Scientific report for NRP Period 2014 - 2017

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 01.11.2014 till 31.12.2017.

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, ERAF and others 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 01.11.2014. till 31.12.2017. 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 84 full length scientific papers were accepted during the NRP Period (performance indicators for Project 1 are 22 full length papers, for Project 2 are 7 papers, for Project 3 − 31 papers, for Project 4 – 13 full length paper, performance indicators for Project 5 are 5 full length papers, for Project 6 – 6 full length paper). **All published papers in full length are included in report ANNEXES (titles and links of papers are given in the Section 2 of this Report).**

Participants of NRP IMATEH took part in **76 international conferences** with oral or poster presentations and presented newest achievements of their research.

33 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 55 master's thesis and 46 bachelor's thesis have been defended in the Period 3.

As planned, **doctoral researchers are involved** in the NRP IMATEH.

The following doctoral theses were defended:

1. 18.06.2015. U. Lencis defended the doctoral thesis „ Methodology for use of ultra sound impulse method in assessment of construction strength" (supervisor A. Korjakins) and obtained PhD in engineering.
2. 10.04.2015. A. Sprince defended the doctoral thesis "Methodology for determination of long-term properties and crack development research in extra fine aggregate cement composites" (supervisor A. Korjakins) and obtained PhD in engineering.
3. 6.04.2016. 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.

The following doctoral theses were submitted for defence:

1. J. Tihonovs „Aphalt concrete mixes from the local mineral material with high exploitation properties" supervisor J. Smirnovs, V. Haritonovs, planned to defend in 2018
2. M. Sinka „Natural fibre insulation materials", supervisor G. Shachmenko, planned to defend in 2018.
3. 07.09.2017. Organized seminar in framework of Institute of Structural engineering and reconstruction with successful pre defence of G. Frolovs's doctoral thesis "Design principles of rational structure of sandwich plates with cell type hollow ribs" (participants 15, protocol Nr. 1/2017.).
4. O. Bulderberga. Polymer composite with damage indication ability: development and determination of properties. Supervisor A. Aņiskevičs. The pre-defence took place on November 17, 2017 at Institute of Material Mechanics of University of Latvia (the defence is planned in 2018).
5. M.Kirpluks "No atjaunojamām izejvielām iegūtu poliuretāna putuplasta un nano izmēra dabas izcelsmes pildvielu kompozītu īpašības", supervisor U.Cabulis (the defence is planned in 2018).
6. A. Fridrihsone: „Dzīves cikla analīze poliuretānu materiāliem, kas iegūti no atjaunojamām izejvielām". supervisor U.Cabulis, (the defence is planned in 2018).

The following doctoral theses are developed:

1. J.Justs „Ultra high performance concrete with diminished autogenous shrinkage technology", supervisor D. Bajare, planned to defend in 2018
2. N.Toropovs „Fire resistance of high performance concrete", supervisor G. Shachmenko, planned to defend in 2018
3. A.Kukule "Kukule "Behaviour of plywood ribs in various conditions of moisture" supervisor J.Sliseris, planned to defend in 2018
4. J.Lungevičs, A method for predicting tribological properties of materials used in mechanical engineering. Supervisor: J Rudzītis, KA Gross, planned to defend in 2019
5. E Jansons, Development of criterion that determine the slidability of metal on ice. Supervisor: J Rudzītis, KA Gross, planned to defend in 2019
6. I.Paeglite "Impact of moving load on the dynamic properties of bridges", supervisor professor, Dr.sc.ing. J. Smirnovs, planned to defend in 2018;
7. A.Freimanis „Risk assessment of secure, efficient and sustainable bridge constructions", supervisor professor Dr.sc.ing. A. Paeglitis, planned to defend in 2018;
8. A.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. 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.

It was planned to defend the above-mentioned doctoral theses during the implementation of the National Research Programme IMATEH. However, due to insufficient funding, some of the doctoral students have decided to pursue their scientific activities at foreign universities (e.g. J. Justs and N. Toropovs signed a two-year contract with the EMPA, Swiss Federal Laboratories for Materials Science and Technology) or to increase their professional skills by accepting job offers in the construction sector. To a certain extent it can be considered a successful outcome leading to successful career. The causes for termination of doctoral studies in the RTU were attributed to insufficient funding and moving to better paid jobs. The implementers of National Research Programme IMATEH and scientific supervisors could not influence their decisions.

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

Patents which are submitted:

1. M. Shinka, D. Bajare, G. Shachmenko, A. Korjakins, A. Shishkins, "Magnesium Phosphate Cement and Bio-based Aggregate Rapid Curing Construction Block and Its Production Method " (P-17-86, submitted on 13.12.2017).
2. M. Shinka, D. Bajare, G. Shachmenko, A. Korjakins, A. Shishkins, "Bio-fiber and Magnesium Oxychloride Cement Multi-layer Construction Panel and Its Production Method" (P-17-77, submitted on 28.11.2017).
3. V. Haritonov, J.Tihonovs, R. Īzaks, A. Šiškins, Self healing asphalt concrete with sound damping properties (submitted on 21.12.2017).
4. J.Lungevics, E.Jansons, K.A.Gross, K.Stiprais, Sliding property determination device and method (P-17-25, submitted on 21.04.2017).
5. J. Dehtjars, S. Kronberga, M. Romanova, Ē. Dombrovskis, I. Kozaks, Fabrication method of a nanostructured composite (pieteikums iesniegts 20.12.2017.)

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.
4. Bajare D. "Innovative materials and smart tehnologies fro environmental safety, IMATEH" Riga Technical University "Safety and security", 4 issue, 2015, pp. 10-12.
5. Paeglītis A. Timber bridges in Latvia – history and perspective). // Būvinženieris, December 2015, Nr.47, 2015, 156-163.lpp. ISSN 1691-9262.
6. Paeglītis A. (2015) "Saspriegta stīgbetona siju tilta nestspējas izpēte"// Būvinženieris, February 2015, Nr.42, 102-108.lpp. ISSN 1691-9262

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"), one M-Eranet project and others. 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**.
7. 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**
8. RTU Research project 2016/2017, RTU Platform of Reseach and Innovation "Hight performance cement composites for energu systems transformation substation, AS Energofirma „JAUDA", 2.01.2017-31.012.2017, **Euro 186290.00**
9. Project Nr. ZP-2016/29. (RTU ID 2335), "Activation of mineral fillers by collision milling in disintegrator for cement composites", **Euro 3000.00**

All planned deliverables are submitted and included in Annexes.

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).
7. "Method to determine the influence of vehicle's mass and spead to the dynamic properties of constructions", approbated in enterprise Inženierbūve Ltd, confirmed from 16.09.2016.
8. "The method of theoretical probability distribution models for bridges for approbation in Latvian conditions", approbated in enterprise Inženierbūve Ltd, confirmed from 11.11.2016.
9. "Determination of threshold values for bridge dynamic characteristics", approbated in enterprise Inženierbūve Ltd, confirmed from 16.03.2017.

The 14 new technologies, methods, prototypes, products or services that have been submitted for implementation (signed contracts on transfer of intellectual property).

Representatives of the project participated in 34 seminars on the development and implementation of the National Research Programme IMATEH.

In 2015, two scientific conferences were organised - IMST "Innovative Materials, Structures and Technologies", on 30.09.-02.10.2015, http://imst.rtu.lv/node/42

In 2017, an international conference was organised - IMST "Innovative Materials, Structures and Technologies" (27.09.-29.09.2017), http://imst.rtu.lv/node/46

Technical and scientific conferences for students were organized in 2015, 2016, 2017 (on 28.04.2015, 27.04.2016 and 27-29.04.2017), http://imateh.rtu.lv/konferences/)

During the 56th and 57th International Scientific Conferences of the Riga Technical University (on 14-16.10.2015, 14.-18.10.2016 and 12-15.10.2017) the participants (Latvian and foreign scientists, students and representatives of the industry, as well as representatives from the scientific commission) were informed about the achievements of the project and the obtained scientific results.

The project achievements and obtained scientific results were also reported at the Scientific and Technical Conference of the Latvian Concrete Association on 10.11.2016. Among the conference participants were students and representatives of the Latvian industry, as well as scientific personnel from the RTU and the Latvia University of Agriculture.

In order to promote the program among students, on April 16, 2015, April 13, 2016 and April 20, 2017, the Concrete Olympiad (the 1st stage of the concrete preparation competition) was organized, where the teams of 3 people prepared concrete samples. After 28 days the samples were tested for their compressive strength in order to determine the winning team who made the concrete

with the highest compressive strength. The aim of the Concrete Competition is to promote putting knowledge into practice and to encourage students developing their technical creativity. 2nd stage of the Concrete Competition took place after four weeks, when the compressive strength of the concrete samples made by the student teams was tested in order to determine the winning team.

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

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 **1 197 000** in the NRM Period. (01.11.2014 - 31.12.2017) as well as agreements for realization of 9 scientific projects corresponding to the NRP objectives with total income **Euro 3 215 446** were signed during period.

1.9. Results of the programme

	Results					
	Planned	**Achieved**				
		year				
	2014.–2017.	**2014**	**2015**	**2016**	**2017**	**Total in period**
Scientific performance indicators						
1. Scientific publications:	**50**	**2**	**23**	**23**	**36**	**84**
number of original scientific articles (*SCOPUS*)(SNIP>1)	17	0	6	12	15	33
number of original scientific articles enclosed in magazines of the database *ERIH (A and B)* or in proceeding of conference articles	33	2	16	11	21	50
number of reviewed scientific monographs	0	0	1	0	0	1
2. In the framework of the programme:	**51**	**6**	**42**	**32**	**26**	**106**
number of defended doctoral thesis	10	0	2	1	2	5
number of defended master's thesis	41	4	19	19	13	55
number of defended bachelors'	0	2	21	12	11	46
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:	**88**	**6**	**52**	**52**	**51**	**161**
conferences	35	1	27	26	22	76
seminars	20	1	11	12	10	34
organized seminars	20	2	10	8	10	30
popular-science publications	8	1	2	3	4	10
exhibitions	2	1	1	2	3	7
Concrete contests	3	0	1	1	2	4
2. Press releases	**138**	**43**	**30**	**33**	**43**	**149**
Economic performance indicators						

1. Amount of private funding attracted to the scientific institution in the framework of the programme, including:	**540000**	**388496**	**639799**	**49322**	**119383**	**1197000**
1.1. co-funding from the private sector to implement the projects of the programme	295000	40670	208402	41250	115933	406255
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	0
1.3. income from contractual jobs that are based on results and experience acquired in the framework of the programme	245000	347826	431397	8072	3450	790745
2. Number of applied for, registered, and valid patents or plant varieties in the framework of the programme:	**540000**	**388496**	**639799**	**49322**	**119383**	**1197000**
in the territory of Latvia	**7**	**1**	**1**	**0**	**5**	**7**
abroad	7	1	1	0	5	7
3. Number of new technologies, methods, prototypes or services that have been elaborated in the framework of the programme and approbated in enterprises	0	0	0	0	0	0
4. Number of new technologies, methods, prototypes, products or services that have been submitted for implementation (signed contracts on transfer of intellectual property)	**19**	**1**	**0**	**6**	**3**	**10**
5. Signed agreements for realization of scientific projects corresponding to the NRP objectives (total amount, Euro)	**8**	**1**	**0**	**8**	**4**	**13**

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

The planned targets of the NRP IMATEH were fully achieved. The planned tasks are completed and the main results obtained.

It was planned to defend the 10 doctoral theses during the implementation of the National Research Programme IMATEH. However, due to insufficient funding, some of the doctoral students have decided to pursue their scientific activities at foreign universities (e.g. J. Justs and N. Toropovs signed a two-year contract with the EMPA, Swiss Federal Laboratories for Materials Science and Technology) or to increase their professional skills by accepting job offers in the construction sector. To a certain extent it can be considered a successful outcome leading to successful career. The causes for termination of doctoral studies in the RTU were attributed to insufficient funding and moving to better paid jobs. The implementers of National Research Programme IMATEH and scientific supervisors could not influence their decisions.

A number of master's theses supervised and defended in the framework of IMATEH correspond to the planned. In the same time the number of students decreased due to economic and

demographic factors, as well as due to high proportion of students who start their career in the industry-related professions during their studies and do not continue or complete their master's studies.

