plywood. Developed product should maintain stiffness/strength comparing to the conventional plywood boards meanwhile assuring weight saving and improving impact resistance, vibration damping and heat isolation properties.***

**Tasks of the project**

1. Experimental investigation of separate sandwich panel components as experimental investigation of finished prototypes
2. Development of design methodology based application of FEM and validated numerical models.
3. Laboratory scale sandwich panel prototyping and development of recommendations for manufacturing scale-up

**Time frame for the core tasks is given in Annexes 2-A.**

### 2.3. Description of gained scientific results

*(Describe scientific results achieved during reporting period, give their scientific importance)*

| Tasks allocated for reporting period | Core achievements |
|---|---|
| ***1. Experimental research on component scale specimens. Additional investigation damping and impact properties on finalised panels with vertical stiffeners.*** | ***Performed experimental investigation of shear and debonding strength of the specimens*** |

Mechanical tests to determine shear and bonding strength of the sandwich panel`s fragments have been performed by Riga Technical University, Institute of Materials and Structures.

Specimens for adhesive debonding tests have a width of one section of the sandwich panel and the same thickness as illustrated in Figure 1.a. Section was filled with foams in the similar manner as full panel, by foam injection. Specimens were attached to the plates of INSTRON E10000 electric test machine by adhesive. Deformation driven tests were performed with the speed of 0.5 mm/min recording time, plate travel distance and load.

Shear tests have been performed of the same machine according ASTM C273 standard (Standard Test Method for Shear Properties of Sandwich Core Materials). Both surfaces of the specimen are bonded to steel plates as shown in Figure 1.b. In the result of the tests shear rigidity, strength and failure modes were acquired. Digital Image Correlation equipment was exploited to measure strains and calculate shear modulus of the sandwich panel in post-processing mode.

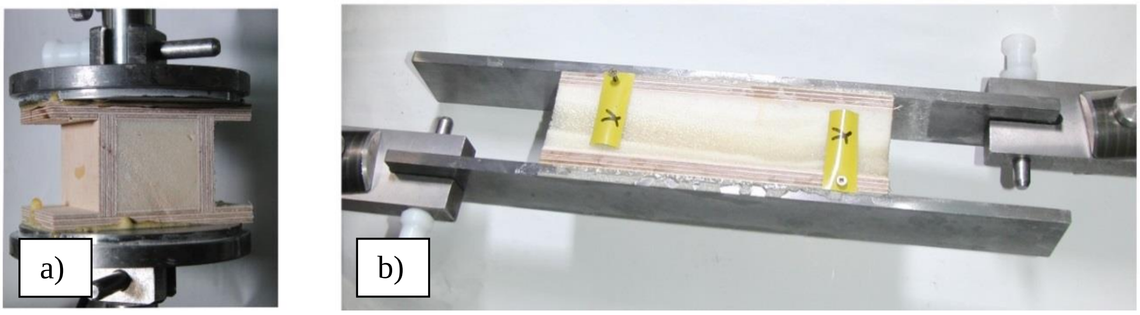



**Figure 1. a) – Debonding strength testing; b) – Shear strength testing**

Debonding strength results in Figure 2 shows that foam density have a significant impact on afhesive strength. Set of four different adhesive densities show the results in the range of 0.48- 0.6 MPa.

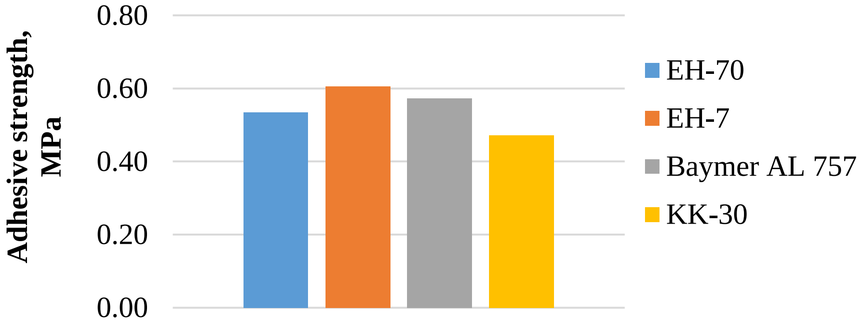



**Figure 2. Debonding strength for various foam mixtures.**

Results of shaer tests in Table 1 show that foam component increases shear strength by approximately 20 % comparing to sandwich specimen without foams. Acquired results are important in order to increase accuracy of failure analysis of the sandwich panel.

**Table 1. Shear strength of the sandwich specimens**

| Core Type | Max load (kN) | Shear strength (MPa ) |
|---|---|---|
| Plywood and Foam | 8.73 | 0.87 |
| Foam only | 6.88 | 0.55 |
| Plywood only | 7.26 | 0.73 |

***2. Virtual modelling and optimisation by numerical methods.*** ***Integration of failure criteria for bending load case***

The aim of the subtask is to asses if failure of the panel does not occur before reaching serviceability limit state.

Numerical modelling of the panel has been performed in ANSYS software employing combined model consisting of shell and solid element types. Loads and boundary conditions were applied as close as possible to experimental 4-point bending set-up according EN 789 standard.

Numerical results in Figure 3. demonstrate that stiffness behaviour of the numerical model corresponds to experimental flexural stress/strain curves in re region of elastic mechanical behaviour up to 20 MPa. Deflection limit is given as a ratio of span length. Limit of 1/300 of span length is serviceability limit state (limitation other than material strength) for wood based structures according to Eurocode 5 -Design of timber structures. Although excessive deflections usually do not cause failure, it can negatively influence the wellbeing of the humans inside buildings and lead to increased vibrations of the structural members. Deflection limit of 1/100 of span length is the critical deflection limitation for timber scaffolding decks according EN 12810 standard. Numerical results in Figure 3 show that flexural strength of the sandwich panel is higher than both serviceability limit states.

Failure of the panel in the result of shear deformations occurs after exceeding 20 MPa load limit. The main failure type is stiffner/surface debonding of the upper layers of plywood face.

Shear strength values in the numerical model were taken from documentation of the product (AS "Latvijas Finieris – Plywood handbook").

The Failure prediction is 18 % higher than the top stress value acquired experimentally, it can be explained by non-even redistribution of loads between all of the stiffeners.

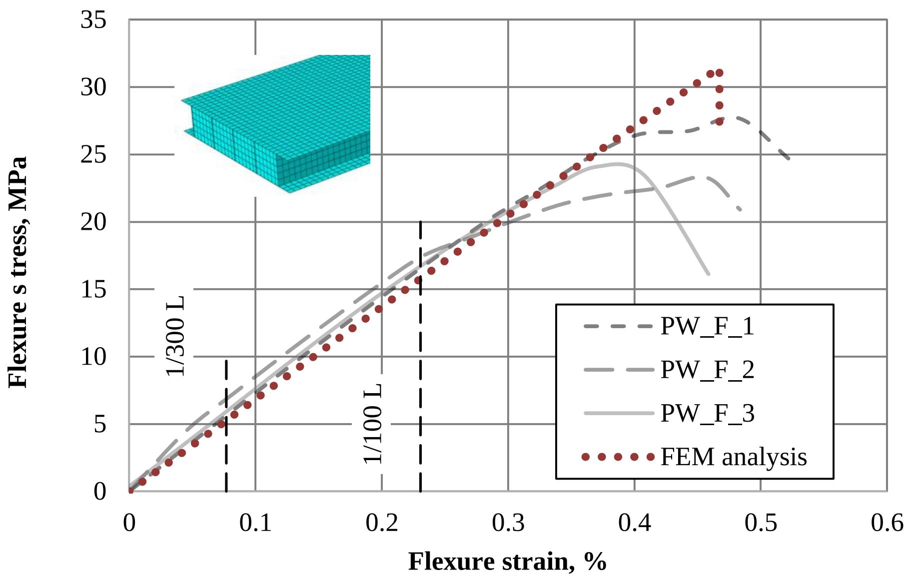



**Figure 3. Flexural stress/strain curves for sandwich panels with foam/stiffener core**

| ***3. Prototyping at laboratory scale. Development of design guidelines*** | ***Optimisation of full scale plywood sandwich panels*** |
| --- | --- |

The goal in this period was performing preliminary analysis before prototyping of full scale plywood sandwich panel. Optimisation of the roof cover panel with 4 m span length and width of 1.5 m was conducted.

Given size is restricted by maximally available dimensions of the plywood sheets. Response function is the price of one square meter of roof panel. Thus boundary conditions are flexural stiffness, strength and thermal conductivity.

Several optimal designs of the sandwich panel has been developed corresponding all design requirements.

Most effective lightweight sandwich panel could be made applying birch plywood with 4.1 mm thickness for skins and stiffeners. Overall thickness of the panel is 190 mm and distance between stiffeners set to boundary value of 250 mm. In all cases lowest core foam stiffness and density is required. Although this design is the most cost and weight efficient, due to thin surfaces and stiffeners it could be not the most optimal for manufacturing and other non-structural reasons. Therefore additional designs were created applying one step higher face and rib thickness. Design shows that increased plywood thickness has only minor influence on price and self-weight.

### 2.4. Further research and practical exploitation of the results

*(Describe further research activities that are planned, describe possibilities to practically exploit results)*

**WP-1: Experimental research on component scale specimens. Additional investigation damping and impact properties on finalised panels with vertical stiffeners.**

**Main results in 3rd review period:**

- Determined debonding strength of the sandwich specimen with various core types;
- Determined shear strength for a sandwich specimens with PU core and stiffener;
- Determined shear strength for a sandwich specimens without PU core;
- Acquired shear strength of the foam material;
- Contract between Latvian State Institute of Wood Chemistry and PolyLabs SIA for the rights to use in-house developed technology of raps and tall tool manufacturing, in the result esterification;
- AS Latvijas Finieris and Latvian State Institute of Wood Chemistry performed series of experiments to evaluate adhesive quality of birch plywood in the environment of liquid nitrogen.

**Further work:**

- Work package is completed and further works are not planned.

**WP-2: Virtual modelling and optimisation by** numerical **methods**

**Main results in 3rd review period:**

- Performed additional experimental validation of numerical models based of FEM;
- Integrated failure criteria of shear delamination of outer plywood surface layers;
- Evaluated conformity of the panel stiffness according EC-5 and EN 12810 standards.

**Further work direction:**

- Development of design guidelines and recommendations based on the results of numerical analysis.

**WP-3: Prototyping at laboratory scale. Development of design guidelines**

**Main results in 2nd review period:**

- Several sets of foams are synthesized to determine optimal configuration for uniform fill of sandwich core cavity;
- Large scale design of roof covering sandwich panel is prepared;
- Contract between RTU and AS „Latvijas Finieris” for development of full scale test rig for validation of the results acquired by FEM;
- Cooperation agreement of Latvian State Institute of Wood Chemistry and SIA Latvani– Reasearch works to integrate new hard polyurethane heat insulation in outer wall structures.

**Further work direction:**

- Development of high density PU foam system with open pore structure.
- Further prototype sandwich panel specimens with open pore structure.

**Practical significance of the acquired results:**

Obtained results foster development of new multifunctional sandwich materials form the raw material available in Latvia

The body of knowledge of foam synthesis is populated with the information about foams made of natural components.

Numerical models created in FEM environment allow to efficiently design sandwich panels with optimized mechanical and thermal properties.

### 2.5. Dissemination and outreach activities

*(Describe activities that were performed during reporting period to disseminate project results)*

**In the project Period 3 of the Project 1 full conferences papers were published (see Annexes):**

1. Kunicina N., Zabasta A., Kalnins K., Asmanis G., Labans E., Latvian timber supply and innovative plywood applications, Smart Energy Regions – Skills, knowledge, training and supply chains Ed. J.R.Calzada et.al.Cardif. 2016. 181-185. ISBN: 978-1-899895-21-2

**Submitted publications:**

1. Kirpluks M., Kalnbunde D., Benes H., Cabulis U., Rapeseed Oil as Feedstock for High Functionality Polyol Synthesis, Journal of Renewable Materials, (submitted in Journal of Renewable Materials)
2. Kirpluks M., Cabulis U., Andersons J., Japins G., Kalnins K., Modeling the effect of foam density and strain rate on the compressive response of polyurethane foams (submitted in SAE International Journal of Materials & Manufacturing)
3. Labans E., Kalnins K., Bisagni C., Flexural behaviour of sandwich panels with cellular wood, plywood and thermoplastic composite core (submitted in Int. J. of sandwich structures)

**Participation in conferences:**

1. Kalnins K., Jekabsons G., Labans E., Optimisation for scaling up of plywood sandwich panels with rigid PU foam-cores, In proceedings of the 11th ASMO UK / ISSMO conference on Engineering Design Optimization Product and Process Improvement / NOED2016, TU. Munich, 18-20 July, 2016.
2. Kirpluks M., Kalnbunde D., Benes H., Cabulis U., Rapeseed Oil as Feedstock for High Functionality Polyol Synthesis, In Proceedings of: 7th Workshop on Green Chemistry and Nanotechnologies in Polymer Chemistry, Costa Rica, San Jose, 21-23 September, 2016
3. Kalnins K., Overview of research towards multifunctional plywood sandwich panels, in proceedings of the 12th meeting of the Northern European Network for Wood Science and Engineering (WSE) 12-13. September, Riga
4. Kirpluks M., Labans E., Kalnins K., Japins G., Plywood rib stiffened sandwich panels filled with bio-based rigid polyurethane foams, In proceedings of the 12th meeting of the Northern European Network for Wood Science and Engineering (WSE) 12-13. September, Riga

**Doctoral thesis:**

1. Labans E. "Integration and optimisation of multifunctionality for plywood sandwich construction", scientific supervisor K. Kalnins, defended in 6$^{th}$ of April, 2016.
2. Kirpluks M. “Properties of Polyurethane foam composites with nano particles from renewable sources”, scientific supervisor U. Cabulis, estimated time of defence – spring of 2017.

**New technologies methods, prototypes and services commissioned by companies:**

1. Contract between Latvian State Institute of Wood Chemistry and PolyLabs SIA for the rights to use in-house developed technology of raps and tall ool manufacturing, in the result esterification.
2. AS Latvijas Finieris and Latvian State Institute of Wood Chemistry performed series of experiments to evaluate adhesive quality of birch plywood in the environment of liquid nitrogen.

3. Cooperation agreement of Latvian State Institute of Wood Chemistry and SIA Latvani– Research works to integrate new hard polyurethane heat insulation in outer wall structures.
4. Contract of Riga Technical University, Institute of Materials and Structures and A/S “Latvijas Finieris” for tests of the plywood production 2nd phase of MNKC program.

**Web page**

Updated IMATEH home page http://imateh.rtu.lv/ with detailed information about publications, attended events and main results.

## PART 2: PROGRAMME PROJECT INFORMATION

**2.1. Project No. 3**

| | | |
|---|---|---|
| Title | ***Risk consideration for safe, effective and sustainable structures*** | |
| Project leader's name, surname | Ainars Paeglitis | |
| Degree | Dr.sc.ing. | |
| Institution | Riga Technical University | |
| Position | Professor | |
| Contacts | *Phone number* | +371 29269448 |
| | *E-mail* | ainars.paeglitis@rtu.lv |

### 2.2. Tasks and deliverables

*(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)*

**Target: *Develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation.***

**The Project is divided in three parts where each part has its own core task:**

***Core task 1:*** *Investigation of the dynamic characteristics of Latvian road bridges and determination of their impact on construction reliability, to develop the new methods for assessment of structural risk, reliability and robustness;*

***Core task 2:*** *Development of the methodology for experimental acquisition of dynamic characteristics (modal frequencies, mode shapes, modal damping) of structural elements with the presence of damage (different failure modes) for structural health monitoring;*

***Core task 3:*** *To develop innovative smart structure with using of renewable natural resources with the increased durability and reliability for structural and infrastructural purposes.*

**Time frame for the core tasks is given in Annexes 3-A, 3-B and 3-C.**

**In addition, specific tasks related to completing core tasks of each Project parts are defined in every Period of the Project corresponding to the calendar year.**

| Nr. | Tasks | Deliverable | Responsible partner | Status |
|---|---|---|---|---|
| 1.1. | Vehicle weight and speed impact on the structural dynamic characteristics | Method for evaluation the impact. | A.Paeglitis, Department of Roads and bridges, Institute of Transport infrastructure engineering, RTU | In progress |
| 1.2 | Approbation of theoretical probability distributions of actions on bridge for Latvian conditions | Development of method's concept | A.Paeglitis, Department of Roads and bridges, Institute of Transport infrastructure engineering, RTU | In progress |
| 2.1 | To develop method for | Methodology of damage | S. Rucevskis, Department | In progress |

| | | | | |
|---|---|---|---|---|
| | localization of damage site and evaluation of damage size in various structural elements by using appropriate signal processing techniques experimentally measured dynamic parameter changes. | identification in different type of structural elements (beam, plate, sandwich) | of Composite Materials, Institute of Materials and Structures, RTU | |
| 2.2 | To develop method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements. | Method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements. | S. Rucevskis, Department of Composite Materials, Institute of Materials and Structures, RTU | In progress |
| 3.1. | Development of design procedure for load-bearing elements from cross-laminated timber. | Design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method. (31.12.2016) | D.Serdjuks Department of Building Constructions Institute of Structural Engineering and Reconstruction, RTU | Finished |
| 3.2. | Experimental check of developed design procedure for load-bearing elements from cross-laminated timber. | Experimental check of developed design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method. (31.12.2016) | D.Serdjuks Department of Building Constructions Institute of Structural Engineering and Reconstruction, RTU | Finished |
| 3.3. | Topology optimization for structure from cross-laminated timber and evaluation of it rational, from the point of view of it materials expenditure, parameters. | Development of computer model for load-bearing structures behaviour prediction. Development of optimization algorithm for structure from cross-laminated timber. | D.Serdjuks Department of Building Constructions Institute of Structural Engineering and Reconstruction, RTU | In progress |
| 3.4. | Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure. | Variants of structural solutions for cable trusses were compared and the rational once was chosen. Material expenditure and maximum vertical displacements were considered as criterions of rationality. Development of physical model of load-bearing structure. | D.Serdjuks Department of Building Constructions Institute of Structural Engineering and Reconstruction, RTU | In progress |

| Tasks for Period 3 | Main results |
|---|---|
| ***1.1. Vehicle weight and speed impact on the structural dynamic characteristics.*** | ***Dynamic amplification factor depend on the bridge type, length, vehicle speed, pavement roughness and bridge system.*** |

Vehicle moving over a bridge cause vibrations in the structure. Vehicle suspension system is a complex system that transfers load from vehicle to bridge superstructure through contact area of a tyre and bridge pavement. To determine vehicle –bridge interaction complicated calculation models should be described:

- Model of the bridge superstructure;
- Model of bridge suspension system;
- Model of Vehicle –bridge interaction (shown in Figure 1);
- Model of bridge pavement surface;
- Every model mathematical calculation algorithm.

Influence of the vehicle weight working on the bridge superstructure depends on number of axles and weight distribution of the vehicle. In bridge dynamic tests vehicles with known weight and number of axles are used, to be able to compare recorded data with the calculation model.

Vehicle speed is very important factor, because in the mathematical model vehicle weight is being converted to a load that is moving along the structure with a certain speed, causing vibrations. In real situation this weight is being distributed between wheels of the vehicle and wheels in contact with the pavement surface generate different forces of inertia. These forces then cause vibration in the structure.

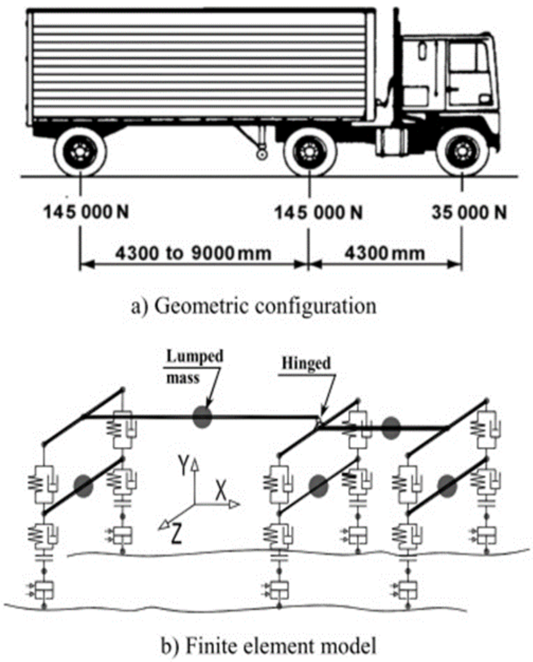



Figure 1. **Figure 1.Vehicle 3D suspension model and interaction points with pavement [1].**

Analysis was done for continuous pre-stressed ribbed slab bridges and Dynamic amplification factor (DAF) and natural frequency correlation with vehicle weight. Vehicle weight itself has small influence on DAF and Natural frequency, although it is necessary to have a certain weight of vehicle to be able to excite structure in necessary level and obtain data. 30t vehicle can excite structure to DAF values from 1.4 to 2.4.

Vehicle weight has much more influence on bridge dynamic than vehicle weight, because this influence is connected to pavement evenness. Road evenness and vehicle speed influence – for lower vehicle speed and uneven pavement condition DAF can be much higher. DAF depend on bridge type. Slender bridges have higher DAF at uneven pavement condition. Slope of the superstructure can make extra dynamic load, especially if the road profile has a one sided slope or the bridge is in the plan radius of the road.

Vehicle weight increase over allowed truck weight does not influence structure dynamic increase, although it is an important factor for bridge load carrying capacity. But vehicle speed together with uneven pavement condition can seriously increase dynamic of the bridge superstructure. At even pavement condition vehicle does not cause extra dynamic load on the bridge superstructure.

| | |
|---|---|
| ***1.2. Approbation of theoretical probability distributions of actions on bridge for Latvian conditions*** | ***Develop method's concept, 1 article.*** |

A simple method of load calculation is as follows:

1. all vehicles are split in lanes and arranged in queues with a constant distance between them, we recommend 5m between the rear of the vehicle and the front axle of the following, if it is necessary to simulate peak situations (long-span bridges), but this assumption is very conservative. It is preferable to use distances measured in congested traffic. For short and medium span bridges it is preferable for the distance to be calculated from the data by

multiplying the distance in time with vehicle speed;

2. Then, if bridge influence lines are not available, a constant span length must be chosen. Queue is divided in the chosen lengths and uniformly distributed load is calculated by dividing the weight of each group with a span length;
3. If bridge influence lines are available, then the same queue is "pushed" over the influence lines and loads are calculated from the formula (1):

$$q_i = max\left(\frac{\sum P*y>0}{A_{pos}};\frac{\sum P*y<0}{A_{neg}}\right) \quad (1)$$

where $q_i$ – uniformly distributed load, $P$ – vehicle axle load, $y$ – axle load's influence upon span, $A$ – positive or negative area of an influence line.