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. Sliseris J., Andrä H., Kabel M., Wirjadi O., Dix B., Plinke B., Estimation of fiber orientation and fiber bundles of MDF, Materials and Structures/Materiaux Et Constructions, vol. 49 (10), 2016

https://www.scopus.com/record/display.uri?eid=2-s2.0-84951917178&origin=resultslist&sort=plf-f&src=s&sid=28dc041dbae47f52964087758063be4d&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=7&citeCnt=1&searchTerm=

2. Sliseris J., Andrä H., Kabel M., Dix B., Plinke B. Virtual characterization of MDF fiber network, European Journal of Wood and Wood Products, vol. 75 (3), 2017

https://www.scopus.com/record/display.uri?eid=2-s2.0-84976318982&origin=resultslist&sort=plf-f&src=s&sid=28dc041dbae47f52964087758063be4d&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=3&citeCnt=1&searchTerm=

3. Janeliukstis R., Rucevskis S., Wesolowski M., Chate A., Experimental structural damage localization in beam structure using spatial continuous wavelet transform and mode shape curvature methods, Measurement: Journal of the International Measurement Confederation, vol. 102, 2017, pp. 253-270

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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

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Programme IMATEH members have participated in the following conferences:

1. 2nd International Conference on Innovative Materials, Structures and Technologies, IMST 2015; Riga; Latvia; 30 September 2015 through 2 October 2015
2. 1st International Conference on Bio-based Building Materials (ICBBM 2015) Clermont-Ferrand, France 22 – 24 June 2015
3. 2015 10th International Scientific Practical Conference on Environment. Technology. Resources; Rezekne; Latvia; 18 June 2015 through 20 June
4. 24th International Baltic Conference on Engineering Materials and Tribology, BALTMATTRIB and IFHTSE 2015; Tallinn; Estonia; 5 November 2015 through 6 November 2015
5. Materials, Systems and Structures in Civil Engineering – 19 - 22.08.2016, Copenhagen, Denmark
6. 18th International Conference on Concrete, Structural and Geotechnical Engineering, 25.-26. 01. 2016, Istanbul, Turkey
7. 12th International Conference Modern Building Materials, Structures and Techniques, MBMST 2016; Vilnius; Lithuania; 26 May 2016 through 27 May 2016
8. 25th International Baltic Conference of Engineering Materials and Tribology – BALTMATTRIB; Riga; Latvia; 3 November 2016 through 4 November 2016
9. Riga Technical University, 57th International Scientific Conference, Riga, Latvia, 14-18 October 2016
10. Transport Research Arena Conference -TRA 2016, 18. -21.04.2016, Warsaw, Poland
11. Latvijas Betona savienības XXV zinātniski tehniskā konference, Rīga, 2016. gada 10. novembrī.
12. 6th Eurasphalt and Eurobitume Congress, Prague, Czech Republic, 1.06. – 3.06.2016.
13. 3rd International Conference „Innovative Materials, Structures and Technologies" IMST 2017, Riga, Latvia, 27. 09.-29. 09. 2017
14. 2nd Intenational Conference of Bio-based Building Materials and First International Conference on ECOlogical valorisation of GRAnular and Fibrous materials), 21.-23.06.17. Clermont-Ferrand, France
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30. 2nd International Conference „Innovative materials, Structures and Technologies" (IMST 2015, 30.09.15. – 02.10.15, Rīga, Latvia) ar ziņojumu Vilguts A., Serdjuks D., Goremikins V. "Design Methods for Load-bearing Elements from Cross-Laminated Timber".
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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
	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. 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.

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.*

Task of Project period 1:	To develop a formulation of high performance cement composites (compressive strength > 100 Mpa) from local raw materials for infrastructure projects and public buildings.
Task of Project period 2:	To test durability of high performance cement composites (compressive strength > 100 Mpa) from local raw materials for infrastructure and public buildings.
Task of Project period 3:	To develop methods for increase of the corrosion and freeze resistance properties for the concrete produced from the Latvian cement.
Task of Project period 4:	To development preparation method for innovative and reinforced cement composite materials for infrastructure projects and public buildings.

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.*

Task of Project period 1:	To develop a formulation for economical, organic, and durable bituminous composites using lower quality local mineral materials.
Task of Project period 2:	To develop a formulation for bituminous composites of high viscosity using lower quality local mineral materials.
Task of Project period 3:	To develop a formulation of the high performance bitumen composites using reclaimed asphalt pavement (RAP) and to continue developing bitumen composites from lower quality local aggregates.
Task of Project period 4:	To develop methodology for the use of recycled asphalt; to develop economic assessment of the use of high performance bitumen composites.

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.*

Task of Project period 1:	To develop a formulation for economical, organic, and durable bituminous composites using lower quality local mineral materials.
Task of Project period 2:	To develop a formulation for bituminous composites of high viscosity using lower quality local mineral materials.
Task of Project period 3:	To develop a formulation of the high performance bitumen composites using reclaimed asphalt pavement (RAP) and to continue developing bitumen composites from lower quality local aggregates.
Task of Project period 4:	To develop methodology for the use of recycled asphalt; to develop economic assessment of the use of high performance bitumen composites.

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

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. The planned tasks are completed and the main results obtained.

It was planned to defend the four doctoral theses during the implementation of the National Research Programme IMATEH. However, due to insufficient funding, some of the doctoral students have decided to pursue their scientific activities at foreign universities (e.g. J. Justs and N. Toropovs signed a two-year contract with the EMPA, Swiss Federal Laboratories for Materials Science and Technology) or to increase their professional skills by accepting job offers in the construction sector. To a certain extent it can be considered a successful outcome leading to successful career. The causes for termination of doctoral studies in the RTU were attributed to insufficient funding and moving to better paid jobs. The implementers of National Research Programme IMATEH and scientific supervisors could not influence their decisions.

A number of master's theses supervised and defended in the framework of Project No. 1 is slightly smaller than planned as the number of students decreased due to economic and demographic factors, as well as due to high proportion of students who start their career in the industry-related professions during their studies and do not continue or complete their master's studies. However, 20 bachelor thesis are related to NRP IMATEH 1 Project tasks.

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 reporting period 4 are fully achieved.

Description of scientific results achieved during reporting period 4:

Tasks for Project period 4	Key Results for Project period 4
To development preparation method for innovative and reinforced cement composite materials for infrastructure projects and public buildings.	***Method for the production of innovative, reinforced cement composite materials; 1 scientific article; 1 patent application***

Traditionally, steel reinforcements are used to improve the tensile strength and bending strength of concrete, and reinforced concrete structures are made. The manufacture of such structures is a labor-intensive process that is subject to the risk of corrosion of the reinforcement and the production of steel is associated with increased CO2 emissions (1.25-3.8 t of CO2 on t of steel)1. Dispersed reinforcement in concrete structures is becoming increasingly popular, with randomly oriented short fibers that can be made of both steel and minerals (fiberglass) or organic (polypropylene) materials. This approach allows improving tensile strength of the concrete and also reduces possible cracking during the curing process under stress and in aggressive environments, while in the long term the corrosion of individual elements significantly reduces the reduction of the momentary strength of the structure. The widest use of dispersed reinforcement of concrete is related to its use in the construction of floor structures, which have large continuous areas and a high potential for appearence of cracks. Dispersed reinforcement in concrete structures is also becoming increasingly popular in the production of bearing structures (beams, etc.).

During the reporting period experimental studies have been carried out on the innovative use of fiberglass as dispersed and oriented reinforcement in cement composites. The glass fibers used in the study were supplied by the JSC "Valmieras stikla šķiedra". Two types of fiberglass (E and K type fiberglass) were used with the main difference in their chemical composition. The chemical composition of E type fiberglass - SiO2 52.3%, Al2O3 14.1%, CaO + MgO 23.4%, Fe2O3 <0.37%, Na2O + K2O <0.9%, B2O3 <8.5%, F2 <0.05%, ZrO2 <0.1%, SO3 <0.15 %, TiO2 <0.05%, the chemical composition of K type fiberglass - SiO2 76%, Al2O3 2.8%, Na2O 21%, Fe2O3 <0.1%, Na2O + K2O <22%. The diameter of the fibers is 6-11 μm.

[1] https://www.globalccsinstitute.com/insights/authors/dennisvanpuyvelde/2013/08/23/ccs-iron-and-steel-production

Figure 1.1 Fiberglass bundles made of fiberglass siftings; disperse reinforcements and specimens made with bundle reinforcement in the stretched zone after the bending strength testing.

Disperse fibers and bundles made from glass production residues were used in the cement composites (Figure 1.1). The added fiber constitutes 1% of the cement composition mass.

Using glass-based materials (reinforcements) in concrete composites, it is necessary to take into account possible alkali-silica reactions that can occur in the concrete structure between the cement stone and the active SiO2 in the glass. Active SiO2 is also found in natural and widespread concrete fillers (intrinsic, volcanic filler), and the problem of these reactions is rapidly growing problem for the concrete industry. As a result of the reaction, the chemical modification of the glass particles occurs, and the final products can cause cracks in the concrete or even lead to concrete delamination. In order to evaluate the influence of fiberglass on cement composites, a series of experiments were carried out to reduce the intensity of reactions for various micro-fillers - microsilica (SF), metakaolin (M), E and K glass microfillers, and recommendations were provided for minimizing these reactions.

Several series of samples were prepared during the research:

1. Reference cement composite compositions with 4 types of micro-fillers to replace 10% of cement (5 compositions in total).
2. Cement composites with disperse K-type fiberglass reinforcement and various micro-fillers (5 compositions).
3. Cement composites with disperse E-type fiberglass reinforcement and various micro-fillers (5 compositions).
4. Cement composites with oriented E-type fibeglass fiber bundle reinforcement and various micro-fillers (5 compositions).
5. Cement composites with oriented E-type fibeglass fiber bundle reinforcement and different micro-fillers (5 compositions).

Mechanical properties, bending strength and compressive strength of the specimens were tested at 7, 28 and 180 days of hardening under standard conditions (Figures 1.2 and 1.3). In addition, the intensity of alkali-silica reactions for cement composites with various micro-fillers was determined for the specimen series 1, 2 and 3 (Figure 1.4).

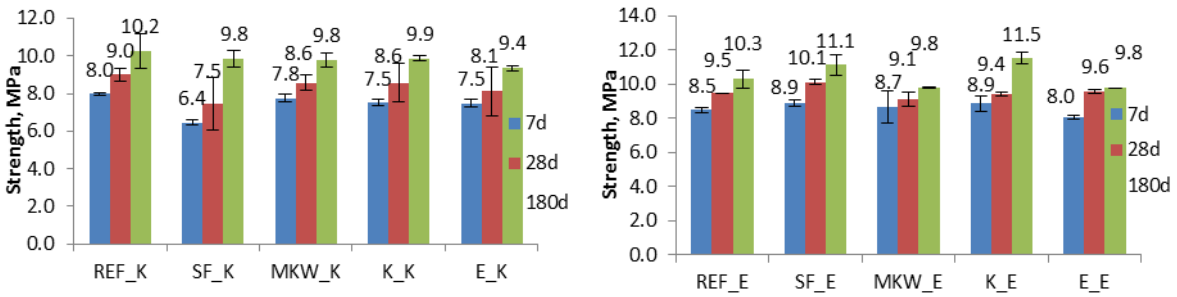

Figure 1.2 Bending strength for cement composites with different micro-fillers and dispersed K fiber reinforcement (index K) and E fiber reinforcement (index E).

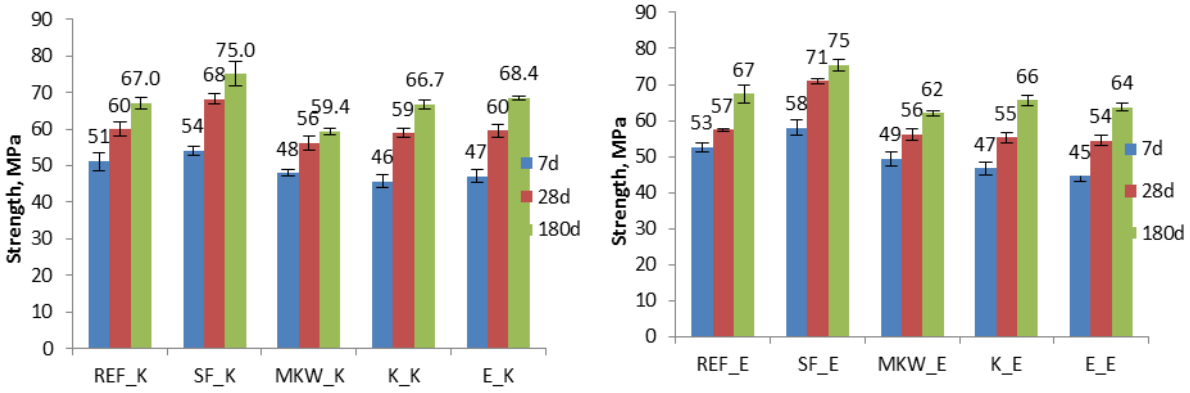

Figure 1.3 Compressive strength for cement composites with different micro-fillers and with dispersed K fiber reinforcement (index K) and E fiber reinforcement (index E).

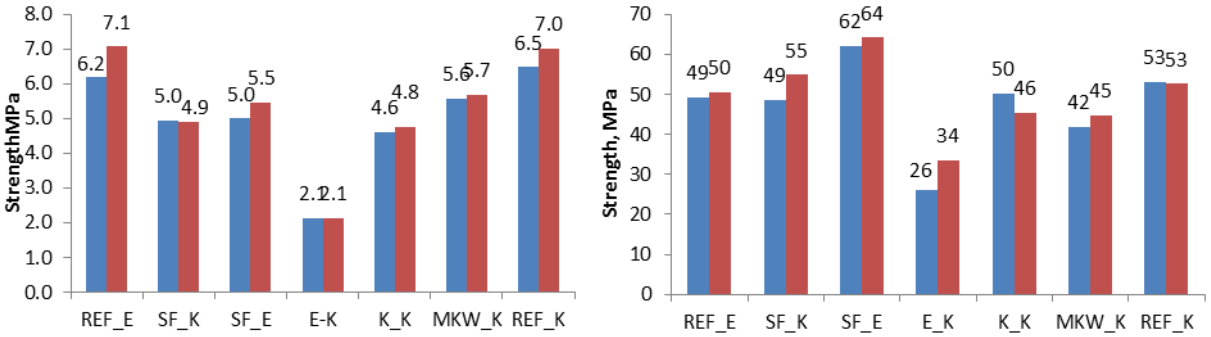

Figure 1.4 Bending and compressive strength depending on the conditions of hardening (in water, 80° C, or in 1M NaOH solution, 80° C) for cement composites with different micro-fillers and dispersed fiberglass reinforcement.

Testing the resistance of concrete with various non-fibrous micro-fillers to the alkali-silica reaction revealed that all micro-fillers, except for the K-type glass micro-filler, do not reduce the resistance of concrete to alkali-silica reaction (Figure 1.5). Minimal increase in dimensions was observed for the concrete specimens with microsilica. Significant cracks were observed in specimens with K-type micro-fillers, while similar cracks were not observed in the specimens cured under normal conditions (Figure 1.6). Incorporating fiberglass reinforcement in the cement composite the reaction intensity remained constant for compositions with E-type fibers. Relative deformations remained within the acceptable limits. In contrast, compositions with K-type fibers showed significant changes in the dimensions, which may indicate undesirable reactions in the concrete structure. It was found that the compressive strength of specimens decreases after alkali-silica reaction resistance test (Figure 1.4).

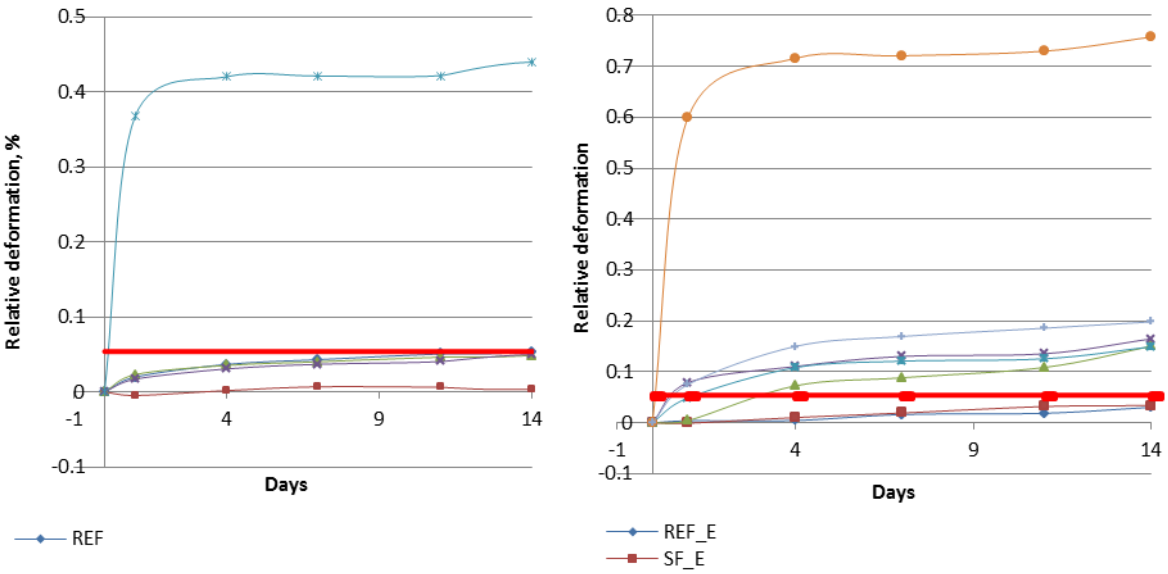

Figure 1.5 Testing of alkali-silica reactions for cement composites with different micro-fillers and dispersed fiberglass reinforcement.

Figure 1.6 Network of microcracks related to alkali-silica reaction on samples with K-type micro-fillers.

Based on the results and knowledge obtained in the framework of PPP IMATEH, the method "Innovative and advanced cement composite material production methods for infrastructure projects and public buildings" has been developed. The obtained results were reported at international scientific conferences and published in scientific articles.

2. To develop methodology for the use of recycled asphalt; to develop economic assessment of the use of high performance bitumen composites.	***Methodology for the use of recycled asphalt; economic assessment of the high performance bitumen composite; 1 scientific article; 1 patent application***

The most effective way to use the asphalt coming from the asphalt milling (hereinafter referred to as RAP - recycled asphalt pavement) is reusing it in bituminous pavements or asphalt concrete. Using RAP as 10-15% of the material does not require significant reconstructions in the asphalt concrete plant but the economic advantage of such a quantity is also insignificant. Using RPP as 50-100% of the material in its turn requires significant reconstruction of the asphalt concrete plant involving such activities as RAP crushing and fractionation, as well as designing of sustainable asphalt concrete composition (homogeneity assessment, use of a restorative additive, solving of fatigue problems, etc.). In this study, high performance asphalt concrete compositions were developed using 15 to 50% RAP in the asphalt concrete. This amount could by optimum solution from the economic point of view, as well as taking into account the relatively small amount of construction works (as in Latvia), as it will not require significant financial investments for the reconstruction of asphalt concrete plant. In the framework of this study sustainable Stone Mastic Asphalt (SMA) bituminous composite material with a ≤50% RAP content was created. Consequently, the study combines two sustainable technologies - SMA structure bitumen composite material and RAP material up to 50%.

In the framework of this study RAP bitumen is characterised and restored to meet the requirements of EN 12591 Standard. Figure 2.1 shows the recovery of bitumen from the RAP material. After bitumen recovery, RAP and "fresh" bitumen were characterized (see Fig. 2.2) and restored (see Fig. 2.3). The homogeneity of the RAP material is assessed according to the Wirtgen Cold Milling Manual. Technology and Application. 2013. Homogeneity is characterised by granulometry (<0.063mm; 0.063-2mm;> 2mm), binder content and softening temperature. By analyzing the results of homogeneity (based on the Wirtgen namogram), it was found that RAP homogeneity indicators allow using it in the amount of ≥ 50%.

Figure 2.1. Bitumen recovery with rotary evaporator.

Figure 2.2 Bitumen softening temperature testing.

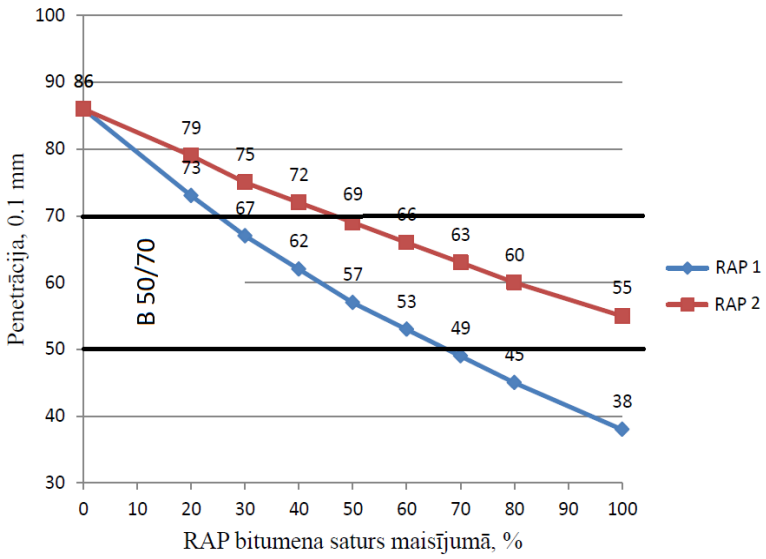

Figure 2.3 RAP bitumen restoration to achieve the intended bitumen class B50/70.

After assessing the properties of the RAP raw materials, raw materials (granite chips, bitumen B70/100) were selected to design SMA asphalt concrete compositions. The amount of bitumen has been optimized based on the compacting property analysis. Under the laboratory conditions, 3.5% compacting with 40% RAP content, which corresponds to recommended compacting limits of 2-5% (see Fig. 2.4)

In the following study, performance analysis of the SMA bituminous composites with high RAP content was done. The rutting resistance has been assessed in accordance with the Standard LVS EN 12697-22, determining the wheel tracking slope (WTSair) and proportional rut depth (RDair). Prismatic asphalt concrete specimens with a height of 40 mm were prepared for the testing purposes. Comparing the obtained results with reference composition (SMA without RAP), it was determined that SMA bituminous composite material with 30% RAP has the highest rutting resistance (see Fig. 2.5). It is important to note that, in accordance with the requirements of the technical regulations for rutting resistance, all compositions are suitable for using on medium and high-traffic roads.

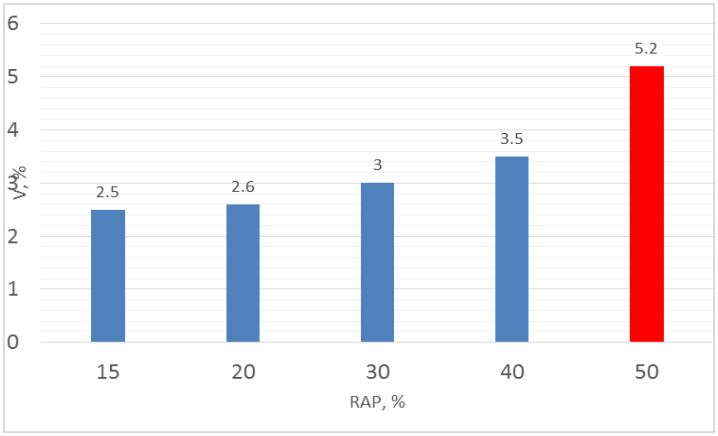

Figure 2.4 Compaction depending on the amount of RAP.

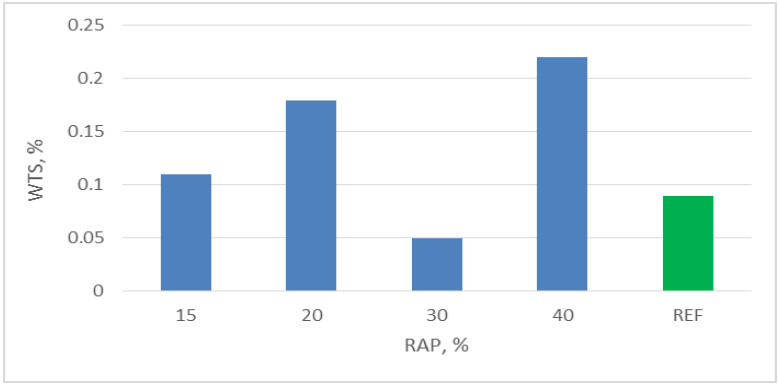

Figure 2.5 Wheel tracking slope depending on the amount of RAP

Research shows that asphalt concrete with RAP has an increased risk of fatigue crack growth. Therefore, the prepared compositions were tested for fatigue resistance using a four point bending test (10° C, 10Hz). The stiffness reduction ≤ 50% of the initial value in controlled-deflection conditions (cyclic load of 106 cycles for a specimen) was selected for the fatigue resistance test criterion. Summarizing the results, it was concluded that SMA with 40% RAP showed lower fatigue resistance (fatigue resistance class - ε6-70), while SMA with 15-30% RAP and reference composition showed higher fatigue resistance (fatigue resistance class - ε6-115). From the obtained results it can be concluded that it is possible to develop high performance SMA bituminous composite, when new materials (aggregate, filler, binder) are partially replaced with

reclaimed asphalt pavement (RAP). This study succeeded in creating high performance SMA bituminous composite with 30% of the RAP.

In the reporting period, a method was developed for the use of recycled asphalt concrete in order to reduce the demand for asphalt concrete binders and, consequently, to reduce costs associated with the production of asphalt concrete mixtures. Guidelines for asphalt recycling:

- Bituminous mixtures containing RAP must comply with the same mixture requirements as mixtures containing only new materials.
- Bituminous mixtures containing RAP should be equal or better than mixtures containing only new materials.

The methodology has been developed based on the research results obtained during this reporting period as well as during the first periods of the project implementation. The methodology includes information on storage, crushing, testing (homogeneity assessment) of reclaimed asphalt pavement and design of bituminous composites with RAP. This information allows to find the most efficient use of recycled asphalt concrete (in asphalt concrete mixtures, not in the lower layers of road pavement). Based on the obtained results, in the "Road Specifications 2017", which is a road construction technical regulation, it is recommended to increase the maximum allowed proportion of RAP from 20 to 30% and to allow using RAP SMA type asphalt concrete for the mixture development.