4. If loads from more than one lane are necessary, then two or more queues are placed side by side, and a constant span weight is calculated by summing weight of all queues and dividing it by the span length. In the calculations with influence lines queues are pushed over the bridge in their driving directions. And the load is calculated from the formula (1) using the entire width of the bridge
5. When the load calculated for all days, choose the daily maximum load. These loads, according to extreme value theory, are best described by Gumbel probability distribution. Authors recommend using Gumbel distribution if the loads were calculated in the manner described above;
6. Different ways to find probability distribution coefficient are described in the literature. Authors recommend using Maximum likelihood estimation (MLE), because of the ease of use of this method.

| ***2.1. Development of methods for damage localization in structural elements*** | ***Method for damage localization in beam, plate and sandwich-type structural elements*** |
|---|---|

In the report period studies concerning development of methodology for structural health monitoring of beam, plate and sandwich type structures were continued and expanded. Mode shapes of the structural elements were used as an input for a Wavelet Transform (WT) technique, yielding a distribution of WT coefficients over entire area of the aforementioned structures. Locations with the largest values of WT coefficients correspond to damage. In order to increase the confidence of damage localisation, all available wavelet functions were used in the calculations. The identification of damage was characterized with a Damage Index (DI) which was subsequently standardized and threshold employing statistical hypothesis testing. A new parameter called Damage Estimate Reliability (DER) that was introduced earlier for a one-dimensional structure and characterizing a confidence of damage localization for a particular wavelet function and expressed in percent's, was extended to two-dimensional structures. The methodology was validated with numerical simulations by artificially contaminating input mode shapes with various levels of noise, as well as exploring different cases of damage severity and reduced amount of mode shape data to study the effect of various densities of sensor grids. Numerical simulations were carried out with a commercial finite element program ANSYS, whereas calculations involving damage localization were made with program MATLAB.

To ascertain for the effectiveness of proposed methodology of damage detection, the following specimens were subjected to experimental vibration tests:

1. two aluminium beams of different length, containing one site of mill-cut damage,
2. two aluminium beams of different length, containing two sites of mill-cut damage,
3. two polymer composite beams of different length, containing one site of impact damage,
4. one aluminium plate, containing one site of damage.

Natural frequencies and corresponding deflection shapes for aforementioned structures were experimentally measured using POLYTEC non-contact laser vibrometer. The obtained results show

| | |
|---|---|
| that the proposed methodology is a reliable tool for damage localization in cases of noisy, as well as limited amount of input mode shape data and different damage severities.<br>Besides the development of vibration- based damage identification methods, a different concept of damage detection based on exploiting electromechanical impedance spectroscopy was also exploited in the report period to develop a method for damage localization in carbon composite sandwich structures. The area of focus for implementation of damage was selected to be a core of the sandwich structure, comprising of an aluminium truss. One element of this truss was cut and a subsequent excitation of the whole structure with a single piezoelectric element took place. An advantage of using piezoelectric elements is that they are cheap and serve as both, actuators and sensors. Electromechanical impedance spectra were measured depicting electrical impedance or admittance vs frequency of AC voltage used for excitation. This method relies on the fact that there is a baseline spectrum of healthy structure which is compared with that of a damaged structure. Any horizontal shifts or differences in amplitude of impedance peaks indicate the presence of damage in the structure. Damage is caused by local changes of stiffness, thus, as damage itself is local, the sensitivity of this method depends heavily on the distance between sensor/actuator and damage. This study will be complemented by use of different types of piezoelectric elements which excite the structure by generating elastic waves either parallel or perpendicular to the surface. | |
| ***2.2. Development of method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements.*** | ***Method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements.*** |
| In the report period an investigation on assessment of the loss of a pre-stress in pre-stressed steel reinforced concrete structural elements by employing dynamic characteristics of the structure was started. A detailed study on detection of reinforcement failure in a pre-stressed reinforced concrete plate employing such dynamic parameters as natural frequencies and mode shapes was conducted. The first stage of this study was devoted to modelling and finite element calculations of the plate. A commercial finite element program ANSYS was used for this purpose. 3D representative finite element models of steel reinforced concrete plate with and without a pre-stress were developed. These models were adjusted and the obtained results were compared. The results suggest that, on one hand, natural frequencies are not considerably affected by the pre-stress, on the other hand, the pre-stress considerably affects mode shapes of the structure. Based on these results, a 3D representative finite element model of a pre-stressed steel reinforced concrete plate with reinforcement damage was developed. This model was also adjusted and the results were compared with those of a respective model without reinforcement damage. The obtained results confirmed the assumption that a method based on changes of dynamic parameters of structural elements may be applicable to a practical assessment of a loss of a pre-stress in pre-stressed reinforced concrete structural elements by utilising appropriate experimental equipment. In the next reporting period numerical studies will be continued and also an experimental investigation on pre-stressed reinforced concrete plate will be conducted. | |
| ***3.1. Development of design procedure for load-bearing elements from cross-laminated timber.*** | ***Design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method.*** |
| ***3.2. Experimental check of developed design procedure for load-bearing elements from cross-laminated timber.*** | ***Experimental testing of design procedure for load-bearing elements from cross-laminated timber. 1 article.*** |
| ***3.3. Topology optimization for structure from cross-laminated timber and evaluation of it rational, from the point of view of it materials expenditure, parameters.*** | ***FEM model, which enables to predict behaviours of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure, was developed.<br>The rational from the point of view of materials*** |

| | |
|---|---|
| | ***consumption geometrical parameters for cylindrical timber roof with a 30 m span were determined. The development of algorithm, which enables to evaluate rational parameters of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure, was started. 2 articles.*** |
| ***3.4. Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure.*** | ***Rational from the point of view of materials consumption and maximum vertical displacements variant of structural solution for cable truss. The development of physical model of innovative smart structure was started.*** |

Evaluation of the main rational parameters of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure is joined with consideration and analyse of large variants amount of considered structure. The results of variants analyse are necessary for obtaining the dependences between parameter of optimization and variables, were rational levels must be determined in course of optimization tasks solution. Simple and enough precise design procedure, which enables prediction of the behaviour of load-bearing elements from cross-laminated timber, subjected to flexure and compression with the bending is necessary. The design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method, was suggested for members subjected to flexure and compression with the bending. Geometrical parameters of the member's cross-sections are determined for the sections which are transformed to the layer, where the stresses must be determined. Check of ULS and SLS for the members must be conducted in accordance with the requirements of sections 6 and 7 of the LVS EN 1995-1-1, correspondingly. Check of the members subjected to compression with the bending stability must be conducted by the equation (6.23) from LVS EN 1995-1-1 independently from the relation between the compression and bending normal stresses.

The K-method (composite method), gamma method and shear analogy method are used at the present moment for designing of cross-laminated timber members subjected to flexure and compression with the bending. The methods are characterized by the increased workability in comparison with the suggested design procedure, which is based on the LVS EN 1995-1-1 and transformed section method. The additional benchmark study was carried out to check the suggested design procedure for behaviour prediction of CLT plate under the different loading cases to complete the number of experiments, which were started on the stages 1 and 2 of current project. One CLT plate, which was experimentally tested in three points bending up to the failure. Freely supported plate with the span equal to 1.8 m was loaded by the concentrated force applied in the centre of the span. Intensity of the load changes from 1 to 22.6 kN with the step equal to 0.2 kN. The plate has dimensions 2X0.35 m and total thickness in 60 mm. The plate was created from the timber board with strength class C24 and dimensions of cross-section 20X110 mm. The fibres of the two external layers were orients in the longitudinal direction. The fibres of one internal layer were oriented under the angle equal to 90° relatively the direction of the fibres of external layers. The layers were glued together by the polyurethane glue under the pressure in 600 kg/m$^2$. The considered plate was analysed by the K-method, gamma method, shear analogy method, suggested design procedure and FEM method, which was realized by the programme RFEM 5.0. The results of analyses were compared.

The cross-laminated timber plate with dimensions 2x0.35 m and thickness in 60 mm, was suspended under the angle equal to 16.8° and subjected to the action of uniformly distributed by two zones of the span load. Intensity of the load changes within the limits from 1.2 to 3.6 kN with the step equal to 1.2 kN. The plate was subjected to compression with the bending. The considered plate was analysed by the K-method, gamma method, shear analogy method, suggested design procedure and FEM method, which was realized by the programme RFEM 5.0. The results of analyses were compared.

Investigations of rational structural solution of innovative smart structure were continued during the period 3 of the project. The cylindrical timber roof with a 30 m span and the main load-bearing structures of lattice arches with elements connected by punched metal plates was considered as an object of investigation. All members of the arch are made of C24 strength class solid timber. The cross-section depth and width of the top and bottom chords of the arch are equal to 180 and 70 mm respectively. All elements of the lattice have equal dimensions of the cross-section: depth and width are equal to 100 and 70 mm respectively. The lattice arch elements are joined with the punched steel plates Kartro. The thickness and teeth length of the Kartro punched steel plates are equal to 1.2 and 12 mm respectively. The rational geometrical parameters of a lattice timber arch with punched steel plated joints were evaluated. Fire resistance and a possibility to increase it for an arch-type timber roof were also considered. The values of the height of the arch, depth of the arch cross-section, and distance between the nodes on the top chord change within the limits from 5.5 to 7.5 m, from 0.5 to 1 m, and from 1 to 1.5 m respectively. The cylindrical timber roof was analysed by the FEM, which was realized by the program AXIS VM11. The considered roof is analysed for Latvian climatic conditions. The current place is the city of Riga. The characteristic values of permanent snow and wind loads were equal to 0.37, 1.25, and 0.56 kN/$m^2$, respectively.

Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure was continued during the period 3 of the project. FEM model, which enables to predict behaviours of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure, was developed for the structure with the span equal to 60m. The programme ANSYS v15 was used for the purposes. The rational structural solution of the cable truss was chosen. The maximum vertical displacements and materials consumption were considered as criterions of cable truss structural solution rationality. The development of algorithm, which enables to evaluate rational parameters of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure, was started. The development of physical model of innovative smart structure was started.

### 2.3. Description of gained scientific results

*(Describe scientific results achieved during reporting period, give their scientific importance)*

**Target of Project 3: *Develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation.***

Target of the national programme and this project is to develop new methods of risk assessment for buildings and structures to ensure their safe, efficient and sustainable operation. Targets set for this reporting period are fully achieved.

***Core task 1:*** *Investigation of the dynamic characteristics of Latvian road bridges and determination of their impact on construction reliability, to develop the new methods for assessment of structural risk, reliability and robustness.*

**Time frame for the Core task 1 activities is given in Appendix 3-A.**

***Tasks for the Period 3:***

*1.1. Vehicle weight and speed impact on the structural dynamic characteristics.*

*1.2. Approbation of theoretical probability distributions of actions on bridge for Latvian conditions.*

**Task Nr.1.1**. Vehicle weight has much more influence on bridge dynamic than vehicle weight, because this influence is connected to pavement evenness. It is not possible to precisely include pavement profile in the calculation, because every pavement is different and there is no function to describe it. There are some devices that measure road surface roughness and profile, but before bridge is built it is not possible to know this information. DAF depend on bridge type. Obtained results showed that slender bridges have higher DAF for uneven pavement condition. Slope of the superstructure can make extra dynamic load, especially if the road profile has a one-sided slope or the bridge is in the plan radius of the road.

Vehicle weight increase over allowed truck weight does not influence structure dynamic increase, although it is an important factor for bridge load carrying capacity. But vehicle speed together with uneven pavement condition can seriously increase dynamic of the bridge superstructure. At even pavement condition vehicle does not cause extra dynamic load on the bridge superstructure.

**Task Nr.1.2.** The general approach, which is given in Eurocode and is meant for all kinds of new structures, is most commonly used to assess the safety of structures. Such an approach gives unduly low design safety assessment for existing bridge structures in service, because it uses loads and material characteristics given in construction regulations. Meanwhile actual transport loads and actual bridge structure's material properties can differ significantly. Therefore, usage of actual loads and material properties can save a structure that has been "written-off", so saving resources meant for bridge renovation and reconstruction. Therefore, it is important to develop a method to determine bridge safety, which takes into account potential risk scenarios, traffic loads typical for Latvia, bridge materials characteristics, damage development models.

In the reporting period, a method to approbate theoretical probability distribution models for actions on bridges in Latvian conditions. The most important actions on bridges, except for self-weight, is transport loads, so we considered precisely those. As the loads for short and medium spans are given in Eurocode 1, then this study discusses the distribution of long-span transport loads.

***Core task 2:*** *Development of the methodology for experimental acquisition of dynamic characteristics (modal frequencies, mode shapes, modal damping) of structural elements with the presence of damage (different failure modes) for structural health monitoring;*

**Time frame for the Core task 2 activities is given in Appendix 3-B.**

***Task for the Period 3:***
***2.1. Development of methods for damage localization in structural elements.***

According to the Core task 2 of the project: "The development of methodology for experimentally measured dynamic parameters (vibration frequencies, vibration modes, vibration damping coefficients) of healthy or damaged (various forms of material degradation) structural elements and its application to structural health monitoring", the planned objectives are fully met.

Developed vibration–based damage identification methods are designed for practical applications. The proposed methodology allows the identification of structural damage invisible from the outside in different types of structural elements. Damage indices are generalized for 1-dimensional and 2-dimensional space thus enabling damage identification in beam-type, plate-type and sandwich-type structural elements. The obtained results also confirmed the assumption that a method based on changes of dynamic parameters of structural elements may be applicable to a practical assessment of a loss of a pre-stress for pre-stressed reinforced concrete structural elements. By employing corresponding equipment developed methods can be employed for the identification of damage in real applications such as buildings, automobile and aircraft structural elements.

***Core task 3:*** *To develop innovative smart structure with using of renewable natural resources with the increased durability and reliability for structural and infrastructural purposes.*

**Time frame for the Core task 3 activities is given in Appendix 3-C**

***Task for the period 3: 3.1. Development of design procedure for load-bearing elements from cross-laminated timber.***

Simple and enough precise design procedure, which enables to predict the behaviour of load-bearing elements from cross-laminated timber, subjected to flexure and compression with the bending is suggested. The precision of the suggested design procedure for the elements from cross-laminated timber subjected to flexure and compression with the bending is comparable with such existing methods as K-method, gamma method and shear analogy method. The suggested design procedure for load-bearing elements from cross-laminated timber is based on the LVS EN 1995-1-1 and transformed section method. Geometrical parameters of the member's cross-sections are determined for the sections which are transformed to the layer, where the stresses must be determined. Check of ULS and SLS for the members must be conducted in accordance with the requirements of sections 6 and 7 of the LVS EN 1995-1-1, correspondingly. Check of the members subjected to compression with the bending stability must be conducted by the equation (6.23) from LVS EN 1995-1-1 independently from the relation between the compression and bending normal stresses.

***Task for the period 3: 3.2. Experimental check of developed design procedure for load-bearing elements from cross-laminated timber.***

The number of experiments, which were started during the period 3, was completed by the additional experiments, which are necessary for evaluation of suggested design procedure precision for behaviours prediction of members from cross-laminated timber subjected to flexure and compression with the bending.

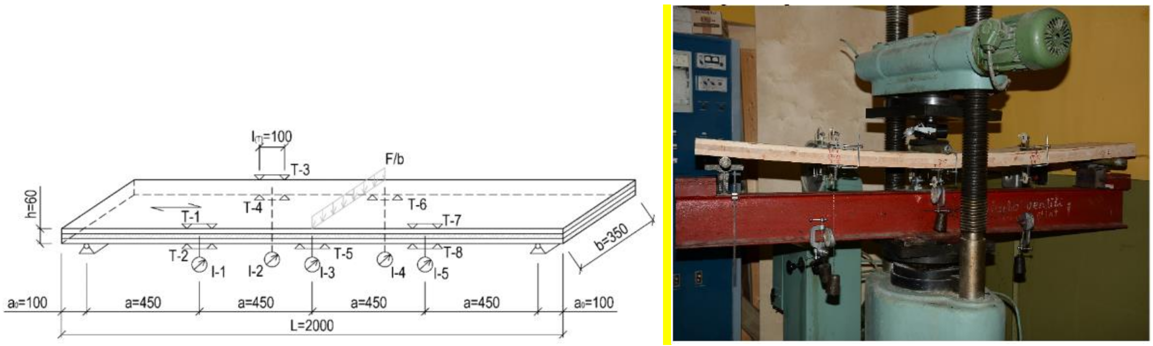
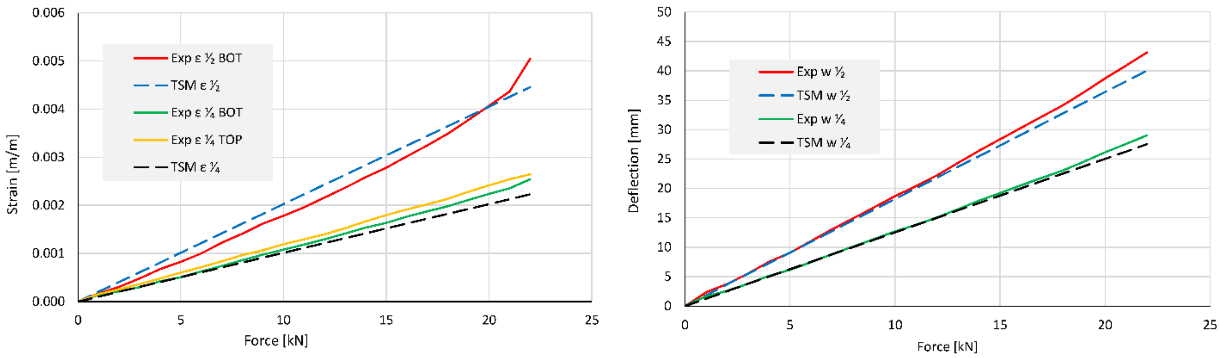



**Figure 1. Loading scheme and placement of apparatus for CLT plate.**

The considered plates from the cross-laminated timber were analysed by the suggested design procedure, which is based on the LVS EN 1995-1-1 and transformed section method, K-method, gamma method, shear analogy method and FEM, which was realized by the programs RFEM 5.0.




*a)* *b)*

**Figure 2. The dependences between experimental and theoretical values of maximum normal stresses *a)* and maximum vertical displacements *b)* and vertical load: TSM–results, which were obtained by the suggested design procedure; Exp – results, which were obtained by the experiment; ½ - in the middle of the span; ¼ - in the quarter of the span; TOP – for the top fibers; BOT – for the bottom fibers.**

It was stated, that the difference of deflections between calculated using suggested design procedure and experimentally obtained does not exceed 7%. The maximum difference between calculated and experimentally obtained strains is 20% in the half-span and 12% in the quarter-span.

The cross-laminated timber plate with dimensions 2x0.35 m and thickness in 60 mm, was suspended under the angle equal to 16.8° and subjected to the action of uniformly distributed by two zones of the span load. The distance between the points of suspensions were equal to 1.8 m. Intensity of the load changes within the limits from 1.2 to 3.6 kN with the step equal to 1.2 kN.

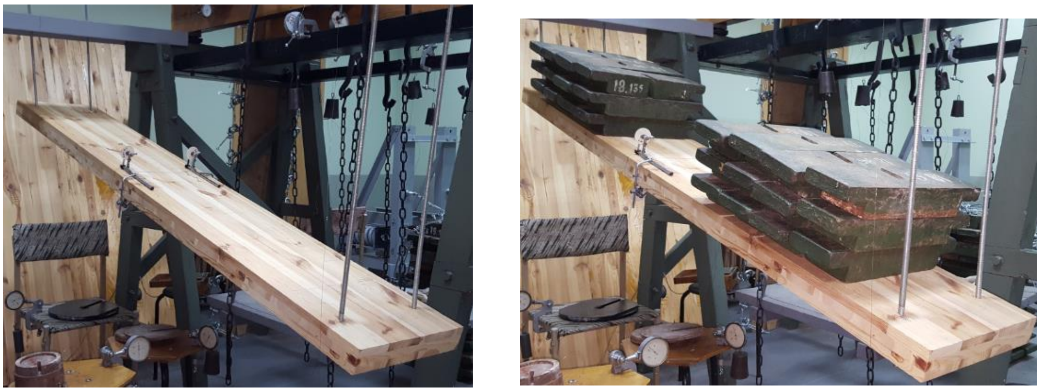


**Figure 3. Loading scheme and placement of apparatus for CLT plate, which is suspended under the angle equal to 16.8°**

The plate was subjected to compression with the bending. The considered plate was analysed by the K-method, gamma method, shear analogy method, suggested design procedure and FEM method, which was realized by the programme RFEM 5.0. The differences between the maximum vertical displacements in the middle of the span of CLT plates obtained by the K-method, gamma method, shear analogy method, suggested design procedure, software RFEM 5.0 and experiment changes within the limits from 1.20 to 2.60%, 14.80 to 19.30%, 10.10 to 14.50%, 1.20 to 2.60% and 1.0 to 1.9% correspondingly. The differences between the maximum normal stresses acting in CLT plates obtained by the K-method, gamma method, shear analogy method, suggested design procedure, software RFEM 5.0 and experiment changes within the limits from 4.30 to 16.86%, 9.12 to 22.26%, 4.30 to 16.86%, 4.30 to 16.86% and 5.32 to 15.76% correspondingly.

It can be concluded, basing on the results, obtained during the periods 2 and 3, that the suggested design procedure, which is based on the LVS EN 1995-1-1 and transformed section method is characterized by simplicity and reasonable precision in comparison with the K-method, gamma method and shear analogy method.