The use of RAP involves indispensable benefits in the environmental perspective and savings in the financial perspective. The environmental benefits include a wide range of downstream benefits, such as emission reductions and reduced fuel consumption, as the extraction and transportation of new materials is reduced, demand for non-renewable resources also decreases. The economic assessment carried out during this reporting period involves replacing the new mineral materials and bitumen binder with RAP material as a cost-saving material, as well as estimating the cost reductions associated with the transport of new materials.

Using RAP material in the production of HMA mixtures, additional costs associated with the use of RAP in asphalt concrete mixtures may occur. The increase in costs depends on the amount of RAP material used in the HMA mixture. Using RAP more than 25% will require several additional testing and recycling technologies to ensure that the final HMA mixture meets the specifications. Typical costs are related to the extraction and processing of RAP material, so that it can be fully used in the production of new HMA mixtures.

Based on the results and knowledge obtained during the implementation of the National Research Programme IMATEH, "Recommendations on the transportation and application of bituminous composite mixture" and "Recommendation on the use of high-viscosity bitumen using hot asphalt production additives" as well as economic assessment "High performance bitumen composites in use" and "Proposals for improvement of road technical regulations" were prepared. The obtained results were reported at international scientific conferences and published in scientific articles.

3. To design and create data collection system, which is suitable for the heat and moisture migration control in the structures of energy efficient buildings.	***Data Collection System Development Guidelines; Proposals for including information on thermal properties of natural fiber composite building materials in the Latvian Construction Standard LBN 002-01; 1 scientific article; 1 patent application***

The most efficient density of hemp composite material is in the range of 250 - 500 kg/m3. Lower density (<250 kg/m3) in hemp composite material does not provide sufficient strength so that it could be used in bearing or non-bearing structures. Hemp composite materials with a density above 500 kg/m3 in their turn are not efficient from the functional point of view because their thermal conductivity is too high for a material to be classified as thermal insulation material or a carrier material with unique thermal insulation properties. The increase in the density of hemp composite materials is linearly correlated with the increase in thermal conductivity, in the range of 200 - 600 kg/m3. This correlation is well illustrated by the research carried out by various authors and pilot studies on the methods of producing hemp composites using a variety of binders (both made in Latvia and imported) and hemp shives from Latvia. Figure 3.1 shows the correlation of density-thermal conductivity of hemp composite materials with different types of lime and magnesium binders. (M. Shinka, G. Shachmenko, D. Bajare, A. Korjakins, E. Namsone, P. Van den Heede, N. De Belie "Magnesium Binders as Alternative for Hempcrete, Their Environmental Impacts, Construction and Building Materials").

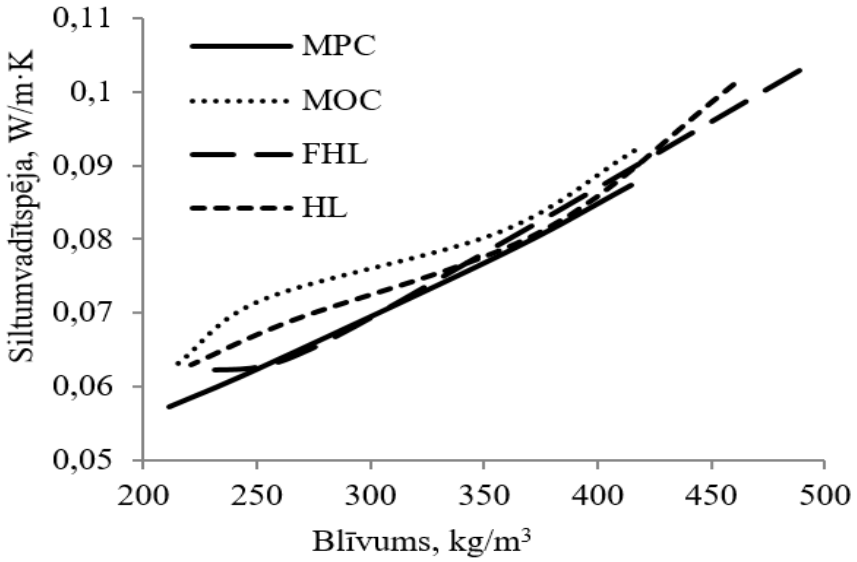

Figure 3.2. The ratio of density and thermal conductivity of hempcrete with hemp shives from Latvia (Sinka et al., 2017)

In the first part, it was concluded after the analysis of the construction standard that, since it does not contain values for calculation of the thermal properties for hempcrete, the construction standard has to be supplemented with the following information. It will allow wider use of construction materials with local origin because both constructors and potential clients will have considerably wider information available and it will be easier to fully integrate these materials in the construction project.

Thermal properties of the hemp composite materials with the density 250 and 500 kg/m3, such as thermal conductivity, specific heat capacity and water vapour diffusion resistance factor. Based on the obtained results, the proposals on including information in the Latvian Construction Standard LBN 002 "Thermotechnics of Building Envelopes" - 5th update in the table 7.

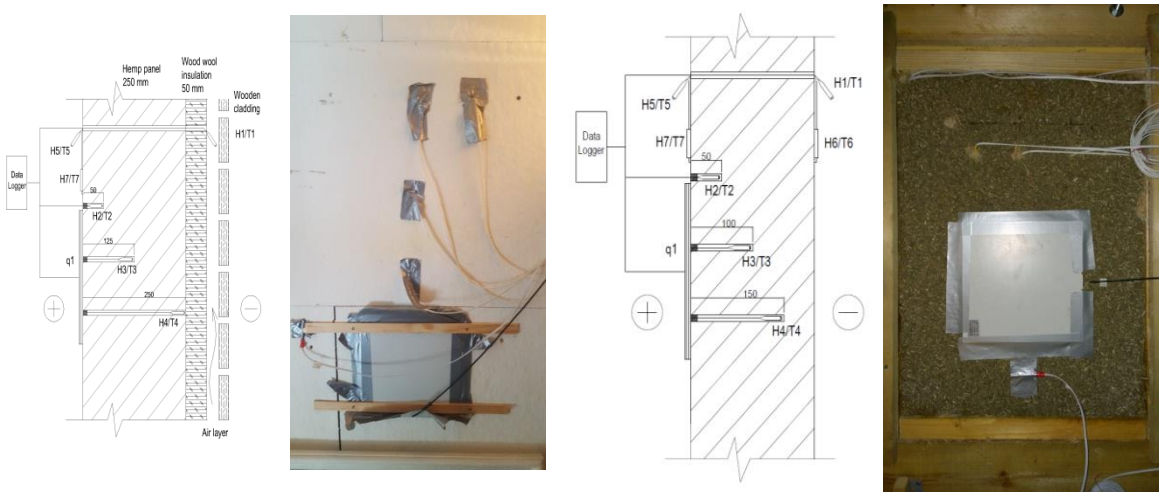

Figure 3.3. Moisture and temperature data collection system in the experimental panel (right) and industrially produced panel in the existing building (left).

Guidelines for the development of data collection and aggregation system were developed in the reporting period. They were developed based on the research results obtained on the first project periods. The developed data collection and aggregation system was integrated in objects providing field conditions. The system was tested for several consecutive seasons and the obtained results used in analysis. It allowed to assess the efficiency and accuracy of the data accumulation and collection system. Guidelines for the development of data accumulation and collection system provide information on the used equipment, data processing devices and recommended data processing methods, as well as specifications of data carriers, working range, accuracy, operating principles, etc.

Basic principles of data collection and aggregation system use are described in the guidelines. Figure 3.2 shows schematic representation of the data accumulation and collection system use of buildings (constructed using the hemp composite material developed in the framework of this project) for monitoring the moisture and temperature levels, as well as for the control of moisture migration and thermal parameters in an experimental, industrially made panel integrated into an existing building.

In addition, the guidelines provide recommendations for the efficient operation of the data collection and aggregation system and possible improvements to the development of the next generation of data collection and aggregation systems.

During the reporting period, a scientific article describing the natural fiber composite materials developed in previous project periods, their properties and applications, as well as their life-cycle calculation containing information on the natural fiber composite material with various binders environmental impact and comparison of various materials, was submitted for publication. The compared materials were composite materials with natural fibers (hemp), where pre-designed formulations of hydraulic lime made from quenched lime binder and industrial by-product, metakaolin, an industrially produced binder consisting of a mixture of quenched and hydraulic lime as well as two types of magnesium-bases binders - magnesium oxychloride cement and magnesium phosphate cement - were used as a binder. Hemp shives from Latvia were used as an aggregate for hemp composite materials. By varying the amount of binder, compositions with different density were obtained. Composite materials with a compressive strength of 0.15 and 0.5 MPa were used for life-cycle analysis and environmental impact assessment.

Calculations for the life-cycle analysis were performed according to the ISO 14040 using life-cycle calculation program SimaPro and Ecoinvent 2.0 database. The functional unit is constructed as a 1 m2 wall section with variable thickness to provide the normative U value for Latvian conditions of 0.18 W / m2 * K.

From the results obtained, it can be concluded that the replacement of the lime-based binder

with magnesium binders is efficient, as it is possible to achieve a significant reduction in the required amount of binder (3 to 4 times) to obtain a hemp composite material with a relatively higher compressive strength after 28 days of hardening, higher early strength and better thermal properties. In addition, the compatibility of magnesium-containing binders with bio-based fillers was studied, and it has been found that biosecurity is significantly better, when magnesium binders are used, namely strength values are higher.

According to the life-cycle analysis and data aggregation it can be concluded that the environmental impact of magnesium phosphate-containing binders and hemp composite materials made from it is considerably more negative (despite their relatively high strength) compared to the materials based on a hydraulic or exhaust lime binder. In almost all life cycle calculations, the use of magnesium phosphate-containing binders for the production of hemp composite materials showed a greater environmental impact than the other binders included in analysis, which is explained by the high environmental impact of the hardener, namely, potassium orthophosphate, which is graphically seen in Figure 3.3.

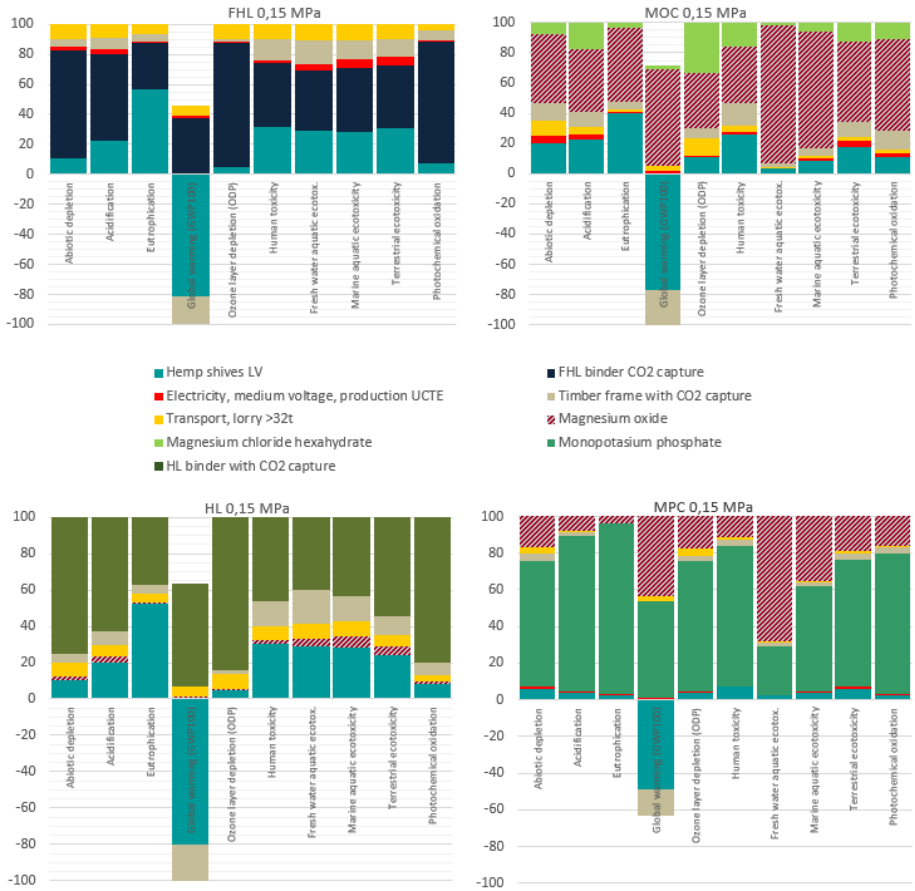

Figure 3.4. The environment impact of various natural fiber compositions using life-cycle calculations.

According to the data obtained from the life-cycle analysis and environmental impact assessment, the magnesium oxychloride cement biocomposite is a material with a relatively lower environmental impact in more than half of the studied categories (Eutrophication, Ozone Layer Reduction, Photochemical Oxidation, Human Toxicity, Abiotic Resource Depletion). Acidification due to the relatively low binder consumption in the biocomposite manufacturing process and the relatively low environmental impact of hardener MgCl2 (Figure 3.3). It results in a low Global Warming Potential (GWP) of the material (-12.68 kg CO2 equivalent).

The environmental impact of lime-based binder biocomposites is also relatively low; the GWP is the lowest for this material. This is due to the fact that, when the lime binder hardens in the air, it absorbs CO2, i.e. it carbonizes. In comparison, the experimental lime-based binder showed the

lowest GWP (-30.91 kg CO2 equivalent), commercially used cured and hydraulic lime binder - slightly higher (-19.28 kg CO2 equivalent). This is due to the fact that a significant amount of metakaolin, an industrial waste product with a low environmental impact, was used for the production of experimental binder, as the economic impact of distribution was used.

In accordance with the timetable, "Proposals for including information on thermal properties of natural fiber composite building materials in the Latvian Construction Standard LBN 002" were developed during the project period 4. Proposals consist of three parts - LBN 002 analysis, a summary of the thermal properties of natural fiber materials and proposals for supplementing LBN 002-15.

Prepared documents describing the methods, recommendations, proposals, etc. developed during the project 1 (attached in electronic format):

No.	Tasks	Deliverable	Responsible partner	Status
1.1.	**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	Submitted
1.2.	**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.**	Production method of innovative and advanced cement composite with microfillers materials for infrastructure projects and public buildings (30.09.2015) Annex 1-A	D. Bajare, Department of Building materials and Technologies, Institute of Materials and Structures, RTU	Submitted
1.3.	**To develop methods for innovative reinforced cement composite material production for infrastructure and public buildings**	Method for innovative reinforced cement composite material production (31.12.2017) Annex 1-A	D. G. Bumanis, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU	Submitted
1.4.	**Parameter optimisation of cement composite mixing process**	Recommendation for parameter optimisation of cement composite mixing process (30.6.2017) Annex 1-A	D. Bajare, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU	Submitted
2.1.	**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	Submitted
2.2.	**To create production method for high performance asphalt**	Production method for high performance asphalt concrete mixes from low	V. Haritonovs, Centre of Construction Science, RTU	Submitted

	concrete mixes from local low quality components.	quality components (30.09.2015) Annex 1-B		
2.3.	**To develop recommendations for transportation and incorporation of asphalt concrete mix**	Recommendation for transportation and incorporation of asphalt concrete mix (30.03.2017) Annex 1-B	V. Haritonovs, Centre of Construction Science, RTU	Submitted
2.4.	**To develop methodology for use of recycled asphalt concrete**	Recommendation for use of high-viscosity bitumen using warm asphalt concrete production additives (30.12.2017) Annex 1-B	V. Haritonovs, Centre of Construction Science, RTU	Submitted
2.5.	**To prepare economic assessment of high performance asphalt concrete exploitation**	Economic assessment of high performance asphalt concrete exploitation (30.12.2017) Annex 1-B	V. Haritonovs, Centre of Construction Science, RTU	Submitted
2.6.	**Recommendations for improvement of road technical rules**	Recommendations for improvement of road technical rules (30.12.2017) Annex 1-B	V. Haritonovs, Centre of Construction Science, RTU	Submitted
3.1.	**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. Shachmenko, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU	Submitted
3.2.	**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. Shachmenko, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU	Submitted
3.3.	**Recommendation for information about thermal properties of natural fibre composite materials to be added to LBN 002-01**	Recommendation for information about thermal properties of natural fibre composite materials to be added to LBN 002-01 (30.12.2017) Annex 1-C	M. Sinka, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU	Submitted
3.4.	**Life-cycle assesment of natural fibre composite materials**	Method for life-cycle assessment of natural fibre composite materials (30.12.2016.) Annex 1-C	M.Sinka, Department of Building Materials and Technologies, Institute of Materials and Structures, RTU	Submitted

2.4. Further research and practical exploitation of the results

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

In order to reach Sub-target 1 of the Project, high performance cement composite formulation was developed and samples were prepared from Cemex CEM I 42.5N cement, which is made in Latvia, and potentially effective micro-fillers allowing to reduce the cement consumption for the production of high-performance cement composite and to improve the mechanical properties and durability of the obtained material. Studies on the efficiency of micro-fillers as a potential partial cement replacement in high performance concrete have been carried out. By using by-products containing metakaolin and microsilica, the cement consumption was rationally reduced to 425 kg / m3, which corresponds to the amount used in normal strength concrete (40-50 MPa). Namely, the amount of cement was reduced by 15% but the mechanical properties of concrete remained in the range of 60-80 MPa or even higher. An innovative micro-filler preparation method - grinding of sand in a disintegrator - was tested experimentally (the obtained data is published). The developed formulation ensured high concrete workability in all tested cases - it is a highly flowable and self-compacting concrete with high placement efficiency, which does not require concrete compacting by vibration. To compare the efficiency of fillers, water-cementitious product ratio was kept constant at 0.38 for all concrete mixtures. The influence of micro-fillers on the yielding properties of concrete was determined as well as the necessary amount of plasticizers to maintain the highly flowable properties of the concrete.

The obtained results show that, by replacing 5-15% of the cement mass with waste products containing metakaolin, the compressive strength of concrete at the age of 28 days is from 65 to 75 MPa, which corresponds to 93-103% of the reference mix strength. Replacing 5-15% of the cement mass with microsilica, the compressive strength of concrete at the age of 28 days was 78 to 90 MPa, which indicates the efficiency of this micro-filler.

The property that characterizes the durability of concrete, namely, chloride migration coefficient, which characterizes the concrete's ability to resist the penetration of chlorides into the structure of material, was also determined. This aspect is important in the structures with reinforced concrete, because concrete provides protection against corrosion of reinforcement, which is particularly intensive under the influence of chlorine ions. It has been concluded that replacing 15% of cement with waste products containing metakaolin results in high performance concrete with improved resistance to the penetration of chloride salts into the structure of material. Chlorine ion migration rate was reduced by up to 3.5 times. Analyzing the obtained results, it can be concluded that in order to obtain ultra-high strength concrete (80-100 MPa), it is necessary to reduce the water-cement ratio, as well as to use effective micro-fillers, such as microsilica and metakaolin.

Analyzing several concrete mixes, it was concluded that the developed and tested compositions of cement composite materials are equivalent to the conventional concrete, but the workability and mechanical properties of the concrete are better. It allows producing the obtained mixes using the existing materials and equipment base without fundamental differences compared to the traditional technologies of concrete production.

Testing the durability properties of high performance cement composites (HPCC), it was concluded that high concrete strength does not automatically ensure freeze-thaw resistance of the concrete as well. The relatively high compressive strength (94 MPa after 180 days of hardening) was observed for samples of composite materials containing cement and microsilica, while the loss of compressive strength after 110 freeze-thaw cycles in saltwater was 16-33%. In contrast, the strength of the reference mix (without micro-fillers) remains within the acceptable limits according to the freeze-thaw resistance methodology and even an increase of strength was observed, which indicates the continuation of hardening in the saltwater environment. On the other hand, use of micro-filler containing metakaolin to replace 10% of the cement mass resulted in a composition of cement composite material, which withstands 150 freeze-thaw cycles in the saltwater according to the Annex C of the standard LVS 156 (corresponding to 500 freeze-thaw cycles in water).

The ultra-accelerated freeze-thaw resistance method was approbated at the temperature -52.5°C to determine the freeze-thaw resistance of high strength cement composites in the shortest possible period of time. It has been proven that in order to determine the freeze-thaw resistance 10-15 freeze-thaw cycles (testing period 2-3 weeks) can effectively replace 110-150 cycles in the standard temperature regime -18°C (testing can take 4-8 months) for high strength cement composite materials with different micro-fillers. In the framework of this study, the fracture intensity of different composite materials was compared during the freeze-thaw resistance testing by using the methods described above. The surface-loss control method according to the standard (LVS EN 1338) was also used in the studies for freeze-thaw resistance testing.

The studies were carried out to limit the alkali-silica reactions in cement composites and the effect of different micro-fillers was assessed. By examining the resistance to alkali-silicon reactions for a composite material with different micro-fillers (without fibers), it was observed that all fillers except K-type glass micro-fillers correspond to the criteria of alkali-silica reactions. The deformations were less considerable for the compositions with microsilica. Significant cracks were observed in specimens with K-type micro-fillers, while the cracks were not observed in the specimens cured under normal conditions. Incorporation of fiberglass reinforcement in cement composite did not change the intensity of the reactions for the compositions with E-type fibers and the relative deformations of the specimens remained within the permissible limits defined by the standards. On the other hand, significant changes in sample diameters and loss of compressive strength after the above-mentioned test were observed for compositions with K-type fibers.

By adding 15% of microsilica, the undesirable deformations of specimens causing cracks and increasing the permeability of concrete gases and solutions were reduced up to 2 times. Based on the results of the durability testing, recommendations for increasing the corrosion and freeze-thaw resistance of concrete were developed.

Experimental studies were carried out on the innovative use of fiberglass as dispersed and oriented reinforcement in cement composites. Two types of fiberglass production waste (E and K type fiberglass) were used in the studies. Using E-type fiberglass as a reinforcement in cement composites, bending strength reaches 23%, while K-type fiberglass contributes to the strength reduction due to aggressive chemical reactivity. The corrosion resistance of fiberglass in cement composites with different micro-fillers was assessed with alkali-silica reaction test.

In order to achieve Target 2 of the Project, the selection of raw materials, raw material sampling and testing was carried out during the reporting Period 1. Softening point, penetration and Frass breaking point of bituminous binder samples were determined. Dolomite and gravel chips with low crushing resistance class (LA≥30) were delivered to the laboratory. Experimental design for the production of HMAC-type high performance asphalt concrete composition from the lowest quality mineral material was developed according to the SPENS D08 specifications (Laboratory and field implementation of high modulus asphalt concrete). The methods were aprobated for determining the performance of bituminous composite materials (fatigue test, thermocrack formation test and wheel tracking test). At the same time, on the Period 1 of the Project by using traditional raw materials reference mixes, which are suitable for use in the climatic conditions of Latvia, were developed in accordance with the requirements of the technical regulation "Road Specification 2014". Theoretical calculations for the composition (formulation), where lower quality local mineral materials are used to obtain bituminous composite material, which is economically advantageous, eco-friendly and durable, were also performed during this reporting period.

Testing of the selected raw material was continued on the reporting Period 2 as well. Bitumen binder B20 / 30 and PMB 20 / 25-60, which were recommended in the SPENS specifications, was delivered for the development of HMAC compositions. Crushing resistance, shape, texture and granulometry of the selected mineral material was determined. Performance characteristics for the produced reference bituminous mixtures with bitumen binder B70 / 100 and granite chips were determined. During this period compositions of HMAC type asphalt concrete compositions were designed. During the design stage, bitumen optimization was performed to achieve the recommended compacting limit of 2-5%. The binder optimization was based on the requirements of

Marshall's method. After optimization of the amount of bitumen, the basic characteristics of the designed compositions (V - porosity, VMA - framework porosity of mineral, VFB - bitumen-filled pores) and performance tests were performed. In this reporting period, HMAC-type high performance asphalt concrete mixes were developed using dolomite and gravel splinters of the lowest quality together with bitumen B20/30 and PMB20/25-60. The created asphalt concrete compositions from lower quality mineral materials showed significantly higher performance properties than reference compositions. Based on the obtained results, formulation (composition of bitumen composite material with high viscosity using lower quality local mineral materials) and high-performance asphalt concrete composition design methodology were developed.

In the Period 3 of the Project analysis of the High Modulus Asphalt Concrete (HMAC) composition properties was continued aimed at developing recommendations for mixing parameter optimization and transportation of this type of asphalt concrete. Development of bitumen compositions with high content of reclaimed asphalt pavement (RAP) was started. RAP bitumen refinement is carried out aimed at obtaining bitumen class that corresponds to the technical regulations. Calculations of the granulometric composition aimed at decreasing the content of small particles (<0.063mm) continue as well. Homogeneity assessment of the recycled material was carried out using namogram (Wirtgen Cold Milling Manual). The methods for using RAP material in the production of High Modulus Asphalt Concrete (HMAC) compositions were analysed. Worn out bitumen (RAP bitumen) was renewed with bitumen B70/100 aiming at obtaining a HMAC composition that meets the standards of the bitumen grade B20/30. The calculations of the granulometric composition were performed to meet the limits defined for asphalt pavement Acb 16 and ACb 22. Based on Wirtgen Cold Milling Manual, a new proportion of RAP bitumen was determined to obtain class B50/70 bitumen.

In this research period of the Project the designed bitumen composite material mixes with RAP were experimentally tested to assess their deformative properties by using testing methods intended for the performance properties - wheel tracking test, stiffness test and fatigue test, thermocrack formation tests as well as water sensitivity (adhesion of the bitumen and aggregate). Based on the obtained results, formulation for high performance bituminous composite compositions were developed.