***Task for the period 3: 3.3. Topology optimization for structure from cross-laminated timber and evaluation of it rational, from the point of view of it materials expenditure, parameters.***

The cylindrical timber roof with a 30 m span and the main load-bearing structures of lattice arches with elements connected by punched metal plates was considered as an object of investigation. All members of the arch are made of C24 strength class solid timber. The cross-section depth and width of the top and bottom chords of the arch are equal to 180 and 70 mm respectively. All elements of the lattice have equal dimensions of the cross-section: depth and width are equal to 100 and 70 mm respectively. The lattice arch elements are joined with the punched steel plates Kartro. The thickness and teeth length of the Kartro punched steel plates are equal to 1.2 and 12 mm respectively. The values of the height of the arch, depth of the arch cross-section, and distance between the nodes on the top chord change within the limits from 5.5 to 7.5 m, from 0.5 to 1 m, and from 1 to 1.5 m respectively. It was shown that the rational values of the height of the arch, depth of the arch cross-section, and distance between the nodes on the top chord are equal to 7.85, 1.10, and 0.95 m respectively. The corresponding minimum material consumptions were equal to 1.856 and 1.273 $m^3$ in case of fire impact and without taking it into consideration.

***Task for the period 3: 3.4. Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure.***

Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure was continued during the period 3 of the project. FEM model, which enables to predict behaviours of load-bearing structure which consists from the two prestressed cable trusses and secondary cross-laminated timber members subjected to flexure, was developed for the structure with the span equal to 60m. The programme ANSYS v15 was used for the purposes. The developed model enables to take in to account interaction between the prestressed cable trusses and cross-laminated timber decking. The rational structural solution of the cable truss was chosen. The maximum vertical displacements and materials consumption were considered as criterions of cable truss structural solution rationality. It was shown, that placement of cross-laminated timber elements of the decking enables to decrease by 16.7% materials consumption in comparison with the case, when the elements of the decking are placed by the top chord of the cable truss. It was stated, that taking in to account interaction between the prestressed cable trusses and cross-laminated timber decking enables to decrease by 17.3% materials consumption. The development of algorithm, which enables to evaluated rational parameters of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure was started. The development of physical model of innovative smart structure was started. The span of the physical model is equal to 2 m.

**2.4. Further research and practical exploitation of the results**

*(Describe further research activities that are planned, describe possibilities to practically exploit results)*

**Core task 1:**
**The following tasks are defined for the Period 4:**

**1.1.task** – Determination and justification of the limit values of the bridge dynamic characteristics based on the developed methods for assessment of bridge dynamic characteristics..

**1.2.task** – Development of method of assessment of safety factors and residual load carrying capacity of existing concrete bridges.

**Core task 2:**

**The following tasks are defined for the Period 4:**

**2.1. task** - Development of a method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements.

**2.2. task** – Numerical and experimental investigation on multiclass probabilistic classification of damage location in a plate structure by employing dynamic parameters obtained by means of embedded deformation sensors.

**Core task 3:**
**The following tasks are defined for the Period 4:**

**3.1. task** – Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure.

**3.2. task** – Topology optimization for structure from cross-laminated timber and evaluation of it rational from the point of view of it materials expenditure parameters.

## 2.5. Dissemination and outreach activities

*(Describe activities that were performed during reporting period to disseminate project results)*

Two workshops were organized and carried out by prof. D.Serdjuks in the Period 3: "Design of Timber Structures by EN 1995-1-1" and "Fire Design of Timber Structures by EN 1995-1-2". The workshops were carried out 24.02.16 and 26 03.16, correspondingly, in Sankt -Petersburg, Russia.

The co-financing coming from the private sector and income from contract work based on the results of the Project 3 constitute EUR 8072 in the Period 3.

**Participation in international scientific conferences and seminars in 2016 with full-text scientific papers:**

1. Buka-Vaivade K., Serdjuks D., Goremikins V., Vilguts A., Experimental Verification of Design Procedure for Elements from Cross-Laminated Timber, 12th International Conference „Modern Building Materials, Structures and Techniques" 2016, May 26 – 27, Vilnius, Lithuania.
2. Serdjuks D., Goremikins V., Buka-Vaivade K., Development of Innovative Smart Structures with Using of Renewable Natural Resources for Structural and Infrastructural Purposes, Riga Technical University International Scientific Conference 2016, October 14–18, Riga, Latvia.
3. Serdjuks D., Design of Timber Structures by EN 1995-1-1, International scientific seminar "Design of Timber Structures by EN 1995-1-1", 2016, 24. February, Petersburg, Russia.
4. Serdjuks D., Fire Design of Timber Structures by EN 1995-1-2, International scientific seminar "Fire Design of Timber Structures by EN 1995-1-2", 2016, 26. March, Petersburg, Russia.
5. Serdjuks D., Design of Timber Structures by EN 1995-1-1, International scientific seminar „Design of Timber Structures by EN 1995-1-1" 2016, 17. November, Riga, Latvia.
6. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares, MoViC & RASD 2016 – „Joint International Conference: Motion and Vibration Control & Recent Advances in Structural Dynamics" 2016, 3.–6. July, Southampton, Great Britain.
7. Janeliukstis R., Rucevskis S., Akishin P., Chate A., Wavelet Transform Based Damage detection in a Plate Structure, WMCAUS – „World Multidisciplinary Civil Engineering Architecture Urban Planning Symposium" 2016, 13.–16. July, Praha, Check Republic.

8. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Multiple Damage Identification in Beam structure Using Wavelet Transform Technique, MBMST 16 – 12th International Conference „Modern Building Materials, Structures and Techniques", 2016, 26.–27. May, Vilnius, Lithuania.
9. Rucevskis S., Janeliukstis R., Akisins P., Chate A., Vibration-Based Approach for Structural Damage Detection, 23rd International Congress on Sound and Vibration, 2016, 10.-14. July, Athens, Greece.
10. Paeglite I., Smirnovs J., Paeglitis A., Traffic load effects on dynamic bridge performance, 8 International IABMAS Conference (IABMAS 2016) Bridge Maintenance, Safety, Management, Resilience and Sustainability, Proceedings of the, Brazil, Foz do Iguacu, 26.-30. June, 2016,
11. Paeglite I., Smirnovs J., Paeglitis A., Dynamic behaviour of pre-stressed slab bridges, 12th International conference "Modern Building Materials, Structures and Techniques", (MBMST 2016), 26.-27 .May, 2016, Vilnius, Lithuania,
12. Freimanis A., Paeglitis A., Mesh sensitivity analysis for quasi-static simulations, 12th International conference "Modern Building Materials, Structures and Techniques", (MBMST 2016), 26.-27. May, 2016, Vilnius, Lithuania.

**Published peer-reviewed papers in 2016 (abstracted in Scopus or in Web of Science):**

1. Buka-Vaivade K., Serdjuks D., Goremikins V., Vilguts A., Pakrastins L., Experimental Verification of Design Procedure for Elements from Cross-Laminated Timber, Procedia Engineering 00(2016) 000-000 (accepted).
2. Saknite T., Serdjuks D., Goremikins V., Pakrastins L., and Vatin N., Fire Design of Arche-type Timber Roof, Magazine of Civil Engineering, Vol. 64, 4, 2016
   http://www.engstroy.spbstu.ru/index_2016_04/03.html, (accepted).
3. Gusevs E., Serdjuks D., Artebjakina G., Afanasjeva E., Goremikins V., Behaviour of Load-Carrying Members of Velodromes Long-span Steel Roof, Magazine of Civil Engineering, Vol 65, 5, 2016, ISSN: 2071-0305, 2071-4726,
   http://www.engstroy.spbstu.ru/index_2016_05/01.html (accepted).
4. Rucevskis S., Janeliukstis R., Akishin P., Chate A., Mode shape-based damage detection in plate structure without baseline data, Structural Control and Health Monitoring, Vol. 23, 9, 2016, pp. 1180-1193. **(SNIP>1)**
   http://onlinelibrary.wiley.com/doi/10.1002/stc.1838/abstract;jsessionid=5415D140388699A27A3163581B086C65.f01t04
5. Janeliukstis R., Rucevskis S., Wesolowski M., Kovalovs A., Chate A., Damage Identification in Polymer Composite Beams Based on Spatial Continuous Wavelet Transform, IOP Conference Series: Materials Science and Engineering, Vol. 111, 1, 2016, pp. 1-12.
   http://iopscience.iop.org/article/10.1088/1757-899X/111/1/012005/meta
6. Rucevskis S., Janeliukstis R., Akishin P., Chate A., Vibration-based approach for structural damage detection ICSV 2016 - 23rd International Congress on Sound and Vibration: From Ancient to Modern Acoustics, 2016, pp. 1-6.
   https://www.scopus.com/record/display.uri?eid=2-s2.0-84987922684&origin=resultslist&sort=plf-f&src=s&sid=65A5B84061915A7510FB3A88D485205C.wsnAw8kcdt7IPYLO0V48gA%3a230&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2816310397700%29&relpos=4&citeCnt=0&searchTerm=
7. Janeliukstis R., Rucevskis S., Akisins P., Chate A., Wavelet Transform Based Damage Detection in a Plate Structure, Procedia Engineering, Vol. 161, 2016, pp. 127-132.
   http://www.sciencedirect.com/science/article/pii/S1877705816327175

8. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares. Journal of Physics: Conference Series, Vol. 744, 1, 2016, pp. 1-12.
   http://iopscience.iop.org/article/10.1088/1742-6596/744/1/012054/meta;jsessionid=E4BB7A397DBB62D5B904A2DD24B7CA9C.c4.iopscience.cld.iop.org
9. Paeglitis A., Freimanis A., Comparison of constant-span and influence line methods for long-span bridge load calculations, The Baltic Journal of Road and Bridge Engineering, Vol. 11, 1, 2016, pp. 84–91. ISSN 1822-427X.
   Available from: doi:10.3846/bjrbe.2016.10. [M.kr.: 02T]; [Citav. rod.: 0.76(F) (2016)] (SCOPUS, WoS).
10. Paeglite I., Smirnovs J., Paeglitis A., Dynamic behaviour of pre-stressed slab bridges, Proceedings of 12th International conference "Modern Building Materials, Structures and Techniques", Procedia Engineering 00(2016) 000-000 (accepted).
11. Freimanis A., Paeglitis A., Mesh sensitivity analysis for quasi-static simulations, Proceedings of 12th International conference "Modern Building Materials, Structures and Techniques", Procedia Engineering 00(2016) 000-000 (accepted).
12. Paeglite I., Smirnovs J., Paeglitis A., Traffic load effects on dynamic bridge performance, Proceedings of the Eight International IABMAS Conference (IABMAS 2016) Bridge Maintenance, Safety, Management, Resilience and Sustainability, Brazil, Foz do Iguacu, 26.-30. June, 2016, pp. 2364-2369
    https://www.scopus.com/record/display.uri?eid=2-s2.0-85000925934&origin=resultslist&sort=plf-f&src=s&st1=Paeglite&st2=&sid=501A65F591CED0EE8CE9DB642C536DB7.wsnAw8kcdt7IPYLO0V48gA%3a10&sot=b&sdt=b&sl=21&s=AUTHOR-NAME%28Paeglite%29&relpos=0&citeCnt=0&searchTerm=

**Conference abstracts or full papers have been prepared and submitted for 2017**:

1. Janeliukstis R., Rucevskis S., Kovalovs A., Chate A., Numerical Investigation on Multiclass Probabilistic Classification of Damage Location in a Plate Structure, ICEDyn 2017 – "International Conference on Structural Engineering Dynamics", 3.-5. July, Ericeira, Portuguese.
2. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Algorithm of damage identification in beam structure based on thresholded variance of normalized wavelet scalogram, IMST 2017 – "3rd International Conference: Innovative Materials, Structures and Technologies", 27.-29. September, Riga, Latvia.
3. Janeliukstis R., Rucevskis S., Chate A., Hybrid localization of damage in a plate structure exploiting classification and wavelet transform, SMAR 2017 – "4th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures", 13.-15. September, Zurich, Switzerland.
4. Kovalovs A., Rucevskis S., Chate A., Numerical Investigation on Damage Detection in a Prestressed Concrete Beam by modal analysis, IMST 2017 – "3rd International Conference: Innovative Materials, Structures and Technologies", 27.-29. September, Riga, Latvia.
5. Goremikins V., Serdjuks D., Buka-Vaivade K., Pakrastins L., Choice of Rational Solution for Smart Innovative Suspension Structure, IMST 2017 – "3rd International Conference: Innovative Materials, Structures and Technologies", 27.-29. September, Riga, Latvia.

**Participation in international scientific seminars in 2016:**

1. Serdjuks D. Design of Timber Structures by EN 1995-1-1, International Scientific Seminar 2016, February 24, Saint Petersburg, Russia.
2. Serdjuks D. Fire Design of Timber Structures by EN 1995-1-2, International Scientific Seminar 2016, March 26, Saint Petersburg, Russia.
3. Serdjuks D. Design of Timber Structures by EN 1995-1-1, International Scientific Seminar, 2016, November 17, Riga, Latvia.

**Defended bachelor theses:**

1. Aleksandrs Trokss-Trasko "Analysis of needs of crossbeams for pre-stressed reinforced concrete girder bridges (project: reconstruction design of overpass over road V972 Madliena – Ledmane) supervisor Dr.sc.ing., prof. Ainars Paeglitis.
2. Andris Vetra "Analysis of use of safety barriers in Latvia (project: Reconstruction of Ramava street in Ramava town, Ķeguma county)" supervisor Dr.sc.ing., prof. Juris Smirnovs.
3. Janis Pralics "The bridge supports scourings and their consequences (project: Reconstruction of road P5 Ulbroka-Ogre)", supervisor Dr.sc.ing., prof. Ainars Paeglitis.
4. Lauris Spigeris "The analysis of road safety problems in Sigulda (project: Reconstruction of stage of road A12 Rezekne – Ludza)", supervisor Dr.sc.ing., prof. Juris Smirnovs.
5. Martins Cepurnieks "Analysis of traffic flow and safety and possible improvement in Limbaži town (project: Reconstruction of Rostokas street in Riga from Zoilitudes street till Jana Endzelina street)", supervisor Dr.sc.ing., prof. Juris Smirnovs.
6. Ivars Loits "Accuracy analysis of concrete coating over reinforcement according to Eurocode 2 requirements (project: Pedestrian overpass over road A5)", supervisor Mc.sc.ing. Ilze Paeglite.
7. Karina Buka-Vaivade „Check of design procedure for load-bearing elements from cross-laminated timber. Rehabilitation centre", supervisor Dr.sc.ing., prof. D.Serdjuks.

**Defended master theses:**

1. Reinis Tukiss "Analysis of the improvement measurement of road safety in Liepaja town", supervisor Dr.sc.ing., prof. J.Smirnovs.
2. Martins Jakobsons "A traffic organisation impact on the quality of the environment in Liepaja", supervisor Dr.sc.ing., prof. J.Smirnovs.
3. Vaivods Edgars "Analysis of road safety in circular road nodes in Latvia", supervisor Dr.sc.ing., prof. J.Smirnovs.
4. Vaivods Edgars "The analysis of road safety problems in Ogre town", supervisor Dr.sc.ing., prof. J.Smirnovs.
5. Renars Krisanovskis "Impact of steel element damages on bridge performance", supervisor Dr.sc.ing., prof. Ainars Paeglitis.
6. Zigmars Krumins "Assessment of appropriate public private partnership method for construction of road E67/A7 Kekavas bypass", supervisor Dr.sc.ing., prof. Ainars Paeglitis.
7. Linards Malmeisters „Behaviours Analyze of Composite Load-bearing Member", (Supervisor Dr.sc.ing. prof. D.Serdjuks).
8. Inga Drobis-Drobisevska „Fire Resistance Analyze for Arch-type Timber Roof", supervisor Dr.sc.ing. prof. D.Serdjuks.
9. Kaspars Spricis „Parameters Analyze of Composite Load-bearing Tensioned Member", supervisor Dr.sc.ing. prof. D.Serdjuks.
10. Janis Stepanovs „Behaviours Analyze of Combined Bridge′s", supervisor Dr.sc.ing. prof. D.Serdjuks.

**Preparation of a doctoral thesis:**

1. Ilze Paeglite "Moving load effect on the bridge dynamic characteristics", scientific supervisor – prof., Dr.sc.ing. Juris Smirnovs, planned to defend in 2017.
2. Andris Freimanis „ Risk consideration for safe, effective and sustainable bridge structures", scientific supervisor prof., Dr.sc.ing. Ainsrs Paeglitis, planned to defend in 2018.
3. Rims Janeliukstis „Development of damage identification methods for structural health monitoring", scientific supervisor prof., Dr.sc.ing. Andris Chate, planned to defend in 2018.
4. Aivars Vilguts „Rational structure of multy-storey buildings from cross-laminated timber", supervisor prof., Dr.sc.ing. D.Serdjuks, planned to defend in 2018.

**Popular-science publication in journal:**

1. Paeglitis A., Glulam timber pedestrian overpass over road P103 Dobele-Bauska 17.44 km in Tervete // Construction in Latvia, 2016, Nr.3, 79-85 pp. ISSN 1691-4058.

**Number of the new methods that have been tested and verified in various companies:**

1. D. Serdjuks, V. Goremikins, K. Buka-Vaivade "Design procedure for load-bearing elements from cross-laminated timber, which is based on the LVS EN 1995-1-1 and transformed section method".

**Participation in the international cooperation projects:**

1. COST Action TU1406 Transport and Urban Development. Quality specifications for roadway bridges, standardization at a European level (BridgeSpec) (2014-2018);
2. FP7 SCP3-GA-2013-605404-DURABROADS „Cost effective DURABLE ROADS by green optimizes construction and maintenance" 2013 – 2016.

**The performance indicators of the programme and project promotion:**

During the reference period is licensed a joined master's program: "Innovative Road and the bridge engineering" what is served in Gedimina Technical University of Vilnius and Riga Technical University. Programme is provided for 1.5 years training in English. The training will be carried out by academic staff of the Riga Technical University and VGTU.

During the Riga Technical University 57th International Scientific Conference (14.-18.10.2016) the conference guests (scientists from Latvia and abroad, students and representatives from industries as well as members of the scientific commission) have been informed about the project achievements and the obtained scientific results.

Upon launching the NRP programme IMATEH website has been created, where information on programme achievements and activities is constantly updated. On IMATEH website http://imateh.rtu.lv/ detailed information on Project 3 is available as well as information on NRP IMATEH activities and updates.

The co-financing coming from the private sector and income from contract work based on the results of the Project 3 constitute **EUR 8072** in the Period 3.

## PART 2: PROGRAMME PROJECT INFORMATION

### 2.1. Project No. 4

| | | |
|---|---|---|
| Title | *Layered wooden composite with rational structure and increased specific bending strength* | |
| | (Phase 3: 01.01.2016 – 31.12.2016) | |
| Project leader's name, surname | Karlis Rocens | |
| Degree | Dr. habil. sc. ing. | |
| Institution | Institute of Structural Engineering and Reconstruction | |
| Position | Senior researcher | |
| Contacts | *Mobile phone* | 22023321 |
| | *E-mail* | rocensk@latnet.lv |

### 2.2. Tasks and deliverables

*(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)*

***The aim of the project is creation of rational wooden composite with rational structure.*** (Time schedule for project 4 is given in Annex 4-A).

Development of load bearing layered wood composite with rational structure (standard plywood plates do not have rational distribution of material through the thickness) that provides increased specific bending stiffness (stiffness to mass ratio), reduced costs, consumption of materials and energy when compared to traditionally used materials (LV Patent No. 14979 and 15083).

A new type of composite construction will be proposed with cell type hollow ribs and skins of plywood or other material. This type of ribs allows to vary the stiffness of wood composites in a more meaningful way as it is for standard plywood or existing sandwich constructions. This solution offers to adjust with load bearing capacity in bending and to reduce consumption of material in less loaded areas of cross section. This material could be widely used in furniture production and for structural applications. At the same time, it will give an opportunity to use the proposed plates in combination with CLT panels in single and multi-storey wood building industry. The section stress field and rational structure vary depending on use of this material. This leads to a need of new design methodologies for load bearing capacity and structural design which harmonizes the section stress field with material resistance field of the developed structure.

| No. | Tasks | Deliverable | Responsible partner | Status |
|---|---|---|---|---|
| 11 | Development of methodology for determination of bending strength and conceptual experimental investigations of plates with cell type hollow ribs | Methodology | K. Rocens Institute of Structural Engineering and Reconstruction | Completed |
| 22 | Development of methodology for determination of specific bending strength for plates with cell type hollow ribs and determination of values for the most typical geometrical parameters. | Methodology | K. Rocens Institute of Structural Engineering and Reconstruction | Completed |
| 33 | Work-out of plate models with most typical types of hollow cell type ribs and experimental investigations to get specific strength in bending, | Model tests for 3 types of plates | K. Rocens Institute of Structural Engineering and Reconstruction | In progress |

| | | | | |
|---|---|---|---|---|
| | consumption of materials, energy consumption and costs (task ends in the 2nd quarter of year 2017). | | | |
| 44 | Recommendations work out for design of geometrical parameters of plates with hollow cell type ribs (task ends in the 3rd quarter of year 2017). | Recommendations | K. Rocens Institute of Structural Engineering and Reconstruction | In progress |
| 55 | Recommendations' work out manufacturing and 'work in' technology principles and produce plates' demonstration models (task ends in the 4th quarter of year 2017). | Technology fundamental principles<br><br>Demonstration models 3 | K. Rocens Institute of Structural Engineering and Reconstruction | In progress |

The calculation method of load bearing capacity in bending for plates with cell type hollow core has been developed. ANSYS FEM software in parametric Design language (APDL) was used to simulate the behaviour of these plates providing possibility to calculate the deformative characteristics depending on parameters of plate consisting elements (skins and elements of hollow ribs) by taking nonlinear Cohesive zone material (CZM) behaviour and failure criteria (FC) into calculations. Production and conceptual experimental investigations were made for various thicknesses (25; 30; 50; 100 and 150 mm) of a plate (according to EN 789) in longitudinal and transversal directions of a plate. The difference between calculated and experimentally achieved results by loading up to 1/200 of a span does not exceed 5%).