Classification of the warm mix asphalt technologies as well as information collection about the aggregates and technologies related to decreasing of production and paving temperatures were carried out during this period. The principles of the warm mix asphalt production were analysed. The disadvantages of this technology were defined. Methodology for assessing the economic effect was summarized.

To reach the target of Period 4 of the Project, the methodology for the use of recycled asphalt was developed and an economic assessment of the high performance bitumen composite was performed. A sustainable bitumen composite material with a RAP value of ≤50% was created in this reporting period. To achieve the goal, two sustainable technologies were combined in the study - SMA structure bitumen composite material and RAP material up to 50%.

The results obtained during the implementation of the project are summarized in the scientific publication "The influence of filler type and gradation on the rheological performance of mastics", which is accepted for publication in the scientific journal “Road Materials and Pavement Design” with SNIP> 1.

In order to reach Sub-target 3 of the Project, the necessary data collection system scheme was created as well as procurement and technical specifications were prepared in the reporting Period 1. The procurement process resulted in the development of system, which first was tested and approbated in a laboratory and then its operation was tested in the field study.

The developed and approbated equipment consists of temperature and humidity sensors, thermal conductivity sensor, set of cables, data collector / logger, measured data storage, processing and sending device, power supply and structural housing. The developed system allows for the multistage collection and transmission of data - it provides data transmission on a wireless mobile network to an e-mail server.

At the same time, in the Period 1 of the Project basic compositions were developed for the production of composite materials suitable for the climatic conditions of Latvia, using binders on the basis of hydraulic lime and special additives. Samples were prepared and hardened under various controlled environmental conditions (temperature, humidity), binder binding dynamics was determined as well as mechanical and thermal properties were tested.

In order to meet the target of the Period 2 of the Project, the developed data collection system was tested in field and laboratory conditions and the following improvements were made:

- In order to ensure separate measurements for both relative humidity and temperature of the ambient air and temperature on the surface of structures, which is necessary for calculating its heat conductivity, two Sensirion SHT75 sensors were added to the existing system.
- Separate ground cable was added to the power supply of the system as testing with various power supply sources revealed possible deviations in the heat flow measurements with ungrounded measurement system.
- Half-finished system and method for the convenient data processing were developed.
- The system was tested and regularised both in the laboratory settings with heat flow meter FOX600 and in the field settings with data logger Ahlborn Almeno 8590-9.

After improvements in the data storage system it was used to measure moisture migration and heat flow processes in the wall block immediately after its production. Natural fibers, namely hemp shives from the local producers, as well as lime based local mineral binder, were used for the production of this block. The initial data coincides with the thermal conductivity coefficient for biocomposite obtained in a laboratory as well as changes of the coefficient during drying period.

At the same time, mechanical and physical properties of the fiber composite materials were determined in the Period 2. Various local raw materials, such as lime base, gypsum base, etc. together with hydraulic additives, such as metakaolin, microsilica, etc. were used to develop several compositions. Hemp shives processed in different ways, which were supplied by all major local producers, were also used. The mechanical and physical properties were determined, such as compressive and flexural strength, heat conductivity, fire resistance, and compared with the properties of similar materials.

Four scientific articles were prepared and reported at three conferences about the first two Project periods.

According to the project schedule, a method "Production of ecological composite materials from textile plants and local mineral binders" was developed in Period 3 of the Project. This method is based on the results obtained in the previous periods and consists of the following sections:

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 CO2 neutral hemp-lime composite, because it involves impact of several technological factors and components on the performance of construction material. Studying the impact that 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 types of short shives with different origin. Samples with higher compressive strength (0.340 MPa to 0.218 MPa) have slightly lower thermal conductivity; however, the increase of thermal conductivity is rather insignificant - up to 0.004 W/m * K. The research shows that the dustiness of the shives has negative impact on the strength of material. Therefore it is recommended that the dust content should not exceed 2% of the total weight of the used hemp shives.

The results of the fire resistance tests show that the developed CO2 neutral composite material with textile plants for the construction purposes can be classified as C s1, d0 according to the standard LVS EN 13823:2010. Classification s1 indicates 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 indicates 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, which could be assigned to the materials labelled with b, is B s1, d0 because the amount of binder. Density should be increased up to around 1000 kg/m3 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 targets and tasks of this Project. Use of alternative binders (magnesium binders), additives consisting boron and aluminium as well as compacting of the concrete with additional pressing are offered as the main prospective solutions for increasing the fire resistance of the material.

In addition, the method "Life-cycle calculations of natural fibre composite materials" was 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 database.

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 leading 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/m3 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 CO2 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 the calculations of this type.

Analyzing the results about generated / accumulated amount of CO2 for different types of hemp-lime materials it was concluded that most of them are CO2 negative, which means that the accumulated amount of CO2 exceeds the amount that has been released during their life-cycle, including the production. The accumulated amount ranges from 15 to 30 kg for a functional unit, which is 50 to 100 kg on 1m3 of the material. This amount is possible because hemp has accumulated significant amount of CO2 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.

When calculating the life cycle of the material, comparisons were made with other alternative materials with analogue value of U (0.19 W / m2* K). A comparison was made with a 500 mm thick aerated concrete wall and a 300 mm thick aerated concrete wall with 100 mm stone wool insulation. The calculation is based on the CML2 Baseline method. It was concluded that the hemp-lime material has great advantages - in almost all indicators it shows significantly lower values (65-75% reduction), even by 125% with regard to the CO2. The only indicator, where this material can not produce such good results, is eutrophication, which can be explained with the fact that hemp needs significant amount of phosphate fertilizer; however, it is only 10-20% higher compared to other materials.

The targets of Period 4 were fully achieved. "Guidelines for the development of data collection system" and "Proposal for an inclusion of thermal and technical properties of natural fibrous composite building materials in the building code LBN 002-01" were developed to achieve them. These guidelines and proposal are important for achieving general targets of the project and have practical application as well.

"Proposal for an inclusion of thermal and technical properties of natural fibrous composite building materials in the building code LBN 002-01" is developed to reduce barriers to the use of natural fiber composite materials in construction projects. Building code LBN 002 “Thermotechnics

of Building Envelopes" determines the thermal engineering design of building elements for buildings with a heating system. It includes new buildings as well as buildings to be refurbished or renovated. However, it is necessary to include information on natural fiber composite materials in the building code. This addition will allow much wider use of this building material with local origin, since both designers and potential customers will have much more information and there will be no obstacles to integrate such material into the building design. In accordance with the analyzed and summarized information, proposals for supplementation to the building code with the thermomechanical properties of natural fiber material were included in the deliverable. This deliverable contributes to the practical application of the scientific results of the Project as well as makes them important for the national economy.

"Guidelines for the development of data collection system" were developed. Based on the experience in developing a data collection system suitable for controlling the heat and moisture migration of energy-efficient structures, in the framework of the project, guidelines for developing such systems were prepared. The system, which is chosen for the needs of the project, is described in the guidelines, including criteria and framework for its design and component selection, operating principles of the system, as well as the measurement methodology for carrying out such measurements in real-world objects. There are also suggestions, what improvements should be made in order to improve existing systems and recommendations, what should be taken into account for choosing the design and component of new systems as well as activities for further development of the concept. These guidelines are a practical contribution to further scientific research, since they make it significantly easier to develop such measuring systems for wider research projects in the future.

Topicality of the obtained results is confirmed by the RILEM Technical Committee 236-BBM "Bio filler-based construction materials" as it published "Recommendation of the RILEM TC 236-BBM: characterization testing of hemp shives to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity" and "State-of-the-Art Report of the RILEM 23 Bio-aggregates Based Building Materials" in 2017.

A scientific article was also written for publication in the journal with SNIP> 1 (M. Sinka, G. Shachmenko, D. Bajare, A. Korjakins, E. Namsone, P. Van den Heede, N. De Belie, Magnesium binders as alternative for hemp concrete, their environmental impact).)

2.5. Dissemination and outreach activities

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

In the Project „Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures" **19 full conferences papers were published or accepted for publishing** (see Annex 7):

1. Obuka V., Sinka M., Klavins M., Stankevica K., Korjakins A., Sapropel as a binder: Properties and application possibilities for composite materials, IOP Conference Series: Materials Science and Engineering, Volume 96, Issue 1, 2015

https://www.scopus.com/record/display.uri?eid=2-s2.0-84960411855&origin=resultslist&sort=plf-f&src=s&st1=M.+Sinka&st2=&sid=9706ec80452d4f6545a15b836dac47ef&sot=b&sdt=b&sl=21&s=AUTHOR-NAME%28M.+Sinka%29&relpos=12&citeCnt=0&searchTerm=

2. Sinka M., Radina L., Shachmenko G., Korjakins A., Bajare D., Enhancement of lime-hemp concrete properties using different manufacture technologies, Proceedings of First International Conference on Bio-based Building Materials", RILEM Publications, 1-8, 2015

http://toc.proceedings.com/33854webtoc.pdf

3. Sinka M., Shachmenko G., Korjakins A., Radina L., Bajare D., Hemp thermal insulation concrete with alternative binders, analysis of their thermal and mechanical properties, IOP Conference Series: Materials Science and Engineering, Volume 96, Issue 1, 2015

https://www.scopus.com/record/display.uri?eid=2-s2.0-84960359582&origin=resultslist&sort=plf-f&src=s&st1=Hemp+Thermal+insulation+Concrete+with+Alternative+Binders%2c+Analysis+of+their+Thermal+and+Mechanical+Properties&st2=&sid=9706ec80452d4f6545a15b836dac47ef&sot=b&sdt=b&sl=125&s=TITLE-ABS-

KEY%28Hemp+Thermal+insulation+Concrete+with+Alternative+Binders%2c+Analysis+of+their+Thermal+and+Mechanical+Properties%29&relpos=0&citeCnt=0&searchTerm=

4. Pleiksnis S., Sinka M., Shachmenko G., Experimental justification for sapropel and hemp shives use as a thermal insulation in Latvia, Environment, Technology, Resources, Volume 1, 2015, 175-181

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Participation in conferences:

1. 2nd International Conference on Innovative Materials, Structures and Technologies, IMST 2015; Riga; Latvia; 30 September 2015 through 2 October 2015
2. 1st International Conference on Bio-based Building Materials (ICBBM 2015) Clermont-Ferrand, France 22 – 24 June 2015

3. 2015 10th International Scientific Practical Conference on Environment. Technology. Resources; Rezekne; Latvia; 18 June 2015 through 20 June
4. 24th International Baltic Conference on Engineering Materials and Tribology, BALTMATTRIB and IFHTSE 2015; Tallinn; Estonia; 5 November 2015 through 6 November 2015
5. Materials, Systems and Structures in Civil Engineering – 19 - 22.08.2016, Copenhagen, Denmark
6. 18th International Conference on Concrete, Structural and Geotechnical Engineering, 25.-26. 01. 2016, Istanbul, Turkey
7. 12th International Conference Modern Building Materials, Structures and Techniques, MBMST 2016; Vilnius; Lithuania; 26 May 2016 through 27 May 2016
8. 25th International Baltic Conference of Engineering Materials and Tribology – BALTMATTRIB; Riga; Latvia; 3 November 2016 through 4 November 2016
9. Riga Technical University, 57th International Scientific Conference, Riga, Latvia, 14-18 October 2016
10. Transport Research Arena Conference -TRA 2016, 18. -21.04.2016, Warsaw, Poland
11. Latvijas Betona savienības XXV zinātniski tehniskā konference, Rīga, 2016. gada 10. novembrī.
12. 6th Eurasphalt and Eurobitume Congress, Prague, Czech Republic, 1.06. – 3.06.2016.
13. 3rd International Conference „Innovative Materials, Structures and Technologies" IMST 2017, Riga, Latvia, 27. 09.-29. 09. 2017
14. 2nd Intenational Conference of Bio-based Building Materials and First International Conference on ECOlogical valorisation of GRAnular and FIbrous materials), 21.-23.06.17. Clermont-Ferrand, France

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

1. Rieksts K., Pettinari M., Haritonovs V., The influence of filler type and gradation on the rheological performance of mastics, Road Materials and Pavement Design (RMPD-15-12-22R1, accepted for publishing).
2. M. Sinka, P. Van den Heede, N. De Belie, D. Bajare, G. Shachmenko, A. Korjakins, Magnesium binders as an alternative for hemp concrete, comparative study using life cycle assessment, Resources, Conservation & Recycling, (04.12.17. accepted for review).
3. G.Bumanis, L.Dembovska, D.Bajare. Applicability of freeze-thaw resistance methods at extreme -52.5°C and standard -18°C testing conditions for high strengt concrete, Case Studies in Construction Materials. (CSCM_2017_227, accepted for publishing).

17 master's thesis and 20 bachelor's thesis have been prepared and defended within Project 1.
Master's thesis:

1. J. Ruskuls, "Impact of Pozzolanic Additives on the Concrete Strength Index", supervisor D. Bajare, 2014;
2. Ofkante "Hemp Shive Composite Material with Lime-Clay Binder" supervisor G. Shachmenko, 2014;
3. Aleksejeva, Head of the "Nanodisperse Additives for Concrete Production", supervisor A .Korjakins, 2014;
4. J. Jankovskis "The Impact of High Performance Concrete Cell Composition and Microstructure on the Properties of Material", supervisor G. Shachmenko, 2014;
5. M. Jaungailis-Gailis "The Use of Nanomaterials and Nanosystems in the Production of Building Materials", supervisor A. Korjakins, 2015;
6. R. Latkovska "Concrete Damages in the Reinforced Concrete Structures Caused by Aggressive Environment", supervisor A. Korjakins, 2015;
7. N. Pleiko, "High Performance Concrete with Dolomite Siftings", supervisor G. Shachmenko, 2015;

8. I. Talanovs "Development of Nanosystem-Based Innovative Building Materials", supervisor A. Korjakins, 2015;
9. E. Zelčs "Comparison of Methods for Calculating the Stiffness Elements of Prefabricated Reinforced Concrete Building ", supervisor A. Korjakins, 2016;
10. L. Lavnika "Corrosion Resistance of High Strength Concrete", supervisor D. Bajare, 2016;
11. M. Jansons "Road Pavement Maintenance, Repair of Holes With Bitumen Emulsion and Gravel", supervisor V. Haritonovs, 2016;
12. E. Bella, "Alternative Adhesion Methods for Evaluation of the Interaction of Bitumen and Mineral Materials", supervisor V. Haritonovs, 2017;
13. I. Zaharova "Research on Using Cold Bituminous Mixtures for the Road Surface Renovation", supervisor V. Haritonovs, 2017;
14. D. Varnecka "Hempcrete in a Wooden Panel House", supervisor G. Shachmenko, consultant M. Shinka;
15. E. Prockans "Investigation of SBS Modified Bitumen Properties", supervisor V. Haritonovs, 2017;
16. J. Baumanis "Frost Influence on Hydraulically Bound Soils", supervisor V. Haritonovs, 2017.
17. A.Jakovļevs "Evaluation of load carrying capacity for corroded renforcesed construction, supervisor A. Korjakins, 2017;
18. A.Bucinskis "Usage of peat binder for heat isolation materials", supervisor A. Korjakins, 2017;
19. M.Sergejevs "Obtaining of effective foam concrete by using magnium oxide", supervisor A. Korjakins, 2017;
20. A.Jarovoja "Evaluation of enregy efficiency of different types buildings" supervisor A. Korjakins, 2017;
21. A.Strateicuks "Evaluation of cots effectiveness for A-line steel girders", supervisor A. Korjakins, 2017.

Bachelor's thesis:

1. M. Demenkovs, "Designing of Concrete Compositions for Radiation Protection" supervisor A. Korjakins, 2014;
2. G. Balahovics, "Micro-granulometric Composition of Marketable Portland Cements" supervisor A. Korjakins, 2014;
3. M. Lurina "Development and Use of Nanomaterials in the Building Material Industry", supervisor A. Korjakins, 2015;
4. E. Namsone "Two-component Bulk Thermal Insulation", supervisor G. Shachmenko, 2015;
5. J. Jankovskis "The Impact of High Performance Concrete Cell Composition and Microstructure on the Properties of Material", supervisor G. Shachmenko, 2015;
6. I. Chikanovics, "Improvement of Reinforced Concrete Structures with Carbon Fiber Composite Materials", supervisor A. Korjakins, 2015;
7. V. Stirane "Correctness of the Mass, Volume and Density of Various Construction Materials in Building Design", supervisor A. Korjakins, 2015;
8. M. Skele, "Assessment of the Reinforcement Impact for Fiber Composite Materials in Bending", supervisor A. Korjakins, 2015;
9. V. Politiko, "Concrete Floors with Dispersed Reinforcement", supervisor A. Korjakins, 2015;
10. V. Ignatjevs "Development of a Self-compacting Concrete Mixture with Recycled Concrete Additives", supervisor A. Korjakins, 2015;
11. J. Krauklitis "Environmentally Friendly Self-compacting Concrete with Reduced Amount of Cement and Replaced Natural Gravel", supervisor A. Korjakins, 2015;
12. J. Umbrovskis "Methodology for Optimum Choice of Wall Thermal Insulation Materials", supervisor G. Shachmenko, 2015;

13. I. Klasa, "Determination of Bituminous Structures and Properties Using the Atomic Force Microscope", supervisor V. Haritonovs, 2015;
14. A. Riekstins, "Research on Thin Layer Pavement Wearing Course (AC-TL) Properties and Use", supervisor V. Haritonovs, 2015;
15. I. Zaharova "Identification and Analysis of the Interaction of Mineral Materials and Bitumen", supervisor V. Haritonovs, 2015;
16. K. Juska "Types of Mezzanine From Wooden Beams, Their Optimum Choice", supervisor A. Korjakins, 2016;
17. A. Novikovs "Optimization of Monolithic Reinforced Concrete Slabs", supervisor A. Korjakins, 2016;
18. J. Sadijeva "Ecologically Friendly Thermal Insulation Materials", supervisor A. Korjakins, 2016;
19. K. Kalnins "Improving of the Mechanical Properties of the Ground Coat Using Wood Ash", supervisor V. Haritonovs, 2017;
20. A. Balodis "Determination of Adhesion Properties of Bitumen and Mineral Materials with Photo Processing Method", supervisor V. Haritonovs, 2017.

The following doctoral theses are developed:

1. J. Justs „Ultra high performance concrete with diminished autogenous shrinkage technology", supervisor D. Bajare, planned to defend in 2017
2. N. Toropovs „Fire resistance of high performance concrete", supervisor G. Shachmenko, planned to defend in 2017

The following doctoral theses were defended:

4. 18.06.2015. U. Lencis defended the doctoral thesis „ Methodology for use of ultra sound impulse method in assessment of construction strength" (supervisor A. Korjakins) and obtained PhD in engineering.
5. 10.04.2015. A. Sprince defended the doctoral thesis "Methodology for determination of long-term properties and crack development research in extra fine aggregate cement composites" (supervisor A. Korjakins) and obtained PhD in engineering.

The following doctoral theses were submitted for defence:

1. J. Tihonovs „Aphalt concrete mixes from the local mineral material with high exploitation properties" supervisor J. Smirnovs, V. Haritonovs, planned to defend in 2018
2. M. Sinka „Natural fibre insulation materials", supervisor G. Shachmenko, planned to defend in 2018

It was planned to defend the above-mentioned doctoral theses during the implementation of the National Research Programme IMATEH. However, due to insufficient funding, some of the doctoral students have decided to pursue their scientific activities at foreign universities (e.g. J. Justs and N. Toropovs signed a two-year contract with the EMPA, Swiss Federal Laboratories for Materials Science and Technology) or to increase their professional skills by accepting job offers in the construction sector. To a certain extent it can be considered a successful outcome leading to successful career. The causes for termination of doctoral studies in the RTU were attributed to insufficient funding and moving to better paid jobs. The implementers of National Research Programme IMATEH and scientific supervisors could not influence their decisions.

Patent applications submitted to the Patent Office of Latvia:

1. M. Shinka, D. Bajare, G. Shachmenko, A. Korjakins, A. Shishkins, "Magnesium Phosphate Cement and Bio-based Aggregate Rapid Curing Construction Block and Its Production Method " (P-17-86, submitted on 13.12.2017).

2. M. Shinka, D. Bajare, G. Shachmenko, A. Korjakins, A. Shishkins, "Bio-fiber and Magnesium Oxychloride Cement Multi-layer Construction Panel and Its Production Method" (P-17-77, submitted on 28.11.2017).
3. V. Haritonov, J.Tihonovs, R. Īzaks, A. Shishkin, Self healing asphalt concrete with sound damping properties (submitted on 21.12.2017).

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.

New technologies methods, prototypes and services commissioned by companies:
Number of new technologies transferred to implementation: two contracts on the transfer of intellectual property have been concluded.

1. Agreement between the Riga Technical University and the JSC "The Latvian State Roads" on the rights to use the technology developed by the RTU involving the restoration of thin layer pavement wearing courses and other bituminous coatings.
2. Agreement between the Riga Technical University and JSC "BMGS" on the right to use methods developed by the RTU involving quality control of building materials.

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 - 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)
7. **Laura Vitola** Department of Building Materials and Products, 9.01.2017-20.01.2017, methods used to determine correlation of high-performance concrete properties and corrosion / negative environmental impact (e.g., dependence of corrosion resistance in alkaline environment on structural properties of high-performance concrete) was acquired.
8. **Diana Bajare, Girts Bumanis**, Department of Building Materials and Products 24.01.2017-28.01.2017, to Angel Palomo / Eduardo Torroja Institute for Construction Science. At the meeting, decisions were made on creating of a joint publication and on other possible cooperation. During the conference, the experience of each participant in the research of self-healing concrete was reported. During the visit in Eduardo Torroja Institute for Construction Science a work plan for further scientific research was developed.
9. **Laura Vitola**, Department of Building Materials and Building Products 24.01.2017-27.04.2017 to Angel Palomo / Eduardo Torroja Institute for Construction Science. Practical methods for conducting high performance concrete durability tests, as well as skills for work with data processing programs Origni, Omnic and Eva was acquired.
10. **Diana Bajare**, Department of Building Materials and Products. During the symposium, decisions on preparing a joint publication and other possible cooperation were taken. During the conference, the experience of each participant in the use of various waste materials in the production of building materials and their safety for human health and the environment was reported. During the visit in the National Institute of Health a work plan for further scientific research was developed.
11. **Diana Bajare**, Department of Building Materials and Products. Visits encouraging cooperation. University of Seville, Institute of Architecture and Building Science and University of Seville, Institute of Architecture and Building Science. A decision to work on the preparation of project application for energy efficient buildings was taken.
12. **Diana Bajare**, **Laura Dembovska**, Department of Building Materials and Products. Collaborative visit to Vilnius Gediminas Technical University and acquisition of methodology for testing corrosion resistance of materials. In addition, a method for evaluating concrete corrosion was acquired.
13. **Girts Bumanis**, Department of Building Materials and Products, 5.03.2017-19.03.2017 During the experience exchange visit, the specimens of high performance cement composites prepared beforehand were tested in the Department of Materials and Ceramic Engineering / Institute of CICECO, University of Aveiro.

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.**
5. RTU Research project 2016/2017, RTU Platform of Reseach and Innovation "Hight performance cement composites for energu systems transformation substation, AS Energofirma „JAUDA", 2.01.2017-31.012.2017, **Euro 186290.00**
6. Project Nr. ZP-2016/29. (RTU ID 2335), "Activation of mineral fillers by collision milling in disintegrator for cement composites", **Euro 3000.00**

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

Performance indicators of the program and project promotion:

Representatives of the project participated in 15 seminars on the development and implementation of the National Research Programme IMATEH.

Popular science article "Innovative materials and smart technologies for environmental safety, IMATEH" was written and published in the Riga Technical University magazine "Safety and security", 2015, Vol. 4 p. 10-12.

Popular science article "Asphalt concrete compositions with local materials" was written and published in the magazine "Būvinženieris", October 2016, Vol. 52 (authors - V. Haritonovs, J. Tihonovs).

In order to promote the project, on April 19, 2016, M. Sinka and G. Shachmenko participated in the scientific discussion "Eco Materials in Construction" with the presentation about the latest trends in eco-friendly construction and the results obtained in the first stages of the research program.

In 2015, two scientific conferences were organised - IMST "Innovative Materials, Structures and Technologies", on 30.09.-02.10.2015, http://imst.rtu.lv/node/42

In 2017, an international conference was organised - IMST "Innovative Materials, Structures and Technologies" (27.09.-29.09.2017), http://imst.rtu.lv/node/46

Technical and scientific conferences for students were organized in 2015, 2016, 2017 (on 28.04.2015, 27.04.2016 and 27-29.04.2017), http://imateh.rtu.lv/konferences/)

During the 56th and 57th International Scientific Conferences of the Riga Technical University (on 14-16.10.2015, 14.-18.10.2016 and 12-15.10.2017) the participants (Latvian and foreign scientists, students and representatives of the industry, as well as representatives from the scientific commission) were informed about the achievements of the project and the obtained scientific results.

The project achievements and obtained scientific results were also reported at the Scientific and Technical Conference of the Latvian Concrete Association on 10.11.2016. Among the conference participants were students and representatives of the Latvian industry, as well as scientific personnel from the RTU and the Latvia University of Agriculture.

In order to promote the program among students, on April 16, 2015, April 13, 2016 and April 20, 2017, the Concrete Olympiad (the 1st stage of the concrete preparation competition) was organized, where the teams of 3 people prepared concrete samples. After 28 days the samples were tested for their compressive strength in order to determine the winning team who made the concrete with the highest compressive strength. The aim of the Concrete Competition is to promote putting knowledge into practice and to encourage students developing their technical creativity. 2nd stage of the Concrete Competition took place after four weeks, when the compressive strength of the concrete samples made by the student teams was tested in order to determine the winning team.