The calculation method of specific load bearing capacity in bending has been developed. It is based on specific genetic algorithm in MATLAB environment that automatically generates the input files for ANSYS APDL and by training Artificial neural network (ANN) optimizes the geometrical parameters of plate depending on aim and restrictions of variables. For example, the specific stiffness of a plate with thickness 25 mm in longitudinal direction is 1,08 $kNm^2/kg$ (40% higher comparing to the plywood with the same thickness), but in transversal direction 0,67 $kNm^2/kg$ (5% higher comparing to the plywood with the same thickness

Creation of three type plate model started.

Development of recommendation for plates with cell type hollow core was stared in this phase of project. The recommendation will describe rational design principles of plates taking into account the geometry of designed structure and applied loads and displacement boundary conditions.

The creation of technological principles for plate with cell type hollow core was started. The method of production of cell type hollow core was investigated according to the method described in patent LV15083.

Part of the achieved results has been showed in 9 (5 in report period) publications and in 2 valid held patents.

The required amount of research in third phase of project for approaching to project aim has been done completely.

***In case of non-fulfilment provide justification and describe further steps planned to achieve set targets and results***

| |
|---|
| - |

## 2.3. Description of gained scientific results

*(Describe scientific results achieved during reporting period, give their scientific importance)*

<table>
<tr><th>Task</th><th>Deliverables</th></tr>
<tr><td>1. Development of methodology for determination of bending load bearing capacity and conceptual experimental investigations of plates with cell type hollow core.</td><td>Methodology of calculations of load bearing capacity in bending taking into account the shear and tensile deformative properties of narrow glued line-joint between the plywood surface and the edge of ribs as well as failure criteria of plywood. Conceptual experimental investigations of deformability for plate's simulations that show the appropriation for achieved results calculated with this methodology.</td></tr>
<tr><td colspan="2">Input file code in ANSYS ADPL has been created taking into account the determinate narrow glued line-joint shear and tensile strength and characteristics of deformability (e.g. failure criteria) of plywood. The structure of a plate could be generated depending on given geometrical parameters (width, length and thickness of a plate; thicknesses and direction of (plywood, MDF, reinforced plastic and other plate material) skins, direction and geometrical parameters of ribs (width of a rib, thickness of straight or waved rib part, length of a wave (or number of waves per span), thickness of distancers etc.)<br>The structure of a plate has been modelled with solid type finite elements (SOLID 185 or SOLSH190) and defined material physical properties, including stiffness and strength parameters. In zones where the plate elements have been glued, the cohesive zone material (CZM) was modelled with interface finite elements (INTER205). The displacements of a plate, stresses in plate's and glued layer's elements were determined. The conceptual experimental investigations for various thicknesses of a plates with cell type hollow core in four-point bending (according to EN789) in longitudinal and transversal directions have been done. The difference between calculated and experimentally achieved results by loading up to 1/200 of a span does not exceed 5%.</td></tr>
<tr><td>2. Development of methodology for determination of specific bending strength for plates with cell type hollow ribs and determination of values for the most typical geometrical parameters (task ends in the 3rd quarter of year 2016).</td><td>Methodology of calculations for specific load bearing capacity in bending (load bearing capacity to one mass unit) for plates with cell type core (for the supports oriented in orthogonal direction of ribs).</td></tr>
<tr><td colspan="2">Specially developed software in MATLAB environment automatically generates input file code in ANSYS ADPL on the basis of the methodology developed in first task. The stiffness properties, glue line and failure criteria were taken into account to simulate the flexural behaviour of plates with cell type hollow core. Database with results is created with the parameters' influence on bending bearing capacity. It is achieved that the orientation of outer layer plies (or MDF fiber orientations) of the waved rib part has minor influence on plate's stiffness in longitudinal direction although the influence increases when the plate only with waved rib parts is used. The achieved database is used as an input for the training and validating of artificial neural network (ANN). The inverse task is solved with genetic algorithm (GA) that calculates objective function by using this ANN. The particular structure's geometrical parameters have been determined by using this methodology of calculations in that way the the section stress field has been harmonized with material resistance field of the developed structure. The developed methodology of calculations allows to compare efficiency of various ribs providing the required load bearing capacity and to determine the specific load bearing capacity that characterizes the material consumption for related type of ribs. The geometrical parameters of plates with cell type hollow core were optimized by using especially developed algorithm (by using achieved data basis and trained ANN):<br>1. Defines the main parameters of plates;<br>2. Definition of plates main directions;</td></tr>
</table>

| | |
|---|---|
| 3. Determination of critical load case (combination);<br>4. Determination of rational cross section geometrical parameters for various plates with various level of loads by using adapted GA and ANN;<br>A version of GA where the variables are real numbers was used in calculations. In each iteration the variables have been modified with reproduction, hybridization and mutation genetic operators, which are called according to previously defined probabilities. The structure of core and the defined specific load bearing capacity have been determined with the developed method of calculations. The difference between calculated and experimentally achieved results by loading up to 1/200 of a span does not exceed 5%). | |
| ***3. Work-out of plate models with most typical types of hollow cell type ribs and experimental investigations to get specific strength in bending, consumption of materials, energy consumption and costs (task ends in the 2nd quarter of year 2017).*** | ***Production of three type plates and experimental investigations of plates have been started.*** |
| The production of plate models and experimental investigations has been started according to schedule. Several series of plate specimens have been produced (more than 5 specimens per sample) for 25 mm and 50 mm (with practical application in mechanical engineering and furniture production) experimental investigations in longitudinal directions of a plate and the similar samples in transversal direction of a ribs. The conceptual experimental investigations were made for larger thickness plates (50 mm, 100 mm, 150 mm with application in civil engineering ) with three layer (4,0 mm) and five layer (6,5 mm) skins followed by EN789. After production of the pre-product of ribs and sawing in required thickness the brief checking of waves shape and visual quality of glued parts were done – the waved rib part was uniform glued with applied pressure to straight rib part and the distancers. After gluing of plates the check of the skin surfaces has been done and the warping was not established. | |
| ***4. Recommendations development for design of geometrical parameters of plates with hollow cell type ribs (task ends in the 3rd quarter of year 2017).*** | ***The development of recommendations started where the guidelines for structure design of these plates providing the highest possible load bearing capacity in bending.*** |
| The recommendations were created by using numerical results that provide possibility to calculate the parameters of the plate's structural elements depending on the geometrical requirements of plate, loading type and restrictions. Special procedures were made for the developed method of calculations, depending on the application of particular plates the optimization task and database of results. In that way the optimization process is are localized to make the optimization process more efficient, safer and faster. In all cases the structure of the plate and the determination method of structure have been tailored to the required application. Plates with cell type hollow core depending on the thickness and the topology of ribs could be used in a wide range – mechanical engineering, furniture production and for structural applications in civil engineering and building manufacturing. | |
| ***5. Recommendations' development manufacturing and 'work in' technology principles and produce plates' demonstration models (task ends in the 4th quarter of year 2017).*** | ***Started the development of pre-product of ribs and fundamental principles of manufacturing.*** |
| The plywood sheet forming waved rib part has been glued to the straight rib part by using dinstancers. In that way, cell type hollow ribs have been obtained. Distancers can be glued to plywood sheets providing additional improvement for the plates or in several cases removed when it is required. To consider the technological principles special laboratory equipment has been made for production of plates and pre-product of cell type hollow ribs providing required bond pressure. The research about the technological principles of application show that for uniformly distributed bond pressure for the narrow glued joint the fixed connection is achieved. The | |

maximal possible width of a rib was determined to avoid the exceeding of the allowable stresses in plywood.

**The activities have been done according to the time schedule and the planned aims have been reached.**
**It is confirmed by:**

- Methodology of calculations of load bearing capacity in bending for plates with cell type hollow core taking into account the shear and tensile stiffness of narrow glued line-joint between the plywood surface and the edge of ribs as well as failure criteria of plywood. Conceptual experimental investigations of deformability for plates simulations show the appropriation for achieved results calculated with this methodology. The difference between calculated and experimentally achieved results by loading up to 1/200 of a span does not exceed 5%
- Methodology of calculations for specific load bearing capacity in bending (load bearing capacity to one mass unit) for plates with cell type core (for the supports oriented in orthogonal direction of ribs) and the design of rational plates' structure (by using the adapted Genetic Algorithm) for maximizing the specific load bearing capacity in bending for given loading case. The difference between calculated and experimentally achieved results by loading up to 1/200 of a span does not exceed 5%
- The production of plate models with the most typical case of ribs for various thicknesses (25, 30, 50, 100 and 150 mm) of plates and experimental investigations have been started according to schedule. The deformability and specifics of fracture depending on the topological structure of a plate have been determined. The achieved results approved that the main specifics of deformability and fracture have been taken into account in the developed model of calculations.

The project personal salary makes 16 388 EUR (bruto salaries – 13 380 + social taxes – 3008) in reporting period.

### 2.4. Further research and practical exploitation of the results

*(Describe further research activities that are planned, describe possibilities to practically exploit results)*

The developed methodology of calculations for plates with cell type hollow core allows to model and design in detail the deformability of these plates with possibility to optimize the geometrical parameters in that way to optimize the specific load bearing capacity in bending (in longitudinal and transversal directions of a plate)

On the basis of the methodology for determination of plate's load bearing capacity in bending specially developed software in MATLAB environment, which automatically generates input file code in ANSYS ADPL and in a parametrical way defines the geometry of plate, properties of materials and applied boundary conditions. ANSYS finite element module calculates the stiffness of a plate and stress-strain field by using this code and generates database of strength and stiffness results depending on geometry of plates. This database is used to train artificial neural network which is used to evaluate the objective function that is used for optimization with genetic algorithm. Two different cases have been taken for ANSYS ADPL – plate's behaviour in general for simulation of the plate's behaviour should be non-linear glued joint and mechanical properties of material that is related to crack propagation in the glue lines and the failure criteria in the elements of the plate and the second case when the joints of the plate have been merged and the failure criteria has not directly taken into account. This nonlinear model of calculations can be used for rational design of energy absorption and vibration damping structures. The plate is designed in two levels. In the first level the plywood elements (ribs and skins) and their behaviour were designed by using SOLID185 or SOLSH190 finite elements which are based on theory of elasticity and spatial stress state.

Nonlinear behaviour of glued joint which is required to take into account for the general design of plate's behaviour is simulated by using the cohesive finite elements that takes into account the crack development in glue layer. It is realized with INTER205 finite elements in ANSYS environment that simulates separation process in glued joint.

In calculations the corresponding interfacial separation $\delta$ (displacement jump across the interface) is defined with division in normal $\delta_n$ and tangential (shear) $\delta_t$ separation. The ultimate normal $\sigma_{max}$ and ultimate tangential stresses $\tau_{max}$ have been defined The mean values have been determined in confidence interval with probability of 95% and standard deviation in all cases smaller than 15%. Mean shear strength was determined 7.11 MPa, mean displacement at fracture was 0.64 mm while the mean tensile strength for plywood edge to surface was determined 3.39 MPa and the mean displacement at fracture was 0.15 mm. The special series of specimens (fig. 2 B) were made to determine the tensile strength of specimens with various orientations of the outer fiber of plywood and various thicknesses of plywood. The experimental investigations were made to determinate the achieved input data have been used to generate the cohesive zone material at glued joint between ribs and it it is required also with the distancing laths as well as to generate the skins to the core.

The obtained experimental results have been used as an input data in ANSYS APDL code and achieved that stress-displacements curves are non-linear behaviour and they lie in between the experimental upper and lower results in that way it is possible to take into account the properties of glued line. (The achieved results are published in conference proceedings with full text article - Shear and tensile strength of narrow glued joint depending on orientation of plywood plys). With the simulations it is possible to determine the stress state of plate's elements and cohesive zones. This approach allows to design a rational thickness of skins, geometry of ribs depending on the load and required geometry of a plate with taking into account the behaviour of ribs and skins in the glued zones of a plate.

In the second level the ribs (and insulation material if needed) are replaced with one homogenized middle layer (thickness equal to the height of ribs) with anisotropic properties that are obtained from results at first level and numerical homogenization. For the analysis of plate with the homogenized middle layer nonlinear properties (modulus of elasticity and shear modulus) depending on the loads is determined. For the complicated geometry finite elements with homogenized middle layer are used. These elements are based on Reissner-Mindlin shear deformation theory. If the geometry and restrictions are relatively simple, an analytical solution of plates bending problem that is described by partial differential equations is obtained.

The experimental investigations have been done for most typical cases of plates with cell type hollow core (figure 1).

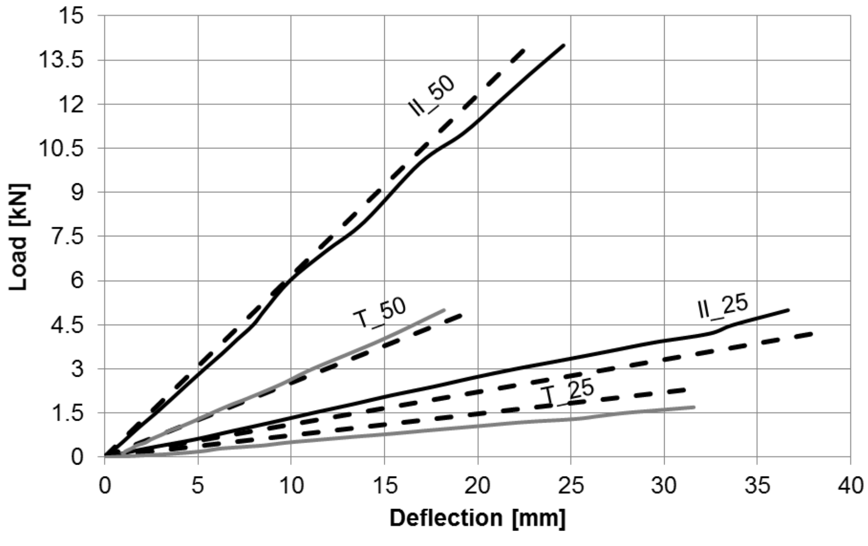


**Figure 1. Characteristics of deformations (by loading up to 80% of ultimate strength) for the plates with cell type hollow core and the thickness of 25 mm and 50 mm in longitudinal and transversal directions. (span 1100 mm; thickness of skins - 4,0 mm; straight rib part- 6,5 mm; waved rib part- 4,0 mm).**

For the plates with the thickness of skins 4,0 mm the fracture occurs due to the local buckling of compressed skin. By increasing the thickness of a skin the local buckling was limited and the fracture appears at glued joint although the serviceability limit state (deflection 1/200 of a span) for the plates with thickness of 50 mm has been reached at about 1/5 of ultimate limit state.

The influence of the geometrical parameters on the specific load bearing capacity of plate with cell type hollow core has been determined. The main factor that have the influence on allowable loads that the plate can resist are the thicknesses of skins and the straight rib part as well as the shape of waved rib part. The constant placement of ribs has been involved in finite element analysis due to the simplification of technology.

The common type of ribs from the manufacturing point of view (the length of a plate 1200 mm, the width of a plate 300 mm, 5 cell type hollow ribs width 60 mm each, thickness of skins and waved rib part 4,0 mm and thickness of straight rib part 6,5 mm) the values of specific load bearing capacity have been determined (confidence interval of mean values with probability of 95% and standard deviation in all cases smaller than 15%). For example for the plates with thickness of 25 mm the specific stiffness in longitudinal direction is 1,08 $kNm^2/kg$, while in transversal direction 0,67 $kNm^2/kg$, and for plates with thickness 50 mm in longitudinal direction 3,51 $kNm^2/kg$, but in transversal direction 1,61 $kNm^2/kg$.

In case when the variable is the thickness of straight rib part (the data basis has been reduced) and the optimization task, the required load carrying capacity and other geometrical parameters and restrictions, the ANN with GA has determined the minimal thickness of straight rib part t=6,5 mm. Like the geometrical parameters in previous task the difference between the experimental achieved and calculated does not exceed 5%. More detailed analysis of specific load bearing capacity for various thicknesses of plates, their skins and straight rib parts as well as curvature of waved rib part is planned in next phase of a project.

To expand the practical use of this material additionally to the planed tasks were done the research about steel joint and the buckling problems were done and could be used as carrying elements of these plates. In additional the influence of temperature and moisture change on the behaviour of the wood material has been investigated.

Samples with the most typical case of ribs and various thicknesses (25, 30, 50, 100 and 150 mm) were made to determine the load bearing capacity of plate in longitudinal and transversal directions (according to EN 789). The determined technological parameters (bond pressure, time of gluing, etc.) were considered and the work has successfully started and will be improved in the final phase of a project. The plates with thicknesses of 25 and 50 mm have been investigated in detail (>5 plates in longitudinal and transversal directions as well as conceptual investigations of plates with other thicknesses (up to 150 mm) and changed intensity of ribs and thicknesses of skins.


**Figure 2. Specimens of plates with cell type hollow core for determination of plates with cell type hollow core. Thicknesses 25 mm; 30 mm; 50 mm; 100 mm and 150 mm.**

Based on the developed methodology the work on recommendations is stared for the design of plates with cell type hollow core. After the completion of these recommendations it will be possible to design rational structure of a plate by calculating the required parameters and the main guidelines for the use of these plates will be given.

The research of manufacturing and the technological principles of gluing rib core parts to each other and to the top and bottom skins have been started before by receiving patents LV14979 and LV15083. In this phase not only the manufacturing of plates' models has been started but also the approbation of technological potentialities by manufacturing the demonstration models for specific use of plates started. The technological possibilities of waved rib parts have been investigated with analysis of technological stresses which appears in waved rib part after forming the required curvature without any additional springs to the equipment. In that way is possible to produce ribs with the width of 70mm when the straight rib parts 6,5 mm and the thickness of waved rib parts 4,0 mm and the grain direction of outer ply is parallel to the distancing lath direction. With special adaptation (fastening the guides) it is possible to use it for the manufacturing of ribs according to the patent LV15083. Demonstration models (scaled prototypes) made according to EN 789 and additional for increased thicknesses of a plate with the same dimensions of a plate (width and length)

**Figure 3. Demonstration model with recycled granulated insulation, without insulation and with polyurethane foam insulation.**

The actuality of these plates and obtained results confirms the achieved first place award at international Invention and Innovation Exhibition MINX 07.10 – 08.10.2016. with patents LV14979 and LV15083 (look at valid held patents) organized by LIA and "Connect Latvia" and supported by Latvian Chamber of Commerce and Industry (LCCI).

**Problems, possible solutions:**

For particular topologies of plate's structure in four points bending the buckling of several elements of the structure was established that requires to determinate the solution of plate's structure's topology to possible avoiding of this problem.

**In phase 4 of the project planned to realize the** aim (All further tasks will be done according to time schedule given in Annex 4-A):

1. Work-out of plate models with most typical types of hollow cell type ribs and experimental investigations to get specific strength in bending, consumption of materials, energy consumption and costs (3 type model investigations).
2. Recommendations development for design of geometrical parameters of plates with hollow cell type ribs (1 recommendations)
3. Recommendations' development of manufacturing and 'work in' technology principles and produce plates' demonstration models (1 principles 3 type demonstration models)

### 2.5. Dissemination and outreach activities

*(Describe activities that were performed during reporting period to disseminate project results)*

**Participation in international scientific conferences:**

1. Frolovs G., Rocens K., Sliseris J., Shear and tensile strength of narrow glued joint depending on orientation of plywood plys 12th international conference "Modern Building Materials, Structures and Techniques" in Vilnius, Lithuania, on 26–27 May, 2016
2. Kukule A., Rocens K., Lukasenoks A., Frolovs G., Change of Moisture Distribution in Ribbed Plate with Different Opposite Surface Temperatures 12th international conference "Modern Building Materials, Structures and Techniques" in Vilnius, Lithuania, on 26–27 May, 2016
3. Sliseris J., Gaile L., Pakrastins L., Deformation process numerical analysis of T-stub flanges with pre-loaded bolts 12th international conference "Modern Building Materials, Structures and Techniques" in Vilnius, Lithuania, on 26–27 May, 2016
4. Frolovs G., Rocens K., Sliseris J., Stress state analysis of plates with cell type ribs under loading, International Conference "Advanced Construction" in Kaunas, Lithuania on 6-7 October, 2016
5. Kukule A., Rocens K., Lukasenoks A., Determination of moisture distribution in ribbed plate used as building envelope, 5th International Conference "Advanced Construction" in Kaunas, Lithuania on 6-7 October, 2016
6. Sliseris J., Gaile L., Pakrastins L., Non-linear buckling analysis of steel frames 5th International Conference "Advanced Construction" in Kaunas, Lithuania on 6-7 October, 2016

**Published papers in scientific journals:**

1. Sliseris J., Andrä H., Kabel M., Dix B., Plinke B., Virtual characterization of MDF fiber network, European Journal of Wood and Wood Products (SNIP 0,930) (Scopus) http://link.springer.com/article/10.1007/s00107-016-1075-5

**Published papers in international conference:**

1. Frolovs G., Rocens K., Sliseris J., Shear and tensile strength of narrow glued joint depending on orientation of plywood plys 12th international conference "Modern Building Materials, Structures and Techniques" in Vilnius, Lithuania, on 26–27 May, 2016 Procedia Engineering 00 (2016) 000–000 (accepted);
2. Kukule A., Rocens K., Lukasenoks A., Frolovs G., Change of Moisture Distribution in Ribbed Plate with Different Opposite Surface Temperatures 12th international conference

“Modern Building Materials, Structures and Techniques” in Vilnius, Lithuania, on 26–27 May, 2016 Procedia Engineering 00 (2016) 000–000 (accepted);

3. Sliseris J., Gaile L., Pakrastins L., Deformation process numerical analysis of T-stub flanges with pre-loaded bolts 12th international conference “Modern Building Materials, Structures and Techniques” in Vilnius, Lithuania, on 26–27 May, 2016 Procedia Engineering 00 (2016) 000–000 (accepted);
4. Sliseris J., Gaile L., Pakrastins L., Non-linear buckling analysis of steel frames Proceedings of the 5th international conference Advanced Construction 2016. ISSN 2029–1213. http://ktu.edu/uploads/files/fakultetai/Statybos%20ir%20architekt%C5%ABros%20fakultetas/files/PROCEEDINGS%282%29.pdf

**Valid held patents:**

1. Rocens K., Kukule A., Frolovs G., Sliseris J., Berzins G., LV14979 „Method for producing ribbed plates” – The Official Gazette of the Patent Office of the Republic of Latvia 20.06.2015, pp 785 http://www.lrpv.gov.lv/sites/default/files/20150620.pdf
2. Rocens K., Frolovs G., Kukule A., Sliseris J., LV15083 “Method and equipment of production for ribbed composite plate with goffered wood-based core”. – The Official Gazette of the Patent Office of the Republic of Latvia 20.12.2015, pp. 1749. http://www.lrpv.gov.lv/sites/default/files/20151220.pdf

**Submitted abstracts for international scientific conferences:**

1. Frolovs G., Sliseris J., Rocens K., Optimal design of plate with cell type hollow core "Environment. Technology. Resources.", Rezekne, Latvia, June 15-17, 2017.
2. Sliseris J., Gaile L., Pakrastins L., Rocens K., Development of beam finite element based on extended-multiscale method for modelling of complex structures. IMST, Riga, Latvia, September 27-29, 2017.
3. Frolovs G., Sliseris J., Rocens K., Stress state analysis of plates with cell type hollow core for typical load cases. IMST, Riga, Latvia, September 27-29, 2017
4. Sliseris J., Gaile L., Pakrastins L., Rocens K., Non-Linear beam finite element based on extended-multiscale method for modelling of complex natural fiber reinforced beams. "Environment. Technology. Resources.", Rezekne, Latvia, June 15-17, 2017.

**Supervised doctoral thesis:**

1. Frolovs G. “Calculations of rational wooden composite structures and their elements” supervisor prof. Dr.sc.ing. Rocens.
2. Kukule A. “Behaviour of plywood ribs in various conditions of moisture”, supervisor prof. Dr.sc.ing. Rocens.

**Defended master thesis:**

1. Levics A. “(Experimental comparison of compressive and flexural strength between 3D printed and monolithic fibro concrete” supervisor prof. Dr.sc.ing. Sliseris.

**Supervised bachelor thesis:**

1. Matveja A. "Validation of plywood panels’ comparison and methodology of calculations”

**Results of the project popularization in phase 3:**

The representatives of the project have been participated in all meetings of State Research program IMATEH about the process and state of art of projects and program.

Participation in RTU 57. International scientific conference State research programme IMATEH section (14.10.– 18.10.2016.).

First place award at international Invention and Innovation Exhibition MINOX 2016 with patents LV14979 and LV15083 (look at valid held patents). In framework of exhibition participation in Business matchmaking program as well as participation on 23.09.2016. in workshop of presenting the inventions.

15.11.2016. Seminar with RTU Faculty of civil engineering, Institute of structural engineering and reconstruction and Eurasian national university (Astana, Kazakhstan) participants with project participants presentations of actual state of research results in 2016. (>15 participants).

Detailed information about activities and actualities of 4th Project has been published in the IMATEH home page http://imateh.rtu.lv/.

Cooperation has been made with Forest and Wood Products Research and Development Institute MeKA, that consists of JSC "Latvijas valsts meži" (LVM), Latvian Forest Industries Federation (LFIF) etc. In framework of this cooperation the product research of MeKA suggested products by involving master students who receive a salary from MeKA for this research.

**New research projects, applications and participation:**

The research is partly extended in framework of ERANet project "Development of eco-friendly composite materials based on geopolymer matrix and reinforced with waste fibers" (2017. approximate 17 000 EUR;), as well as Riga Technical university grants in academic year 2015./16. for J. Sliseris (8000 EUR) and in academic year 2016./17. for G. Frolovs (8000 EUR). Prepared and applied for European Regional Development Fund project application (ERAF) Measure "Industry-Driven Research" project Smart, resource saving, sustainable and safe structural timber multi-story buildings with composite structures.

## PART 2: PROGRAMME PROJECT INFORMATION

**2.1. Project No.5**

| | | | |
|---|---|---|---|
| Title | ***Material mechanical micro- nano- scaled features and their impact on human safety*** | | |
| Project leader's | | | |
| Name, surname, | Jurijs Dehtjars (Yuri Dekhtyar) | | |
| Degree | Dr. habil. phys. | | |
| Institution | Riga Technical University, Institute of Biomedical Engineering and Nanotechnologies | | |
| Position | Head of the Institute, Professor | | |
| Contacts | *Phone Number* | | +371 29469104 |
| | *E-mail* | | jurijs.dehtjars@rtu.lv |

**2.2. Tasks and deliverables**

*(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)*

**Project goal:** ***To investigate early destruction of surface of polymer composite materials aimed to develop methods of early destruction diagnostics, and analyze its application ways at enterprises.***

Each reporting period of the project corresponds to the calendar year and has specific Tasks.

**Tasks for the Period 3**:
***Task 1.*** Development of methods for diagnostics of early destruction of surface of polymer composite materials: using *in situ* electron emission spectroscopy, and evaluate the influence of aquatic microorganisms on destruction.
***Task 2.*** Development of the method of visual recognition of early destruction of polymer composite materials using destruction-induced staining.

**Time-frame for the tasks is given in Annex 5-A.**

**State-of-the-art: novelty of the developed methods.**
***Task 1.***

Nowadays, the use of composite materials in engineering is developing rapidly. Composites are considered not just the today's materials, but they are materials of the future. Despite the wide use of the composites in engineering, unexpected collapses of constructions still happen. This can be explained by difficulties in detection and forecasting of alterations of the material mechanical properties that leads to unexpected destruction of the materials. This happens due to the lack of methods for early diagnostics of destruction. An effective way to identify early destruction of the composites is application of *in situ* methods during mechanical loading.

Micro and nano cracks that are formed during the early destruction influence electronic properties of the surface, therefore, to detect the destruction process, it is necessary to study surface electronic properties. To determine the beginning of cracking, surface electronic properties have to be measured at nanoscale and during rearrangement of atoms that leads to cracking. The cracks are formed chaotically at the surface layer of the material and therefore it is difficult to predict localization of the cracks and observe the cracking process if measurements are fixed at the nanoscale. Therefore, the method of pre-threshold photoelectron emission was selected that allows to control the surface area at a millimetric scale covering an expected area of crack formation. However, the measurements provide information on the processes taking place in surface nanolayers.

It is known that electrons are emitted from the surface layer of material during mechanical destruction[1]. Energy for the electron emission is provided as a result of crack formation. Such type of emission is observed without any additional stimulation and can be used to detect the destruction. However, the formation of cracks due to rearrangement of atoms alters electron density which also influences electron work function ($\varphi$). If photons are used to excite emission of electrons, emission current ($I$) depends on $\varphi$, especially when photon energy (E) slightly (with accuracy of $kT$, $k$ – Boltzmann constant, $T$ – temperature in degrees Kelvin) exceeds $\varphi$:

$I \sim (E-\varphi)^m$ , $E \geq \varphi$, $m>1$.

Since the exponent $m>1$, slight change of $\varphi$ significantly influences the current $I$.

In the project, the method of the pre-threshold photoelectron emission spectroscopy to detect early destruction of composites was developed.

Nowadays old pipes of drinking water supply systems are being replaced with pipes made of polymer materials (polyvinylchloride or polyethylene). Polymer materials have long lifetime and are not susceptible to corrosion. During manufacturing of pipes organic and inorganic additives are added to the polymer in order to control plasticity and increase lifetime of the pipes. It was shown that polyethylene and polyvinylchloride as well as the additives leach organic substances into water[2,3]. These compounds are expected to be nutrients for bacteria and are able to form carcinogens due to reactions with disinfection agents (like chlorine). The organic substances also influence organoleptic properties of water such as taste and smell. Mechanical loading such as soil movements, deformation of buildings and temperature variations promotes weakening of the pipes and crack formation. This could further increase leaching of organic compounds from the material. In the reporting period an influence of organic compounds leached from walls of polymeric pipes on multiplication of natural aquatic bacteria (bacteria of Evian water) and E.coli bacteria (indicator of fecal contamination) was studied.

***Task 2.***

When the destruction begins, micro and nanocracks appear in the composite material. These cracks act as capillaries that can draw up liquids with high wetting ability. If the liquid is coloured, this gives possibility to recognize early destruction and visualise its location. So far this method has not been realized for composite materials. The project focused on two types of microcapsules: (1) containing low viscosity dye and (2) containing a developer. Both of the capsules were embedded into a composite material surface. The shell of the microcapsules breaks at a local overload and the dye chemically reacts with the developer. As the result, the damaged place is coloured.

**The following Deliverables were delivered upon the completion of the Period 3:**

| No. | Task | Deliverable | Responsible partner | Status |
|---|---|---|---|---|
| 1. | Development of methods for diagnostics of early destruction of surface of polymer composite materials: the method for diagnostics of early destruction using *in situ* electron emission spectroscopy; the method for diagnostics of early destruction, based on influence of | Method for diagnostics of early destruction of surface of polymer composite materials using *in situ* electron emission | J. Dehtjars, Institute of Biomedical Engineering and Nanotechnologies, RTU | Delivered |

[1] Dekhtyar Yu., Kawaguchi Y., Arnautov A. Failure and relaxation of carbon fibre-reinforced plastic tested by exoemission and luminescence methods. Int. Journal Adhesion and Adhesives. 1997, V.17, N 1, 75-78.

[2] Brocca D., Arvin E., Mosbaek H. Identification of organic compound migrating from polyethylene pipelines into drinking water. Water Research. 2002. pp 3675-3680.

[3] Skjevrak I., Due A., Gjerstad K.O., Herikstad H. Volatile organic components migrating from plastic pipes (HDPE, PEX and PVC) into drinking water. Water Research. 2003. pp 1912-1920.

| | | | | |
|---|---|---|---|---|
| | aquatic microorganisms. | spectroscopy | | |
| 2. | Development of methods for diagnostics of early destruction of surface of polymer composite materials: the method of visual recognition of early destruction using destruction-induced staining | Method for diagnostics of early destruction of surface of polymer composite materials using destruction-induced staining | A. Aniskevics, Institute of Material Mechanics, University of Latvia | Delivered |

### 2.3. Description of gained scientific results

*(Describe scientific results achieved during reporting period, give their scientific importance)*

The below results were achieved employing 0.65 FTE of workload.

| Tasks of the Project | The main results |
|---|---|
| 1. Development of methods for diagnostics of early destruction of surface of polymer composite materials:<br>the method for diagnostics of early destruction using *in situ* electron emission spectroscopy;<br>the method for diagnostics of early destruction, based on influence of aquatic microorganisms. | The method for diagnostics of early destruction of polymer composites using *in situ* prethreshold photo electron emission spectroscopy was developed.<br>Influence of organic substances leached from polymer pipes due to destruction of chemical bonds on water contamination by microorganisms was identified. |

**The following results were achieved during the reporting period:**

***1. To develop the method for early diagnostics of destruction, in situ (during mechanical loading of material) pre-threshold photoelectron emission was used.***

***To determine the influence of molecular bond breaking on microbiological contamination of drinking water, in vitro experiments were made.***

***A. Method of diagnostics based on pre-threshold photoelectron emission***

The maximum photoemission response to deformation process can be achieved if:

- the highest electron emission current ($I$) is emitted from the sample during deformation;
- the photon energy applied to excite photoemission corresponds to the condition $E \geq \varphi$.

The electron emission current (if $\varphi$=const) is directly proportional to the quantum yield ($Y$) (number of electrons emitted per absorbed photon) and the photon flux ($\Phi$). The value of Y depends on physical properties of the material and cannot be adjusted by the experimenter. The value of $\Phi$ can be increased by light source power or by focusing the light beam on the surface of the test object. In the experiments commercial Hg light source was used (DRT-220, Russia). To focus the light beam, an optical system was developed and assembled, optical quartz components were in use. The value of the photon flux $\Phi$ of the focused beam was selected to ensure the local temperature on the sample surface was not higher than the room temperature (+20 °C).

To match the material destruction spot with the light incidence spot, grooves as a stress concentrator were delivered on the sample surface (marked with “A” in Fig.1). The light beam was directed perpendicularly to the surface (marked with “Φ” in Fig.1).

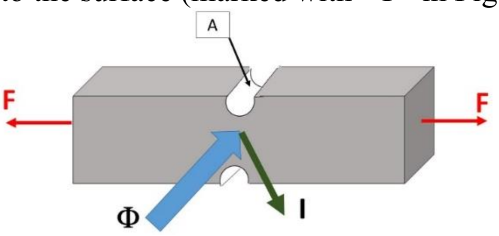



**Fig.1. Location of grooves (A), incident light beam (Φ), electron current (I) and forces (F) on the sample**

**surface**

Shape and size of the stress concentrators were optimized in order not to influence parameters of sample deformation (force, strain (*L*)). As the result, the concentrator was optimized as the arc with a radius of 0.5 mm. The force registered to deform the samples with and without concentrator differed by *S*≤4% that did not exceed a force deviation (*D*) for the samples without concentrator (Fig. 2).

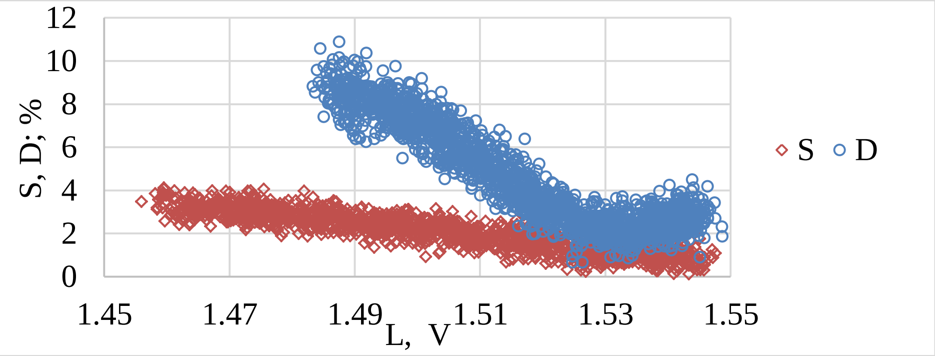



**Fig.2.** ***S*** **and D values in dependence on the electrical signal (*L)* from the deformation sensor**

In order to choose the photon energy to excite photoemission, the photoelectron work function (φ) of epoxy resin composite with carbon nanotubes was measured. The work function was equal to 4.8 eV. To choose the optical filter that meets the E≥φ criterion and selects the corresponding wavelength of the light source spectrum, the Signal/Noise ratio was estimated as a ratio of the maximum electron current recorded during the sample deformation to the electron current recorded at zero deformation. Fig.3 shows the values of Signal/Noise ratio for different optical filters. The optical filter BS12 was selected based on the results.

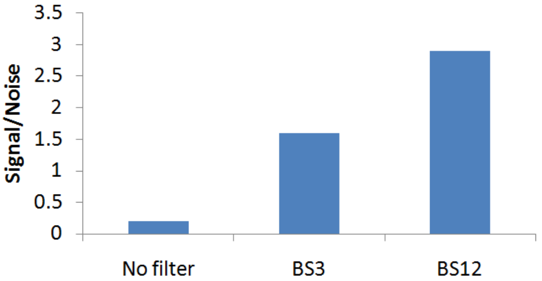



**Fig.3. Signal/Noise ratio for epoxy resin composite with carbon nanotubes (the maximum values of the energy: ~4.9 eV for unfiltered light, ~4.8 eV for BS12 filter, ~4.5 eV for BS3 filter).**

It was found that the electron emission current tends to increase during tensile deformation (Fig.4, green line). At the same time sawtooth oscillations of the photoelectron emission current were observed. This was related to the rearrangement of the atoms or destruction of the molecular bonds during deformation, both leading to formation of micro and nano cracks. As the electron work function of a crack differs from electron work function of the surrounding intact material, this influences the emission current.

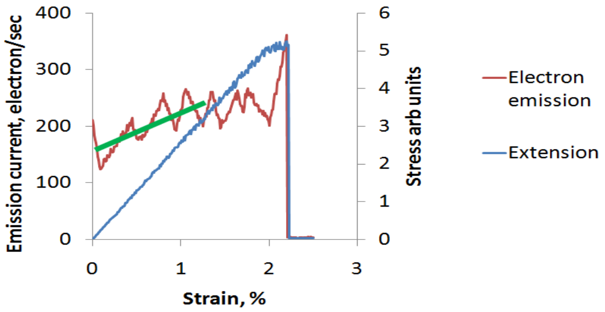



**Fig.4. Typical stress- and the photoelectron emission current- strain relationship of epoxy resin composite with carbon nanotubes**

To confirm the above, the surface electric potentials of the crack and the surrounding intact material were measured using the Kelvin probe force microscopy. Fig.5 demonstrates that the surface electric potential of the crack is significantly reduced against the surface electric potential of the surrounding material. This results in the higher photoemission current.

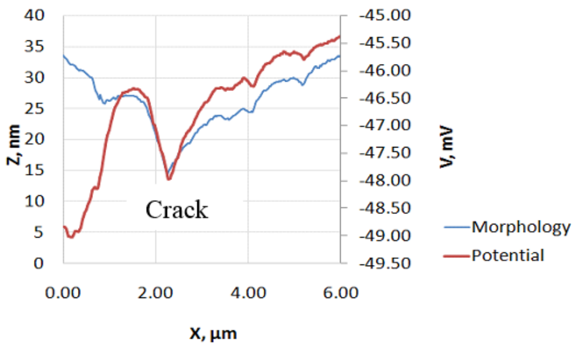



**Fig.5. Surface morphology and electrical potential of the epoxy resin composite with carbon nanotubes**

The concentration of the carbon nanotubes influences electron emission: the ratio of the maximum and minimum values of the sawtooth oscillations of photoelectron emission current (Altitude of the max) depends on the nanotubes concentration (Fig. 6).

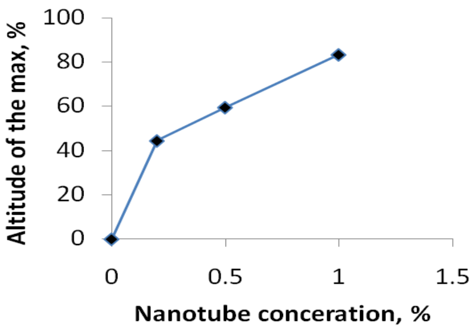



**Fig.6. Ratio of the maximum and minimum values of sawtooth photoelectron emission current oscillations in dependence on the carbon nanotubes concentration in the epoxy resin composite**

The modulus of elasticity of the composite material also correlates with the concentration of the nanotubes (Fig. 7).

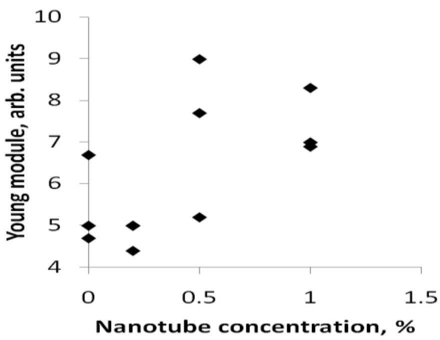



**Fig.7. Modulus of elasticity in dependence on the concentration of carbon nanotubes in the epoxy resin composite**

Attempts were made to apply the developed method to analyse the destruction of the novel composites, namely, the epoxy resin composite with charged $SiO_2$ microparticles (~20 µm). However, so far it failed to achieve homogeneous distribution of the particles in the material. Therefore it was not possible to obtain homogenous samples for the research. The experiments will continue using other methods to improve mixing the particles and epoxy.

The method has been approbated with fiberglass and epoxy resin composite. At the beginning of the elastic deformation electron emission current increases uniformly (Fig.8), but at a strain of 0.25% sawtooth oscillations of the emission current appear. This indicates that there are structural alterations in the material surface layer. Further deformation accumulates structural alterations that are displayed as subsequent emission current peaks and general increase of the emission current.

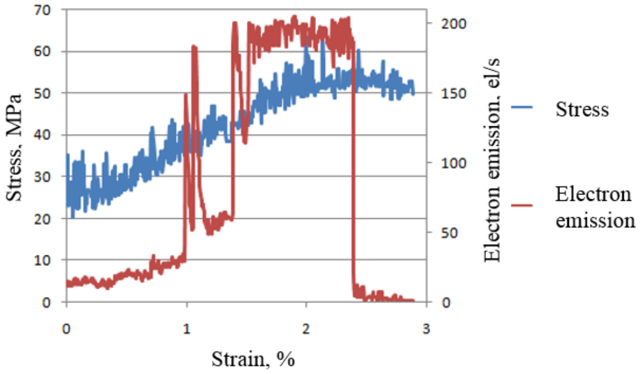



**Fig.8. Stress- and photoelectron emission current - strain relationship of the fiberglass and epoxy resin composite**

The presented results demonstrate the possibility to apply the developed method for the detection of early destruction of surface layers of polymer composites.

***B. Influence of the destruction of polymer molecular bonds on microbiological contamination of drinking water.***

Organic matter migration tests were performed using HDPE (high-density polyethylene) pipes. Regular pipes (PE80) and environmental stress crack resistant pipes Ultrastress (with a special crack resistant coating) were tested. Briefly, the pipes were kept in filtered (0.22 μm) Evian water 24h at 60˚C. Afterwards water with leached organic substances was collected and procedure was repeated twice with the same pipes. The water collected from every migration test was then cooled, and E.coli or bacteria naturally occurred in Evian water were inoculated. The samples with bacteria were kept for 72h at 30˚C to evaluate bacterial count. All tests were performed in triplicates. The bacteria were counted using the flow cytometry method. The results showed that both tested regular and crack resistant pipes leached organic substances in water promoting growth of the bacteria (Fig.9). The growth rate of the Evian water bacteria was higher compared to the other specimens with bacteria. This phenomenon was explained by the fact that the Evian water bacteria were used to live in limited nutrient conditions, whereas the tested E.coli were more used to nutrient agar.

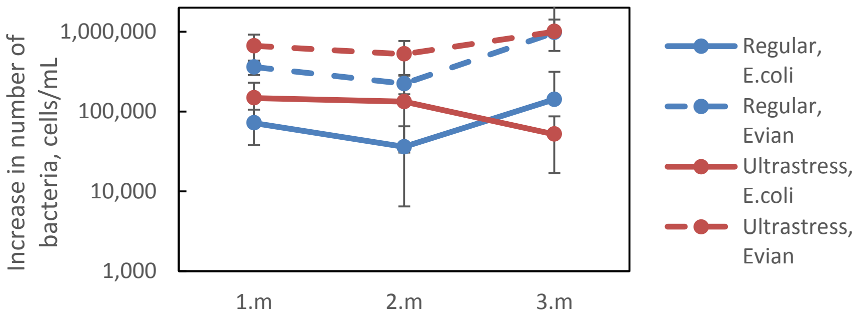



**Fig.9. Increase in number of *E.Coli* bacteria and Evian water bacteria during migration tests (1.m, 2.m, 3.m) in regular HDPE and Ultrastress pipes.**

The experiments allow to predict that early destruction of polymers under mechanical loading those results in leaching of the organic compounds from the polymers will promote bacterial growth in drinking water. Experiments will continue to test this hypothesis.

| | |
|---|---|
| ***2. Development of methods for diagnostics of early destruction of surface of polymer composite materials: the method of visual recognition of*** | ***The method for visual recognition of early destruction of polymer composites using destruction-induced staining has been*** |

| | |
|---|---|
| ***early destruction using destruction-induced staining*** | ***developed.*** |

**To develop polymer composite material with integrated ability of visual recognition of early damage using damage-induced staining, the following was reached.**

During the fabrication process of the polymer composite, the sensitive layer with ability of visual recognition of early damage using damage-induced staining was integrated into the structure of composite. The sensitive layer was presented by glass fiber impregnated with microcapsules having leuco dyes and particles of colour developer. Fabricated samples were tested on compression and tension. General view of the polymer composite sample with integrated sensitive layer is presented in Fig. 10.

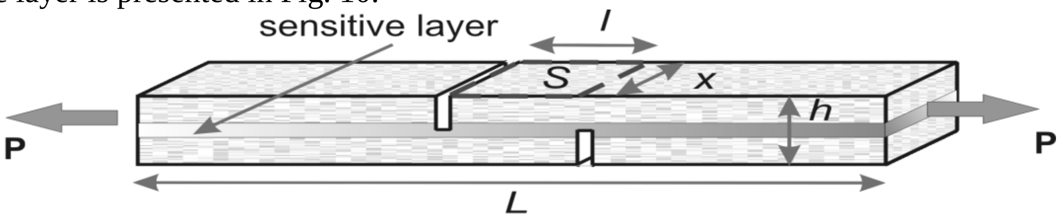



**Fig.10. General view of the sample with integrated sensitive layer for tensile tests.**

During tensile tests, the kinetics of visual response was estimated at the place of the sample damage (Fig. 11). After the compression tests, the kinetics of visual response was estimated as well (Fig. 12).

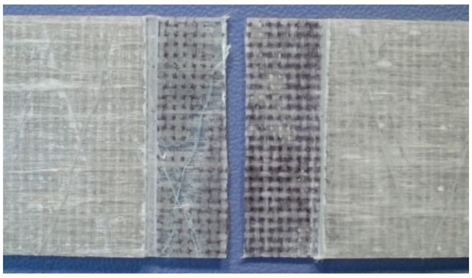


**Fig.11. Polymer composite sample with the integrated sensitive layer after tensile test**

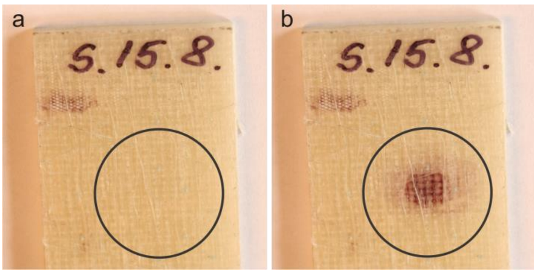



**Fig.12. Polymer composite sample with the integrated sensitive layer (a) before and (b) after compression tests.**

After the loading tests of the samples having the integrated sensitive layer, the alteration of the coloured spot was recognized in time. This was detected by a photo camera. The samples were photographed at 5 s intervals during the first minute of development, and with the 10 min interval after the first minute. The correlation between brightness (α) of the visual response and time (*t)* after the fracture was defined:

$$\alpha = 1 - exp(-k_1 t) \quad (1)$$

$k_1$- constant, that was identified from the experiment.

The maximal $\alpha$ value was observed within 2-3 h after the applied load (Fig. 13). To predict kinetics of visual response at room conditions, the constant $k_1$ was determined as well. The results were published [4,5].

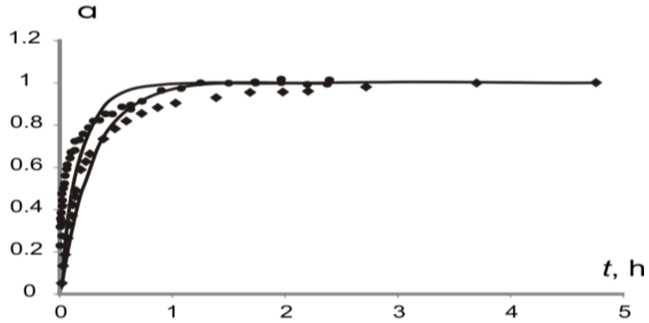



**Fig.13. Visual response $\alpha$ vs. time t after the fracture (♦) in tensile tests up to the fracture of specimen and in compression tests (●) without fracture; (♦,●) – data from the experiment, (—) – and approximation by Eq. (1).**

To predict the properties of the sensitive layer, it is necessary to know the mechanical properties of a single microcapsule and its size. The diameter of microcapsules determined using SEM method was in the range of 0.7 and 12 µm, the shell thickness of the capsules – 0.1 µm (Fig. 14). AFM was employed to identify the stiffness of microcapsule: 36±3 GPa.

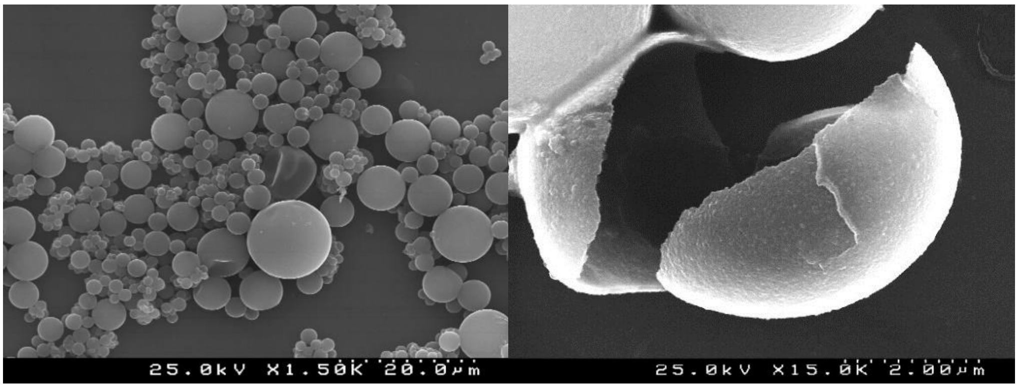



**Fig.14. Scanning electron microscopy images of microcapsules**

The finite element method was in use for the first approach to simulate the mechanical properties of the microcapsule under loading. The capsule was simulated as a sphere having a shell (Fig. 15).

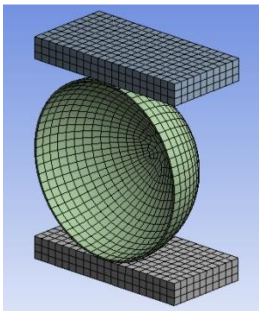


**Fig.15. A model of the capsule between two compressing plates.**

Further development and verification of the mathematical model is planned for the next

[4] O. Bulderberga, A. Aniskevich, S. Vidinejevs. A glass-fiber-reinforced composite with a damage indication function. Mechanics of Composite Materials, 2016, Vol. 52, pp.155-162.

[5] D. Zeleniakiene, V. Leisis, P. Griskevicius, O. Bulderberga, A. Aniskevich. A Numerical Simulation of Mechanical Properties of Smart Polymer Composite with Microcapsules for Damage Sensing Applications. Proceedings of 17th European Conference on Composite Materials (ECCM17), 2016, pp. 1-8, ISBN 978-3-00-053387-7.

project period.

A novel approach to apply electroconductivity measurements to localize damaged places of the polymer composite material was developed[6]. For this the electroconductive carbon nanotubes (CNT) were integrated into the material. (Another method for diagnostics of early destruction of similar composite was presented in Task 1 of the project.) The composite was made of glass fibre textile and CNT-enhanced resin. To fabricate the composite, a novel method to integrate the resin into continuous textile reinforcement was developed. The method imprints a liquid reactive resin into the textile pre-forms. Series of targeted injections form a pattern of conductive patches with controlled dimensions (Fig. 16). During exploitation of the material the electroconductivity of each spot/sensor will be measured and the damage of the composite will alter electroconductivity. Thus, the damaged place could be identified locally.

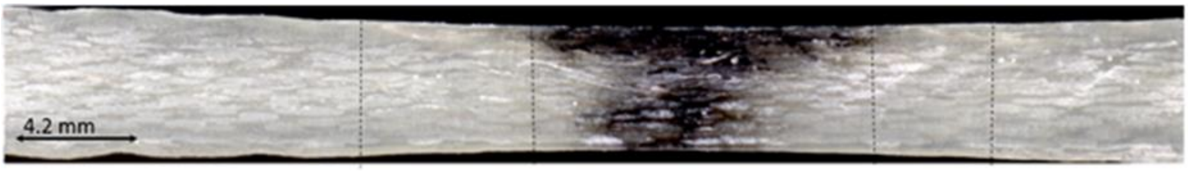



**Fig.16. The cross section of the composite within the place of targeted injections**

The resistance of composites having a CNT-modified binder against the aggressive environmental factors (e.g. atmosphere humidity) was studied. Kinetic of moisture sorption process (relative moisture content (*w*, %)) vs. square root of the time (*t*) hours is presented in Fig. 17. Moisture content was measured by sorption method. The specimens were exposed to the atmosphere with relative humidity of 98 %. It was found that addition of moisture-impenetrable CNTs both to the epoxy resin and carbon fibres reinforced composite slowed down the moisture diffusion. On the other hand, CNTs, having high stiffness and strength, improved the flexural properties of these materials.

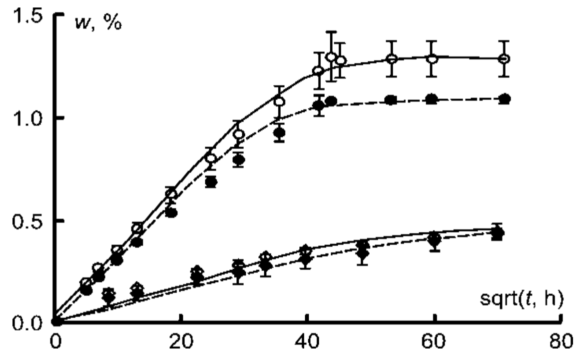



**Fig.17. Moisture absorption kinetics for different materials: (○) epoxy resin, (●) epoxy resin with CNT; (◊) carbon fibres reinforced composite; (♦) carbon fibres reinforced composite with CNT epoxy resin**

***For the first time*** it has been found that addition of moisture-impenetrable CNTs to the composites causes the retardation of moisture diffusion into the material, thus the mechanical properties of composite are improved and durability of materials increase.

[6]D.S. Ivanov, Y.M. Le Chain, S. Arafati, A. Dattin, S.G. Ivanov, A. Aniskevich. Novel method for functionalising and patterning textile composites: liquid resin print. Composites Part A: Applied Science and Manufacturing, 2016, Vol. 84, p.175-185(SNIP 2015 2.055).

### 2.4. Further research and practical exploitation of the results

*(Describe further research activities that are planned, describe possibilities to practically exploit results)*

The tasks planned in the reporting period were achieved. The technological readiness is achieved for the implementation of the Period 4 of the Project.

**The achieved results have the following scientific significance:**

2. The method for diagnostics of early destruction of surface of polymer composite materials using *in situ* prethreshold photoelectron emission spectroscopy was developed ***for the first time*** (the Deliverable). The method is based on measurements of the pre-threshold photoelectron emission during mechanical loading of the material. The method will allow to identify the beginning of the destruction of the surface nanolayers when micro/nano cracks start to form.
3. The following results were achieved ***for the first time*** using the *in situ* electron emission spectroscopy method:
    a. nano-objects (carbon nanotubes) added to epoxy resin composite change the kinetics of emission current related to mechanical loading.
    b. fine sawtooth oscillations of the electron emission current were detected which occur due to the destruction of molecular bonds or rearrangement of atoms in a surface layer of the composite with thickness <100 nm. The electron current starts to appear at the deformation of ~0.1 %, i.e. ≤10 % of quasi-elastic deformation.
    c. the kinetics of emission current depends on the modulus of elasticity of the composite material.
4. In the *in vitro* experiments, it was shown ***for the first time*** that destruction of molecular bonds of the walls surface of the polymer pipes („high-density polyethylene") increases reproduction of E.coli bacteria. The results allow to foresee that early destruction of polymers promotes reproduction of bacteria in water.
5. The method for diagnostics of early damage of composites by visual recognition was developed (the Deliverable). The method ***for the first time*** confirms the possibility of visual recognition of early damage using damage-induced staining. During the method development the following results were achieved ***for the first time***:
    a. sensitive layer with ability of visual recognition of early damage using damage-induced staining was developed;
    b. the sensitive layers were integrated into the composite material;
    c. experimental approbation of the sensitive layer by compression and tensile tests was performed;
    d. influence of the sensitive layer on mechanical properties of the composite was examined (mechanical properties of the composites with and without integrated layers were compared);
    e. the new concept of manufacturing of composite with integrating electro conductive carbon nanotubes was presented that will be in use for diagnostics of early damage of composite.

**Practical significance of the achieved results:**

1. The method for diagnostics of early destruction of surface of polymer composite materials using *in situ* electron emission spectroscopy allows to analyse beginning of destruction of surface nanolayers in a non-contact way starting from ≤10 % of quasi-elastic deformation. This is necessary to forecast destruction of materials and assess quality of materials (safety, biological activity etc.).
2. The method for diagnostics of early damage of composite by visual recognition was developed. Applying the method, it is possible to produce composites with integrated

function of visual recognition of early destruction, taking into account composite exploitation requirements. Presented method is a fundamentally new solution for polymer composite structural health monitoring. It is possible to increase the safety of the construction during the operation, to simplify monitoring of the technical condition and reduce the time required for large area inspection

***The results achieved in the Period 3 of the Project will allow to diagnose early destruction of polymer composite materials. The developed methods will be exploited in the Period 4 when the results will be discussed with the partners from industry with the aim to approbate the developed methods in manufacturing of machinery and constructions, provision of technological control and development of new materials.***

**Tasks for the Period 4:**

***Task 1.*** To analyze application possibilities of the methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – manufacturing of machines and constructions.

1. Development of recommendations on application of diagnostic methods in machinery manufacturing and constructions will be developed (the Deliverable).

***Task 2.*** To analyze application possibilities of the methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – in manufacturing of polymeric pipes for drinking water.

1. Development of recommendations on application of diagnostic methods in manufacturing of polymeric pipes for drinking water will be developed (the Deliverable).

**The following research will be done:**

1. The developed methods of early diagnostics will be approbated taking into account aims and wishes of enterprises working in testing of composites and manufacturing of polymer pipes.
2. In addition, the method of electron emission spectroscopy will be approbated:
    - o using composite materials with charged $SiO_2$ particles,
    - o using fibreglass and epoxy resin composite.
3. Influence of bacteria and chlorine that are present in water supply system on early destruction of polymer pipes will be analysed.
4. Mathematical model of mechanical behaviour of microcapsules will be developed and verified.

## 2.5. Dissemination and outreach activities

*(Describe activities that were performed during reporting period to disseminate project results)*

**During the 3$^{rd}$ Period project results were disseminated at 4 international conferences:**

1. Aniskevich A., Bulderberga O., Dekhtyar J., Korvena-Kosakovska A., Kozak I., Romanova M., Electron emission of the carbon nanotube-reinforced epoxy surface nano layer towards detection of its destruction induced by elastic deformation. International Nanotechnology Conference & Expo (Nanotech-2016*)*, April 4-6, 2016, Baltimore, USA.
2. Zeleniakiene D., Leisis V., Griskevicius P., Bulderberga O., Aniskevich A., A Numerical Simulation of Mechanical Properties of Smart Polymer Composite with Microcapsules for Damage Sensing Applications. Poster No. PO-3-02, ECCM17 – 17th European Conference on Composite Materials, June 26-30, 2016, Munich, Germany.
3. Chimbars E., Dekhtyar J., Kozaks I., Aniskevich A., Influence of high-frequency radiation on early collapse of composite material with embedded nanotubes. Riga Technical University 57th International Scientific Conference, October 17, 2016, Riga, Latvia.

4. Dehtjars J., Aniskevics A., Bulderberga O., Romanova M., Gruskevica K., Balodis A., Material mechanical micro- nano- scaled features and their impact on human safety. Riga Technical University 57th International Scientific Conference, October 17, 2016, Riga, Latvia. (presented at the special session of the conference dedicated to IMATEH)

**Three full-text papers were published in journals indexed by Web of Science and Scopus data bases:**

1. Ivanov D.S., Le Chain Y.M., Arafati S., Dattin A., Ivanov S.G., Aniskevich A., Novel method for functionalising and patterning textile composites: liquid resin print. Composites Part A: Applied Science and Manufacturing, 2016, Vol. 84, 175-185 (***SNIP 2015 2.055***).
   http://www.sciencedirect.com/science/article/pii/S1359835X16000336
2. Glaskova-Kuzmina T., Aniskevich A., Martone A., Giordano M., Zarrelli M., Effect of moisture on elastic and viscoelastic properties of epoxy and epoxy-based carbon fibre reinforced plastic filled with multiwall carbon nanotubes. Composites Part A: Applied Science and Manufacturing, 2016, Vol. 90, 522-527 (***SNIP 2015 2.055***).
   http://www.sciencedirect.com/science/article/pii/S1359835X16302822
3. Bulderberga O., Aniskevich A., Vidinejevs S., A glass-fiber-reinforced composite with a damage indication function. Mechanics of Composite Materials, 2016, Vol. 52, pp. 155-162.
   https://link.springer.com/article/10.1007/s11029-016-9568-1

**One full-text paper was published in conference proceedings:**

Zeleniakiene D., Leisis V., Griskevicius P., Bulderberga O., Aniskevich A., A Numerical Simulation of Mechanical Properties of Smart Polymer Composite with Microcapsules for Damage Sensing Applications, proceedings of 17th European Conference on Composite Materials (ECCM17), 2016, pp. 1-8, ISBN 978-3-00-053387-7.

**One doctoral thesis is being developed:**

O. Bulderberga "Polymer composite with damage indication ability: development and determination of properties", supervisor Dr.sc.ing. A. Aniskevich, the pre-defence is planned in 2017.

**One master thesis was defended:**

Anda Pujate "Homogeneity of polymer composite with charged micro- and nanoparticles", supervisor A.Homko, defended in June 2016.

**One bachelor thesis was defended:**

Edgars Cimbars "High-frequency radiation impact on early collapse of composites with nanotubes", supervisor Dr.habil.phys. Prof. J. Dehtjars, defended in June 2016.

**Two master theses are being developed (the defence is planned in June 2017):**

1. Eriks Dombrovskis "Influence of electrically charged micro/nano particles on early destruction of composite", supervisor Prof. J.Dehtjars/ A.Homko
2. Dainis Silins "Changes of mechanical properties of epoxy resin composite with carbon nanotubes under influence of accelerated electrons and alfa particles", supervisor Prof. J.Dehtjars/ A.Homko

**Other dissemination and outreach activities.**

In 2016 workshops were delivered:

1. with manufacturer of polymer pipes "Evopipes" Ltd. - about the results achieved in the project and the possibility to implement the results in water pipes manufacturing;

2. with composite material testing centre “Aviatest” Ltd. - about the results achieved in the project and possibility to implement the results for testing of composites and constructions used in aviation.

The information about Project implementation is being regularly updated on the website of IMATEH Programme: http://imateh.rtu.lv/.

## PART 2: PROGRAMME PROJECT INFORMATION

### 2.1. Project No. 6

| | | |
|---|---|---|
| Title | ***Modification of metal surfaces for the reduction of friction and wear*** | |
| Project leader's name, surname | Karlis Agris Gross | |
| Degree | PhD | |
| Institution | Riga Technical University | |
| Position | Lead researcher, Assoc. Professor | |
| Contacts | *Telephone* | +371 2020 8554 |
| | *E-mail* | kgross@rtu.lv |

### 2.2. Tasks and deliverables

*(List all tasks and deliverables that were planned for reporting period, list responsible partner organizations, give status, e.g. delivered/not delivered)*

**Goal:** ***Optimize metallic surface properties for reduced friction on ice.***

The third stage of the project has two tasks.

| No. | Tasks | Deliverable | Responsible partner | Status |
|---|---|---|---|---|
| **1** | Determine the influence of material surface properties on the ease of sliding on ice**.** | The influence of roughness, hardness and wettability on slideability on ice. | K.A. Gross Faculty of Materials Science and Appl. Chem. | In progress |
| **2** | Produce a method to test the sliding of larger geometries on ice. | A method to test the slidability of long rails on a longer ice track. | K.A. Gross Faculty of Materials Science and Appl. Chem. | In progress |

***Task 1: Determine the influence of material surface characteristics on the ease of sliding on ice.***

Surface characteristics control the ease of sliding over ice, but little attention has been directed to a thorough characterization of metal surfaces. Others have only used generic measures for roughness, such as $R_a$ (Wear, 258 (2005) 26-31), but we found that an expression involving the area of contact with ice provides a more insightful measure that shows a correlation with sliding speed. For increasing the hardness of metal, we tempered metal, rapidly solidified metal (laser treatment) and have considered an additional method of increasing the hardness by plastic work. The influence of hydrophobicity has been shown on the wettability and sliding speed. Control of surface characteristics is important, and in the next stage we will show the relative importance of roughness, hardness and wettability. This will allow us to optimize each surface characteristic to get the best sliding performance on ice.

***Task 2: Produce a method to test the sliding of larger geometries on ice.***

It is difficult to find reports of large objects modified for testing on ice. All testing is limited to small objects with a report on the co-efficient of friction. We have addressed the sliding speed on ice, by starting with laboratory scale experiments, and then increased the scale of testing from a 4m long track to a 16m long ice track. This provides direct relevance and gives a practical useful measure; sliding speed as opposed to the co-efficient of friction. The outcome will show whether the factors that show an influence on slideability in laboratory conditions will also prevail in practical conditions.

**<u>A view of the project in perspetive of a three year project.</u>**

This project is a completely new research endeavour at RTU, requiring the development of new test methods – selection of the best surface inspection method for quality control purposes, development of a roughness parameter for roughened surfaces, development of a method to assess the roughness to indicate an influence on slidability, and the development of a new sliding test method.

The progress is slower compared to projects 1-4 within the IMATEH research platform, since this is a totally new research direction without an existing pool of students that can be readily integrated into the research activities.

**The tasks for the 3rd stage of Project 6 have been completed as planned.**

1. Stainless steel blocks have been roughened with sandpaper to various levels of unevenness at the mikro and macro levels. Roughness measurement of the surface is required for required to determine Rsm; a deciding factor in influencing the slidability on ice. The roughness can only be assessed after conducting a surface map and determining the roughness along the ridges generated by the scratches. This is a new method for assessing the surface roughness and has been reported in a conference publication and a submitted journal paper to the journal Measurement.
2. A method for preparing a surface with parallel surface has been prepared for larger surfaces. This provides relevance to applications in society.
3. Stainless steel blocks have been hardened by tempering, characterized for surface topography, and tested for hydrophobicity and ease of sliding. A method has been developed for tempering larger steel objects to increase the surface hardness. Metal blocks have also been surface hardened by laser treatment and tested for slideability.
4. The influence of hydrophobicity on ease of sliding has been investigated. Hydrophobic thin films have been applied onto steel blocks, the wetting measured and ease of sliding determined. Six different surfaces with different contact angles have been tested for speed of sliding.
5. A method has been tested for determining the ease of sliding on long rails down a long ice track in winter time. Trials have been conducted to test if the laboratory conditions agree with the results from the longer ice track.

*In case of non-fulfilment provide justification and describe further steps planned to achieve set targets and results*

| |
|---|
| The planned targets of the NRP IMATEH Project 6 „*Modification of metal surfaces for the reduction of friction and wear*" were fully achieved in the reporting period from 01.01.2016 till 31.12.2016. The main results have been achieved, but the authors are still awaiting a response from the journal Measurement for the acceptance of the submitted manuscripts. |

## 2.3. Description of gained scientific results

*(Describe scientific results achieved during reporting period, give their scientific importance)*

| Tasks | Deliverables |
|---|---|
| ***1. Modify metallic surfaces. Determine the slideability of materials with different surface characteristics.*** | ***A recommendation has been started for surface modifications that increase the slideability of metal on ice. Participation at a conference, a publication.*** |
| A more detailed investigation has been conducted on the surface characteristics that influence the sliding ability on ice. Three characteristics were addressed: surface roughness, hardness and hydrophobicity. Previous reports on surface roughness have only shown a difference in friction on | |

ice for the direction of scratches and discuss very rough surfaces (Kietzig et al., J. Appl. Phys. 106, 2009, Article 024303). In agreement with Skovaklis et al (Tribol. Int., 49, 2013, 44-52) who commented on the importance of surface contact, this report will show the roughness along contact lines with ice and relate it to slideability.

The most emphasis has been placed on roughness, since it is simple, cheap and quick. The range of surface roughness parameters listed in the standard ISO 25178 was addressed and a correlation sought with sliding time. The roughness average step ($R_{Sm}$) in relation to the surface roughness average ($S_a$), representing the roughness steepness indicated that smoother surfaces (those with a higher $R_{Sm}/S_a$ value) led to greater sliding speeds, Fig 1. This was shown for blocks abraded with 400, 600, 1500, 2000 and 3000 grade sandpapers. Experiments conducted on four separate days, labelled as 1 to 4, showed that rougher surfaces (lower $R_{Sm}/S_a$) led to slower metal speeds, but surfaces smoother than 1000 $R_{Sm}/S_a$ no longer increased the block speed on ice. This critical value is new and practically shows that abrading with a sandpaper smoother than 600 grit has no further improvement, and so finer abrasion is not necessary.

The outcome shows that the contact area is only relevant down to a critical level of surface smoothness. Ease of movement on ice beyond the critical $R_{Sm}/S_a$ will be further assessed at the commencement of movement and compared to the total sliding time. The contact area will be further assessed at larger scales of surface uneveness to include the overall shape. Such a detailed assessment over the different length scales has never been reported, only the micron scale roughness (Stamboulis C et al. Trib. Int. 55 (2012) 59-67).

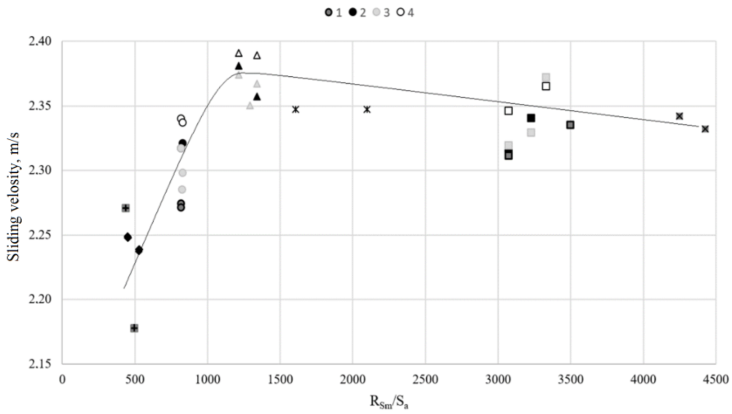



**Fig. 1. Influence of smoothness (expressed as RSm/Sa) on the speed of sliding on ice on four days of testing the slideability over ice.**

Surface hardness was addressed as the second surface characteristic with an influence of sliding on ice. This stemmed from the observation that scratching has a negative effect on the sliding speed and so making a harder surface could decrease the depth of scratching. Termpering was addressed as the simplest means of imparting a higher hardness to the surface. This thermal process increased the Brinell hardness from 340 to 440. The reference block and the hardened block were polished, and then abraded with 600 and 1500 sandpapers to determine the effect of slideability.

The hardened blocks exhibited a greater resistance to scratching, but the smoother surfaces from the scratched tempered metal blocks showed the opposite effect – a slow sliding speed resulted from the tempered stainless steel, Fig 2. The same test was reproduced on a different day, but showed the same trend, confirming the initial observation. Since various surface characteristics could change concurrently, the surface energy was investigated on the tempered surfaces; tempering created more hydrophilic surfaces that slowed better sliding. Metal blocks have been tempered to four levels of hardness to see whether a relationship exists between hardness and slideability. Other hardening operations such as peening will also be applied to conform the findings from another perspective.

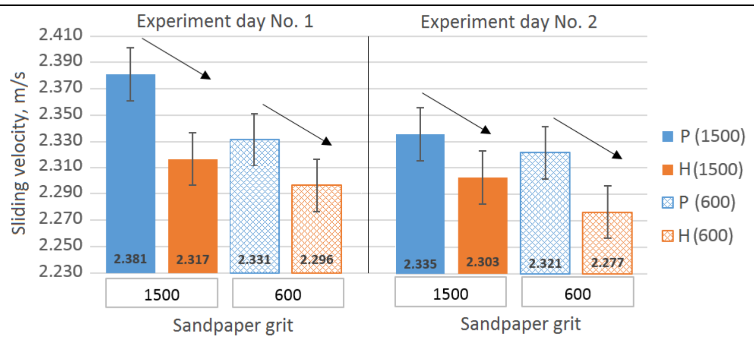



**Fig. 2. Sliding speed for hardened (H) & plain (P) metal showing that tempering reduces slideability.**

The metal surface was laser treated to increase the hardness, to for evaluating the influence of hardness on sliding over ice. A range of laser power settings were selected to alter the amount of heat for melting the metal, resulting in the control of surface hardness. A nano-indentor showed that the hardened layer was only 0.2 microns thick, Fig 3. The laser treatment on the metal did not show an increase in the sliding speed, Fig 3. A confirmation on hardness having no influence on slidability will be sought with plastically deformed metal blocks.

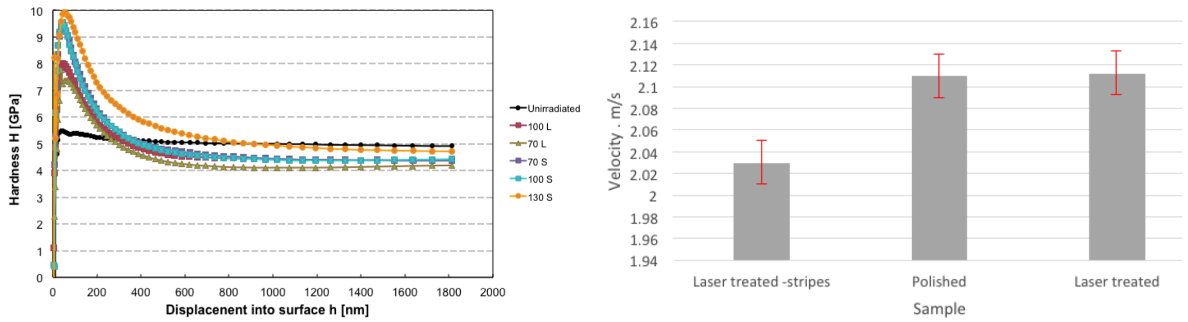



**Fig 3. The variation of hardness with depth determined by nanoindentation, and an illustration that hardness did not show an influence of hardness on slideability over ice.**

Hydrophobicity was addressed as the third surface characteristics. Six polymers were investigated for contact angle and the sliding speed – polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE) and polyoxymethylene (POM. Lower contact angle polymer surfaces supporting more wetting lowered the sliding speed, but more hydrophobic surfaces (PE and PTFE) increased sliding speed, Fig 4. Other surfaces with a highest hydrophobicity are being sought to understand the sliding speed for surfaces with a lower wettability. The general trend was observed over a range of temperatures.

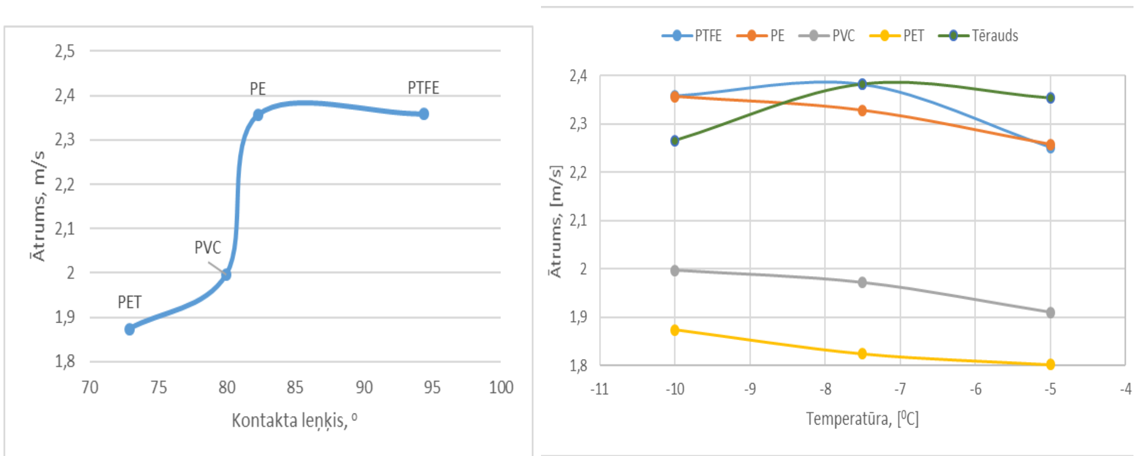



**Fig. 4. Influence of the contact angle on the ease of sliding on ice.**

Conference publication C1 and journal publication J1.

| ***2. Develop a method for testing slidability on larger metal surfaces*** | ***Data acquisition, data analysis. The method for modifying larger surfaces has been initiated.*** |
|---|---|

Practical usefulness of the laboratory results is only useful if testing can be made in real-life situations - outdoors on a longer ice track with larger metal rails. Testing was confirmed suitable at the sled training ramp. This location was open to changes in ice temperature and humidity, but not the UV rays and the wind that can have devastating effects on the ice temperature and overall condition. Two ramp angles are available for conducting the tests. Optical sensors, like in the laboratory detected movement and measured the sliding time.

Skeleton sliders were chosen for surface modification since they are the smallest of any construction equipped for sliding on ice. The rail has a suitable diameter that fits into the groove on the ice platform, it can easily accommodate additional weights to determine the effect of weight, and surface modifications would be the easiest on these smallest rails. Sliders scratched with 3000, 1500, 600 and 320 grit sandpaper showed a similar trend in sliding speed to that observed in the laboratory, Fig 5. A similar trend was observed on two different days.

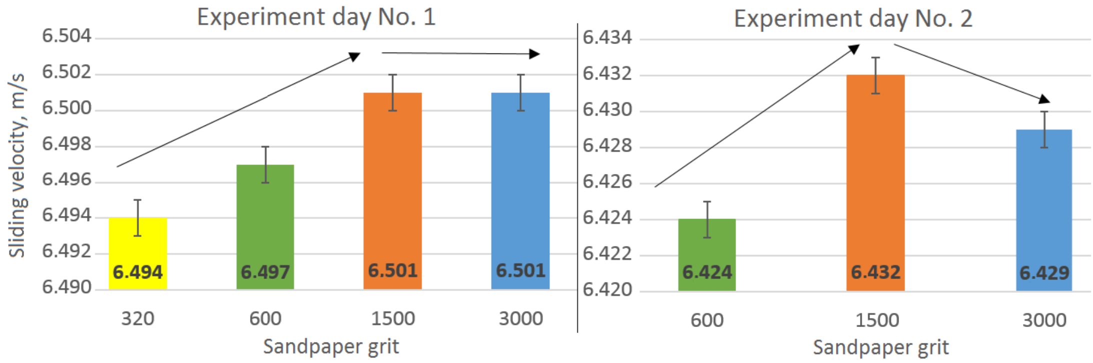



**Fig. 5. Influence of surface roughness on the sliding speed on a longer ice track on 2 days.**

Other experiments have shown the influence of weight on the metal sliders. The effect of roughness appeared to play a smaller role at increased loading conditions. These test results were from a different testing day, allowing the effect of ice temperature, surrounding temperature and air humidity to play a role on the test results. These separate factors will be continually monitored to see whether a correlation exists between the metal rail sliding speed and the external factors. A comparison will be made with the established information from laboratory experiments that show better sliding on colder ice.

The effect of weight was also investigated, and a variation in the sliding speed was found both with the applied weight, and also the location where the load was applied. For reproducibility, further testing will apply the weight in precisely the same location for all experiments.

## 2.4. Further research and practical exploitation of the results

*(Describe further research activities that are planned, describe possibilities to practically exploit results)*

For movement on ice, the measurement of sliding speed is more meaningful than the coefficient of friction. The errors in ice friction are too large causing overlap, and the surface is never assessed in sufficient detail to understand the source of inpediments to movement over ice. The methods in this project use a new surface topography measurement, a new inclined plane equipped with optical sensors for measuring speed of the metal bock. These developments have scientific relevance and practical usefulness. The measurement of block speed not only include the effect of the surface, but also factor in the aerodynamics, vibration and movement down the ice track, that collectively determine the block speed.

The optimum surface roughness has been found beyond which there are no further improvements in sliding over ice. Further work will characterize the surface over several orders of magnitude to give a complete surface characterization. This will potentially lead to an expression that includes measures of nonuniformity at different length scales that can related to the sliding speed.

As expected, a harder surface provides greater resistance to scratching, but the change in the wettability appears to have a larger influence. The preparation of other hardness samples will provide a greater understanding on the effect of wettability, and show the relative importance over other factors on the sliding speed.

Hydrophobicity has clearly shown a strong influence. Further samples needs to be made with still hydrophobicity combining both chemical and surface roughness effects. From the surface roughness, only the lotus leaf effect has been investigated, but this does not provide a deeper understanding of friction over ice.

A method for testing the sliding speed of larger metal object has been tested on an ice ramp with optical sensors. Testing in the environment shows practical testing conditions and so provides an insight into what happens outside the laboratory.

The research on ice-friction, although conducted for a long time, has not clearly shown the friction mechanisms on ice, as stated by Gagnon RE in a publication this year (Cold Regions Science and Technology, 131, 2016, 1-9). More detailed research needs to be conducted, that can show promise for understanding ice-friction more clearly from this interdisciplinary research endeavour.

Reproducibility of sliding times has required testing of three identical metal blocks each for 15 times to provide a statistically relevant sliding time. The preparation of the laboratory ice track for three days before testing and the limited capacity of the air conditioner before it freezes means that three days are needed before the ice track is ready, and then one day for testing. The preparation of the ice track and testing a multiple of samples has limited the experimental output to one day a week. A new sensor is being made to measure the environmental and ice conditions, so the same instrument can be used in both the laboratory and the environment.

Testing of large surfaces is limited to the winter months from November to March decreasing the number of tests that are available in the project. To optimize this difficulty we are looking to access to the sled training ramp as much as possible to provide the best output for the project.

Finally, this particular project does not get the benefit of research students already undertaking research on the topics of the research projects. Therefore, the output from this project looks smaller, but it is attributed to the output from part-time labour, that is more difficult to manage.

Progress has appeared slow in the start up with the project, as with any new endeavour, but the second year is providing useful output with new contributions to science. The final year will provide the best indicator of the return on investment for this project. Additional output not listed in the original program will produce a prototype of the new sensor, involve more methods for modifying the surface and additional sliding test results. The output will exceed that originally promised in terms of publications. This research activity is also reaping rewards since it has successfully achieved one of the purposes of the national research project by obtaining additional support for the continuation of the research activity into the next period. This next project will allow the research to delve deeper into the research questions for addressing the characteristics of metal surfaces that not only assist faster movement over ice, but also show how movement over ice can be made more difficult so as to improve the safety of movement over ice.

**Tasks for the 4th period**

1. Investigate how surface perturbations influence the ease of metal block sliding on ice. These surface irregularities will be investigated at three different levels of order- at the microscale, the 10-100 micron level and at the 1mm-10mm scale. The deliverables will show how the preparation of metal with a specific irregularity will increase the ease of sliding on ice. Information will be given on the measurement method to detect this irregularity before it is linked to the ease of sliding.
2. Investigate how hardness, surface irregularities and wetting influence the ease of sliding. This will produce a relationship between several surface characteristics and the ease of sliding.

3. Determine the correlation between the ease of sliding in laboratory conditions with sliding on a longer ice track. The deliverable will include the method for measuring ease of sliding on the ice track with a comparison to ease of sliding measurements in the laboratory.
4. Investigate which surface preparation conditions improve the ease of sliding on a longer ice track. The outcome of this research will be a recommendation for altering the ease of sliding on ice. This will have practical importance for improving the safety and ease of movement over ice.

### 2.5. Dissemination and outreach activities

*(Describe activities that were performed during reporting period to disseminate project results)*

The following conference presentations were made during the 3rd stage of Project 3 „ ***Modification of metal surfaces for the reduction of friction and wear***": The first two conference papers were accepted for publication.

1. Jansons E., Lungevics J., Gross K.A., Surface roughness measure that best correlates to ease of sliding, 15th International Scientific Conference Engineering for Rural Development. 25-27 May 2016, Jelgava, Latvia. Oral presentation.
2. Lungevics J., Jansons E., Rudzitis J., Gross K.A., Use of an inclined plane with additional time measurements to investigate surface slidability on ice, 12th International Conf. Mechatronic Systems & Matls. 3-8 July 2016. Bialystok, Poland. Oral presentation.
3. Lungevics J., Gross K.A., Modification of metal surfaces for achieving a lower friction and wear. Riga Technical University 57th international scientific conference, session: National Research Project "Innovative materials un intelligent technologies for safety in the environment, "IMATEH". 17 October 2016. Riga, Latvia.

**Participation at a seminar:**

1. The largest tribology meeting in the Baltic States in the Baltmatrib conference, "Hardening, Coatings, Surface Engineering and Tribology" session. 3-4 November 2016. Riga, Latvia.

**Journal publications** (attached in electronic form):

1. Jansons E., Lungevics J., Gross K.A., A surface roughness measure that best correlates to ease of sliding, Engineering for Rural Development, January 2016, pages 687– 695.

**Submitted in Journals:**

1. Lungevics J., Jansons E., Gross K.A., Rudzitis J., A measurement method for surface slidability on ice using an inclined plane equipped with motion detection sensors (submitted to *Measurement, SNIP>1*).
2. Gross K.A., Zavickis J., Pluduma L., Lungevics J., Evaluation of visual examination methods for the quality control of polished surfaces (submitted to *Measurement*, SNIP>1).

**Scientific magazine publication:**

A new method to help improve safety on ice. Slippery conditions are reproduced in the laboratory for testing the slidability of different materials on ice. Ilustrētā zinātne (in Latvian), December 2016.

**Completed Masters thesis:**

1. J. Lungevics "Evaluation methods of surfaces with a lower friction and wear", supervisors Dr.sc.ing. J. Rudzitis and Dr.sc.ing. K.A .Gross, June 2016
2. E. Jansons "Influence of surface roughness on the sliding of metal on ice", supervisors Dr.sc.ing. J. Rudzitis and Dr.sc.ing. K.A. Gross, June 2016

**Bachelor research project:**

1. K. Stiprais "Chemical modification of metals for lowering the friction", supervisor Dr.sc.ing. K.A. Gross (to be completed in June 2017).

**PhD research projects**:

1. J. Lungevics "A method for predicting tribological properties of materials used in mechanical engineering", supervisor Dr.sc.ing. J Rudzitis (to be defended in 2019)
2. Ed Jansons "Development of criterion that determine the slidability of metal on ice", supervisor Dr.sc.ing. J. Rudzitis (to be defended in 2019)

**Grant proposal**:

1. European Regional Development Fund project on basic scientific research "The quest for disclosing how surface characteristics affect slideability". Submitted June 2016. Awarded November 2016.

**Dissemination of results:**

Meetings held with other IMATEH project leaders on 11 January, 1 April, 28 June, 16 September, 27 September, 05 October, 27 October and 23 November for discussing the project tasks and achievements. Meetings every 2 weeks amongst the team members discussed the progress of the project.

**New research projects:**

An European Regional Development Fund project was awarded with the objective of increasing the research personnel and improving the ability of winning a H2020 project. This funding will start in 2017 and will dovetail from the existing project to go into more detailed characterization of surfaces. It will address the influence of vibration on sliding speed, look at microdesigned features on the surface, and study the ice as the other interface that move against solid materials.

**Time frame the Core task 1 activities of the Project 1**
***Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures***

| | 2014 | | 2015 | | | | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. To create production method of high performance concrete composites (compression strength >100MPa) for use in infrastructure and public buildings, partly replacing concrete with microfillers having local origin.** | x | x | x | x | x | | | | | | | | | |
| 1.1.1. To design high strength concrete mixes | x | x | x | x | x | | | | | | | | | |
| 1.2. To determine mechanical and physical properties. | x | x | x | x | x | | | | | | | | | |
| 1.3. Preparation method for innovative and advanced cement composite with microfillers materials for infrastructure projects and public buildings (deliverable) | | | | | x | | | | | | | | | |
| **2. To develop recommendation on increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement.** | | | x | x | x | x | x | x | x | x | | | | |
| 2.1. To assess sulphate resistance of the developed concrete mixes | | | x | x | x | x | x | x | | | | | | |
| 2.2. To determine alkali silica reaction resistance of the developed concrete mixes | | | | | | | x | x | x | x | | | | |
| 2.3. To assess carbonisation resistance of the developed concrete mixes | | | x | x | x | x | x | x | x | x | | | | |
| 2.4. To assess resistance to the impact of chloride of the developed concrete mixes | | | | | x | x | x | x | | | | | | |
| 2.5. To assess freeze resistance of the developed concrete mixes | | | x | x | x | x | x | x | x | | | | | |
| 2.6. Recommendation on increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement (deliverable) | | | | | | | | | | x | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **3. To develop methods for innovative reinforced cement composite material production for infrastructure and public buildings** | | | | | | | | | | | x | x | x | x |
| 3.1. To design mixes for glass fibre reinforced concrete composites | | | | | | | | | | | x | | | |
| 3.2. To determine mechanical and physical properties of the designed mixes | | | | | | | | | | | x | x | x | |
| 3.3. To assess alkali silica reactions by using pozzolanic additives in glass fibre reinforced concrete composites | | | | | | | | | | | | x | x | |
| 3.4. Method for innovative reinforced cement composite material production (deliverable) | | | | | | | | | | | | | | x |
| **4. Parameter optimisation of cement composite mixing process** | | | | | | | | | | | x | x | | |
| 2.1. Recommendation for parameter optimisation of cement composite mixing process (deliverable) | | | | | | | | | | | | x | | |
| **4. Publications, Scopus** | | | | | | | | | | | | | | |
| **5. Conferences** | | | | | | | | | | | | | | |
| **6. Supervision of doctoral thesis and master's thesis** | x | x | x | | | x | x | | x | x | x | | x | x |

Annex 1-B

**Time frame the Core task 2 activities of the Project 1**
***Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures***

| | **2014** | | **2015** | | | | **2016** | | | | **2017** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. To create production method for high performance asphalt concrete mixes from local low quality components.** | x | x | x | x | x | x | | | | | | | | |
| 1.1.To select raw materials, to deliver them, to assess their properties | x | x | x | x | x | x | | | | | | | | |
| 1.2. To design high performance asphalt concrete mixes by using local dolomite shiver and bitumen B20/30 | | | x | x | x | x | | | | | | | | |
| 1.3. Production method for high performance asphalt concrete mixes from low quality components (deliverable) | | | | | | x | | | | | | | | |
| **2. To develop recommendations for parameter optimisation of mixing process for asphalt concrete mixes** | | | | | x | x | x | x | x | x | | | | |
| 2.1. To design high performance asphalt concrete mixes by using local gravel shiver and bitumen B20/30 | | | | | x | x | x | x | | | | | | |
| 2.2. To design high performance asphalt concrete mixes by using local gravel and dolomite shiver and polymer-modified bitumen PMB | | | | | | | x | x | x | x | | | | |
| 2.3. Recommendation for parameter optimisation of mixing process for asphalt concrete mixes (deliverable) | | | | | | | | | | x | | | | |
| **3. To develop recommendations for transportation and incorporation of asphalt concrete mix** | | | | | | | | | | | x | x | | |
| 3.1. Recommendation for transportation and incorporation of asphalt concrete mix (deliverable) | | | | | | | | | | | | x | | |
| **4. To develop methodology for use of recycled asphalt concrete** | | | | | | | | | x | x | x | x | x | x |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.1. To select raw materials, to deliver them, to assess their properties | | | | | | | | | x | x | | | | |
| 4.2. To determine design and exploitation properties of the designed mixes | | | | | | | | | x | x | x | | | |
| 4.2.1 To restore properties of asphalt concrete mix recovered from recycled material with traditional bitumen having lower viscosity | | | | | | | | | x | x | | | | |
| 4.2.2 To restore properties of asphalt concrete mix recovered from recycled material with warm asphalt concrete production additives | | | | | | | | | | | x | x | | |
| 4.3. Methodology for use of recycled asphalt concrete (deliverable) | | | | | | | | | | | | | | x |
| 4.4. Recommendation for use of high-viscosity bitumen using warm asphalt concrete production additives | | | | | | | | | | | | | | x |
| **5. To prepare economic assessment of high performance asphalt concrete exploitation** | | | | | | | | | | | x | x | x | x |
| 5.1.To assess external factors – transport load and temperature | | | | | | | | | | | x | x | | |
| 5.2.To select forecasting model (based on results of laboratory experiments) and to determine parameters for functions of the model | | | | | | | | | | | | x | x | |
| 5.3. Economic assessment of high performance asphalt concrete exploitation (deliverable) | | | | | | | | | | | | | | 1 |
| **6. Recommendations for improvement of road technical rules** | | | | | | | | | | | | | x | x |
| **4. Publications, Scopus** | | | | | | | | | | | | | | |
| **5. Conferences** | | | | | | | | | | | | | | |
| **6. Supervision of doctoral thesis and master's thesis** | | | | | | x | x | | x | x | x | | x | x |

## Time frame the Core task 3 activities of the Project 1
### *Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures*

| | 2014 | | 2015 | | | | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. To develop method for production of ecological composite materials from textile plants and local mineral binders.** | | x | x | x | x | x | x | | | | | | | |
| 1.1. To design fibre composite materials mix | | x | x | x | | | | | | | | | | |
| 1.2. To determine mechanical and physical properties | | x | x | x | x | x | | | | | | | | |
| 1.3. Method for production of ecological composite materials from textile plants and local mineral binders (deliverable) | | | | | | | x | | | | | | | |
| **2. To develop and write guidelines for data collection system, which is suitable for heat and humidity migration control in energy-efficient buildings.** | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 2.1.To develop plan for sensor installation in real stand (in cooperation with producer) | x | x | | | | | | | | | | | | |
| 2.2. To install sensors | | x | x | | | | | | | | | | | |
| 2.3.To collect data (humidity, temperature, etc.) | | | x | x | x | x | x | x | x | x | x | x | x | x |
| 2.4. To develop model based on the collected data | | | | | | | | x | x | x | x | x | x | x |
| 2.5. Guidelines for data collection system (deliverable) | | | | | | | | | | | | | | x |
| **3. Life-cycle calculations of natural fibre composite materials** | | | | | | x | x | x | x | x | | | | |
| 3.1. To collect and process data | | | | | | x | x | x | x | x | | | | |
| 3.2. Method for life-cycle calculations of natural fibre composite materials (deliverable) | | | | | | | | | | x | | | | |
| **4. Recommendation for information about thermal properties of natural fibre composite materials to be added to LBN 002-01** | | | | | | | | | | | x | x | x | x |
| 4.1. To prepare recommendations for information about thermal properties of natural fibre composite materials to be added to LBN 002-01 (deliverable) | | | | | | | | | | | | | | x |
| **4. Publications, Scopus** | | | | | | | | | | | | | 1 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5. Conferences** | | | | | | | | | | | | | | |
| **6. Supervision of doctoral thesis and master’s thesis** | x | x | x | | | x | x | | x | x | x | | x | x |

## Time frame activities of the Project 2
### *Innovative and multifunctional composite materials for sustainable buildings*

| | **2014** | **2015** | | | | **2016** | | | | **2017** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. Experimental research on component scale specimens. Additional investigation damping and impact properties on finalised panels with vertical stiffeners** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | | | | |
| 1.1 Identification of material mechanical properties | X | X | X | | | | | | | | | | |
| 1.2. Identification of material thermal properties | X | X | X | X | X | X | | | | | | | |
| 1.3. Identification of vibration damping properties | | X | X | X | X | | | | | | | | |
| 1.4. Identification of impact properties | | | | | X | X | X | | | | | | |
| **2. Virtual modelling and optimisation by numerical methods** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | |
| 2.1 Updating of the Finite Element numerical model | X | X | X | X | X | X | X | | | | | | |
| 2.2 Optimisation of the product/process | | | | X | X | X | X | X | X | | | | |
| 2.3 Validation of numerical model with experimental results | | | | | X | X | X | X | X | X | | | |
| 2.4 Development of design methodology | | | | | | | | | X | X | X | X | |
| **3. Prototyping at laboratory scale. Development of design guidelines** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** |
| 3.1. Upgrading of the chemical coposition of foam material | X | X | X | X | X | | | | | | | | |
| 3.2. Laboratory scale prototyping | | | | X | X | X | X | X | X | X | | | |
| 3.3 Scale-up of industrial manufacturing | | | | | | | | X | X | X | X | X | X |
| **4. Dissemination** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** |

## Time frame the Core task 1 activities of the Project 3
### *Risk consideration for safe, effective and sustainable structures*

| | 2014 | | 2015 | | | | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. Develop method for assesement of bridge dynamic characteristics**. | X | X | X | X | X | X | X | X | X | X | | | | |
| 1.1.Studie about vehicle weight and speed impact on the bridge structure dynamic characteristics. | | | X | X | X | X | X | X | X | X | | | | |
| 1.2.Develop a method to asess heavy and very heavy vehicle dynamic effects on the bridge structure. | | | | | | | X | X | X | X | | | | |
| 1.3.Determine and justify limit values of the bridge dynamic characteristics based on the developed methods for assesment of bridge dynamic characteristics. | | | | | | | | | | | X | X | X | X |
| **2. Analyse traffic load influence on bridge structure using theoretical probability distribution models.** | X | X | X | X | X | X | X | X | X | X | | | | |
| 2.1. Develop a method for external action correlation forecasting. | X | X | X | X | X | X | X | | | | | | | |
| 2.2.Study about properties range of materials used in bridge construction. | X | X | X | X | X | X | X | | | | | | | |
| 2.3.Develop theoretical probabilistic distribution models for in construction used materials property variation. | | | | X | X | X | X | X | X | | | | | |
| 2.4.Analysis about ageing process influence on the construction material properties and its variation for existing structures. | | | X | X | X | X | X | X | X | X | | | | |
| 2.5.Develop a probabilistic model for building accuracy and description of other “human factor” induced structural properties variation and their impact on load–carrying capacity. | | | | | | | X | X | X | X | | | | |
| 2.6.Comparison of resulting action and material resistance probabilistic modes using limit state method defined in Eurocode, it will allow to determine existing bridge | | | | | | | | | X | X | X | X | X | X |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| safety and robustness (with appropriate safety factors). | | | | | | | | | | | | | | |
| **3. Publications, Scopus** | | 1 | | | | 3 | | | | | | | | 2 |
| **4. Conferences** | | 1 | | | | 3 | | | | 2 | | | | 2 |
| **5.PhD and Master theses** | X | X | X | | | X | X | | X | X | X | | X | X |

**Time frame the Core task 2 activities of the Project 3**
***Risk consideration for safe, effective and sustainable structures***

| | 2014 | | 2015 | | | | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. Develop of method for localization of damage site and evaluation of damage size in various structural elements by using appropriate signal processing techniques experimentally measured dynamic parameter changes.** | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 1.1. identification of damage in beam-type structural elements | X | X | X | X | X | | | | | | | | | |
| 1.2. identification of damage in plate-type structural elements | | | | X | X | X | X | X | X | | | | | |
| 1.3. identification damage in sandwich-type structural elements | | | | | | | X | X | X | X | X | X | | |
| 1.4. methodology for exploitation damage identification in various structural elements | | | | | | | | | | | X | X | X | X |
| **2. Development of new technologies for monitoring and diagnostics of aviation engines and various elements of rotary machines.** | | | X | X | X | X | X | X | X | X | X | X | | |
| 2.1. investigation of aviation structural element health monitoring and diagnostics | | | X | X | X | | | | | | | | | |
| 2.2. experimental investigation of dynamics parameters of aviation structural elements | | | | X | X | X | X | X | | | | | | |
| 2.3. exploitation damage identification in aviation structural elements | | | | | | X | X | X | X | X | | | | |
| 2.4. recommendation for health monitoring and diagnostics of aviation structural elements | | | | | | | | | | X | X | X | | |
| **3. Development of method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements.** | | | | | | | X | X | X | X | X | X | X | X |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.1. investigation of methods, based on analysis of loss of pre-stress in pre-stressed steel-reinforced concrete structural elements | | | | | | | X | X | X | X | | | | |
| 3.2. numerical modelling and simulations of pre-stressed steel-reinforced concrete structural elements | | | | | | | | | X | X | X | X | X | |
| 3.3. experimental estimation of dynamic parameters of pre-stressed steel-reinforced concrete | | | | | | | | | | | X | X | X | |
| 3.4. method for evaluation of pre-stress loss in prestressed steel-reinforced concrete structural elements | | | | | | | | | | | | X | X | X |
| **4. Publications, Scopus** | | | | | | 2 | 1 | 1 | | | | 1 | 1 | |
| **5. Conferences** | | | | | | | | | 1 | | | | 1 | |
| **6. Supervision of doctoral thesis and master's thesis** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** |

Annex 3-C

**Time frame the Core task 3 activities of the Project 3**
***Risk consideration for safe, effective and sustainable structures***

| | **2014** | | **2015** | | | | **2016** | | | | **2017** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| **1. Development of design procedure for load-bearing elements from cross-laminated timber** | x | x | x | x | x | x | x | x | x | x | | | | |
| 1.1. Data generalization for development of design procedure for load-bearing elements from cross-laminated timber | x | x | x | | | | | | | | | | | |
| 1.2. Development of design procedure for load-bearing elements from cross-laminated timber | | | x | x | x | x | x | x | | | | | | |
| 1.3. Experimental testing of design procedure for load-bearing elements from cross-laminated timber | | | | x | x | x | x | x | x | x | | | | |
| **2. Topology optimization for structure from cross-laminated timber and evaluation of it rational, from the point of view of it materials expenditure, parameters** | | | | | | | x | x | x | x | x | x | x | x |
| 2.1. Model of behaviour for structure from cross-laminated timber | | | | | | | x | x | x | x | | | | |
| 2.2. Development of optimization algoritme for structure from cross-laminated timber | | | | | | | x | x | x | x | x | x | x | x |
| 2.3. Evaluation of it rational parameters for structure from cross-laminated timber | | | | | | | x | x | x | x | x | x | x | x |
| **3. Development of load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flecture** | | | | | | | x | x | x | x | x | x | x | x |
| 3.1. Development of Numerical model of the structure | | | | | | | x | x | x | x | x | x | x | x |
| 3.2. Development of physical model of the structure | | | | | | | | | | | x | x | x | x |
| **4. Conferences, papers** | | 1 | 2 | | | | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5. Supervision of doctoral and masters thesis** | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| **6. Publications, Scopus** | | | | | | | | | | | | | | |

Appendix 4-A

## Time schedule for project 4.
## *Layered wooden composite with rational structure and increased specific bending strength*

| | 2014 | | 2015 | | | | 2016 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. Methodology work-out for determination of bending strength and conceptual design of plates with cell type hollow ribs** | x | x | x | x | x | x | x | X | | | | | | |
| 1.1. work-out of calculation methodology | x | x | x | x | x | x | x | X | | | | | | |
| 1.2. determination of specimens' mechanical properties | | | | x | x | x | X | | | | | | | |
| 1.2.1 Developement of shear Resistance determination methodology for glued joint joint between plywood surface and edge. | | | | x | x | X | | | | | | | | |
| 1.2.2 Determination of deformability and strength of plates in bending | | | | | x | x | X | | | | | | | |
| **2. Methodology work-out for determination of specific bending strength for plates with cell type hollow ribs and determination of values for the most typical geometrical parameters.** | | | | | x | x | x | x | X | | | | | |
| 2.1. work-out of calculation methodology | | | | | x | x | x | X | | | | | | |
| 2.2. determination of specific bearing capacity | | | | | | | x | x | X | | | | | |
| **3. Work-out plate models with most typical types of hollow cell type ribs and experimental investigations to get specific strength in bending, consumption of materials, energy consumption and costs.** | | | | x | x | x | x | x | x | x | x | X | | |
| **4. Recommendations work out for design of geometrical parameters of plates with hollow cell type ribs.** | | | | | | | | | x | x | x | x | X | |
| **5. Recommendations' work out manufacturing and 'work in' technology principles and produce plates' demonstration models.** | | | | | | | x | x | x | x | x | x | x | X |
| **6. Publications, Scopus** | | | | | | | | | | | | | 1 | |
| **7. Conferences** | | | | | | 1 | | | 1 | | | | 1 | |
| **8. Supervision of doctoral thesis and master's thesis** | x | x | x | | | x | x | | x | x | x | | x | x |

Annex 5-A

## Time frame of the Project 5

***Material mechanical micro - nano- scaled features and their impact on human safety***

| | **2014** | | **2015** | | | | **2016** | | | | **2017** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **III** | **IV** | **I** | **II** | **III** | **IV** | **I** | **II** | **II** | **IV** | **I** | **II** | **III** | **IV** |
| **1. Development of research methods for early diagnostics of destruction of surface of polymer composite materials** | **X** | **X** | **X** | **X** | **X** | **X** | | | | | | | | |
| 1.1. a method to study the influence of aquatic microorganisms on early destruction of materials | X | X | X | X | X | X | | | | | | | | |
| 1.2. a method to study visual recognition of early destruction using destruction-induced staining | X | X | X | X | X | X | | | | | | | | |
| **2. Development of methods for early diagnostics of destruction of polymer composite materials** | | | | | | | **X** | **X** | **X** | **X** | | | | |
| 2.1. the method for early diagnostics of destruction using *in situ* electron emission spectroscopy | | | | | | | X | X | X | X | | | | |
| 2.2. the method for early diagnostics of destruction, based on the influence of aquatic microorganisms | | | | | | | X | X | X | X | | | | |
| 2.3. the method of visual recognition of early destruction using destruction-induced staining | | | | | | | X | X | X | X | | | | |
| **3. Application of methods for early diagnostics of destruction of surface of polymer composite materials in enterprises** | | | | | | | | | | | **X** | **X** | **X** | **X** |
| 3.1. Application of diagnostic methods in machinery manufacturing and constructions (development of recommendations) | | | | | | | | | | | X | X | X | X |
| 3.2. Application of diagnostic methods in manufacturing of polymeric pipes for drinking water (development of recommendations) | | | | | | | | | | | X | X | X | X |
| **4. Number of scientific publications** | | | | | | **1** | | | | **2** | | | | **2** |
| 4.1. Scopus | | | | | | | | | | 1 | | | | 1 |
| 4.2. Proceedings of conferences | | | | | | 1 | | | | 1 | | | | 1 |
| **5. Conferences** | | | | | | **1** | | | | **1** | | | | **1** |
| **6. Development of doctoral and master theses** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** |
| **7. Registered Latvian patent** | | | | | | | | | | | | | | **1** |

# Time frame of the Project 6
## *Processing of metal surfaces to lower friction and wear*

| | **2014** | | **2015** | | | | **2016** | | | | **2017** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | III | IV | I | II | III | IV | I | II | III | IV | I | II | III | IV |
| **1. To characterize the metal surface and determine the best test methods** | X | X | X | X | X | X | | | | | | | | |
| 1.1. Develop a method for the preparation of the metal surface of the samples - cutting, rough polishing, fine polishing | X | X | | X | X | | | | | | | | | |
| 1.2. Develop a method for full sample surface analysis (optical microscopy, atomic force microscopy, scanning electron microscopy, profilometry) | | | X | X | X | X | | | | | | | | |
| **2. To develop a test apparatus to simulates an ice track and a climate simulator to test metal surface friction and wear reduction** | X | X | X | X | X | X | | | | | | | | |
| 2.1. Develop testing apparatus (simulation of bobsled track) and software to detect movement of the sample at a certain angle | X | X | | | | | | | | | | | | |
| 2.2. Develop a climate simulator which can be adjusted to work at low temperatures | | X | X | X | X | | | | | | | | | |
| 2.3. Develop a method for measuring slip under laboratory conditions | X | X | X | X | X | 1 | | | | | | | | |
| **3. To modify the metal surface, and calculate the new slip determined by any modifications made** | | | | | X | X | X | X | X | | X | X | | |
| 3.1. Develop a method for metal surface modification to increase slip (surface roughness, hardness, chemical modification) | | | | | X | X | X | X | X | | X | | | |
| 3.2. Optimise metal surface for increased gliding on ice (report) | | | | | | | | | | | X | 1 | | |
| **4. Determine the relationship of gliding between the metal surfaces and ice (report)** | | | | | | | | | | | X | X | 1 | |
| **5. To develop methods for the optimisation for the gliding surface with real track conditions** | | | | | | X | X | | X | | X | X | X | X |
| 5.1. Develop a method for determining the slip under real track conditions, in comparison with laboratory equipment (report) | | | | | | X | X | | | | X | 1 | | |
| 5.2. Develop a method for surface modification of a larger metal sample | | | | | | | | | X | | X | X | | |
| 5.3. Make a modification recommendation for the metal surface to improve gliding in track | | | | | | | | | | | | | X | 1 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| conditions (report) | | | | | | | | | | | | | | |
| **6. Publications** | | | | | | 1 | | | | | | | | 1 |
| **7. Conference** | | | | | 1 | | | | 1 | | | | 1 | |
| **8. Science publications** | | | | | | | | | 1 | | | | | |
| **9. Seminars** | | | | | | | | | | | | | | 1 |
| **10.Master's thesis** | X | X | X | X | X | X | X | X | X | | X | X | X | X |
| **11. Patent results in Latvia** | | | | | | | | | | | | | | 1 |
| **12. New methods for exploitation** | | | | | | | | | | | | | | 1 |