Detailed information on both the Project 1 and National Research Programme IMATEH is available on the IMATEH website http://imateh.rtu.lv/.

The amount of private co-funding and revenues from contract work, based on the results obtained in the Project 1 is **EUR 509 636.**

PART 2: PROGRAMME PROJECT INFORMATION

2.1. Project No. 2

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

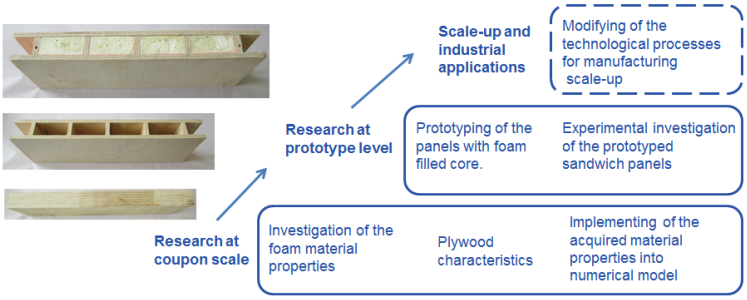
2.2. Tasks and deliverables

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

The general aim within IMATEH 2nd project "Innovative and multifunctional composite materials for sustainable buildings" is to scale up the technology for production of plywood sandwich panels consolidated by polyurethane foams in one step procedure.

Tasks within subproject:

Within the current project the focus is devoted to development of advanced sandwich panels which would facilitate/benefit from a raw resources available in Latvia – birch plywood and rapeseed oil for polyurethane synthesis. Developed product should maintain mechanical stiffness/strength comparing to the conventional plywood boards meanwhile assuring weight savings while improving impact resistance, heat isolation properties and vibration damping – those characteristics which are essential for sustainable building manufacturing. Obtained experimental characteristics of various ingredient synthesis for both coupon and assembly tests has been integrated in numerical analysis and optimization procedure. Obtained optimum configurations was verified by lab scale prototype tests, to continue assemblies reassemble conventionally produced plate dimensions. Within project analysis of both economic impact and life cycle assessment has been evaluated. Obtained results has been disseminated within scientific and industrial society, as well as outreach given to general public for example within "Science night" annual event.



Project "Innovative and multifunctional composite materials for sustainable buildings" flow diagram.

2.3. Description of gained scientific results

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

Task 1. Innovation in sandwich production technology – scaling up.
Task 2. Summary evaluation of polyol synthesis methods, for greening of sandwich panel production.
Task 3. Life cycle assessment of both sandwich panel ingredients and while structure.

A laboratory scale foam pouring machine have been designed which hasn`t been originally foreseen to be done, thus a more extensive verification of newly assembled equipment are foreseen only for 2018*.

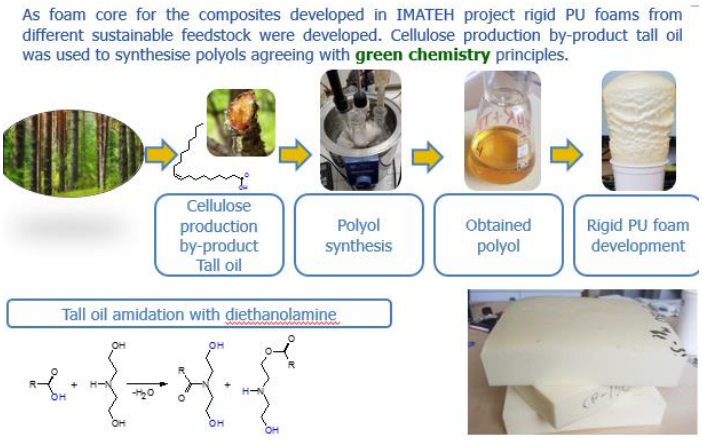
The assessment of prototyped panel performance versus numerical designs has been reported in several scientific publications:

1. E.Labans, K.Kalnins, C.Bisagni Flexural behavior of sandwich panels with cellular wood, plywood stiffener/foam and thermoplastic composite core, Journal of Sandwich Structures & Materials, 2017 doi: 10.1177/1099636217699587. Impact Factor 2.933
2. E. Labans, K. Zudrags, K. Kalnins. Structural Performance of Wood Based Sandwich Panels in Four Point Bending. In Procedia Engineering, 2017, Vol.172, pp. 628-633, doi: 10.1016/j.proeng.2017.02.073.

Mechanical performance in longitudinal direction similar to 50 mm plywood

Core type	Reference 50 mm plywood	Vertical stiffeners and foam	Vertical stiffeners	Corrugated thermoplastic composite core
Mass, kg/m²	34 (100%)	21.1 (-34 %)	13.8 (-59 5%)	13.6 (-60 %)
Thermal conductivity, W/mK	0.12 (100%)	0.07 (-41%)		
Vibration damping, LF, %	1.5 (100%)	1.4 (-7 %)	1.8 (+20 %)	1.7 (+14 %)
Plywood thickness corresponding to impact energy_A	50 mm	23 mm	21 mm	23 mm
Plywood thickness corresponding to impact energy_B	9/6.5 mm	12 mm (+25 %)	9 mm	9 mm(+30 %)
Transverse stiffness, (relative to longitudinal%)	90	85	31	55
Raw material cost, EUR/m2	25	35	18	55
Complicity of production	$	$$	$$	$$$
Additional benefits		Rapid manufacturing, improved fire resistance		Increased biological resistance

Partial assessment results of polyol synthesis methods, for greening of sandwich panel production has been published recently: M.Kirpluks, D.Kalnbunde, Z.Walterova, U.Cabulis, Rapeseed Oil as feedstock for high functionality polyol synthesis, Journal of Renewable Materials, 2017, 5(3-4), 258–270. doi: 10.7569/JRM.2017.634116



Life cycle assessment (LCA) for polyurethane has been published recently in very high (5.715) impact journal which outlines the level of excellence achieved: A.Fridrihsone, F.Romagnoli, U.Cabulis. Life Cycle Inventory of rapeseed cultivated in Northern Europe for biobased polyurethane production. Journal of Cleaner production. Volume 177, 10 March 2018, Pages 79–88. https://doi.org/10.1016/j.jclepro.2017.12.214

2.4. Further research and practical exploitation of the results

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

Recently both project partners Riga technical university, institute of materials and structures and Latvia sate institute of wood chemistry has submitted project proposals for European Space Agencies call. Projects namely: *Light Weight Polyurethane insulation for Bulkhead of Ariane Rocket, produced with next Generation Blowing Agents and Environmentally Friendly Catalyst (CRYAFOAMS-LV)* and *Development and validation of methodology for assessment of damage resistance properties of sandwich structures for European Space Sector: Phase 2* are covering and continuing in development of topic on advances in sandwich structures and polyurethane. Both projects have been retained for negotiation in early 2018. Moreover two ph.d thesis with project developments are foreseen for public defence at 2018 those achievements are backbone of further exploitation of research results.

2.5. Dissemination and outreach activities

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

Scientific Publications:

1. 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. Resubmitted to SAE International, Journal of Materials & Manufacturing (accepted).
2. Labans E., Kalnins K., Bisagni C., Flexural behavior of sandwich panels with cellular wood, plywood stiffener/foam and thermoplastic composite core, Journal of Sandwich Structures & Materials, 2017, Impact Factor 2.933

http://journals.sagepub.com/doi/pdf/10.1177/1099636217699587

3. N.Kunicina, A. Zabasta, K. Kalnins, G. Asmanis, E.Labans 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
4. Fridrihsone A., Romagnoli F., Cabulis U., Life Cycle Inventory of rapeseed cultivated in Northern Europe for biobased polyurethane production, Journal of Cleaner production, vol. 177, 2018, pp. 79–88 (accepted)
5. Labans E., Zudrags K., Kalnins K., Structural Performance of Wood Based Sandwich Panels in Four Point Bending, Procedia Engineering, vol.172, 2017, pp. 628-633

https://www.scopus.com/record/display.uri?eid=2-s2.0-85016243021&origin=resultslist&sort=plf-f&src=s&st1=Structural+Performance+of+Wood+Based+Sandwich+Panels+in+Four+Point+Bending&st2=&sid=b8abcf0be359e7f31ecc1ff97ca9a45f&sot=b&sdt=b&sl=81&s=TITLE%28Structural+Performance+of+Wood+Based+Sandwich+Panels+in+Four+Point+Bending%29&relpos=0&citeCnt=1&searchTerm=

6. Kirpluks M., Kalnbunde D., Walterova Z., Cabulis U., Rapeseed Oil as feedstock for high functionality polyol synthesis, Journal of Renewable Materials, vol, 5(3-4), 2017, pp. 258–270

https://www.scopus.com/record/display.uri?eid=2-s2.0-85024405179&origin=resultslist&sort=plf-f&src=s&st1=Rapeseed+Oil+as+feedstock+for+high+functionality+polyol+synthesis&st2=&sid=b8abcf0be359e7f31ecc1ff97ca9a45f&sot=b&sdt=b&sl=72&s=TITLE%28Rapeseed+Oil+as+feedstock+for+high+functionality+polyol+synthesis%29&relpos=0&citeCnt=0&searchTerm=

7. Labans E., Kalnins K., Experimental Validation of the Stiffness Optimisation for Plywood Sandwich Panels with Rib-Stiffened Core, Wood Research, vol.59(4), 2014, pp.793-802

https://www.scopus.com/record/display.uri?eid=2-s2.0-84995680636&origin=resultslist&sort=plf-f&src=s&st1=Experimental+Validation+of+the+Stiffness+Optimisation+for+Plywood+Sandwich+Panels+with+&st2=&sid=b8abcf0be359e7f31ecc1ff97ca9a45f&sot=b&sdt=b&sl=94&s=TITLE%28Experimental+Validation+of+the+Stiffness+Optimisation+for+Plywood+Sandwich+Panels+with+%29&relpos=0&citeCnt=3&searchTerm=

Conferences:

1. Fridrihsone A., Cabulis U., Romagnoli F., Life cycle assesment of rapeseed oil based polyols for biobased polyurethane, The 6th International Conference on Biobased and Biodegradable Polymers (BIOPOL-2017), Belgium, Mons, 11-13 September, 2017

2. Japins G., Labans E., Fridrihsone A., Kirpluks M., Kalnins K., Zudrags K., Experimental investigation of shear properties of plywood sandwich panels, 23rd Annual internacional scientific conference: Research for Rural Development 2017, Latvia, Jelgava 15-17 March, 2017
3. Fridrihsone A., Cabulis U., Romagnoli F., Cellulose production by-products as a raw material for polyurethane industry – a life cycle assessment approach, 8th Workshop on Green Chemistry and Nanotechnologies in Polymer Chemistry, Czech Republic, Prague, 6–8 September, 2017
4. Kalnins K., Jekabsons G., Labans E., Optimisation for scaling up of plywood sandwich panels with rigid PU foam-cores, 11th ASMO UK / ISSMO conference on Engineering Design Optimization Product and Process Improvement / NOED2016, TU. Munich, 18-20 July, 2016
5. 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, Costa Rica, San Jose, 21-23 September, 2016
6. Kalnins K., Overview of research towards multifunctional plywood sandwich panels, 12th meeting of the Northern European Network for Wood Science and Engineering (WSE) Riga, 12-13. September, 2016
7. Kirpluks M., Labans E., Kalnins K., Japins G., Plywood rib stiffened sandwich panels filled with bio-based rigid polyurethane foams, 12th meeting of the Northern European Network for Wood Science and Engineering (WSE), Riga, 12-13. September, 2016
8. Labans E., Jekabsons G., Kalnins K., Zudrags K., Rudzite S., Kirpluks M., Cabulis U., Evaluation of plywood sandwich panels with rigid PU foam-cores and various configurations of stiffeners, 3d International Conference – Optimization and Analysis of Structures, Tartu, Estonia August 23-25, 2015
9. Cabulis U., Kirpluks M., Paberza A., Fridrihsone-Girone A., Vitkauskiene I., Balance between renewable and recyclable feedstock for rigid polyurethane foams, 6th Workshop on Green Chemistry and Nanotechnologies in Polymer Chemistry, Braganca, Portugal, July 2015
10. Kirpluks M., Kalnbunde D., Cabulis U., High functionality polyols from rapseed oil as raw material for polyurethane thermal insulation, Baltic Polymer Symposium, Sigulda, Latvia September 16-18, 2015
11. Kalnins K., Labans E., Cabulis U., KirpLuks M., Sinerģija starp 7-IP un VPP – sendviča paneļu izstrādē. WIRE Riga, Latvia, June 3-5, 2015
12. Labans E., Kalnins K., Japins G, Zudrags K., Rudzite S., Smart sandwich structures of plywood and GF/PP, EuroNanoForum, Riga, June 10-12, Latvia, 2015

The following doctoral theses were submitted for defence:

1. M.Kirpluks "No atjaunojamām izejvielām iegūtu poliuretāna putuplasta un nano izmēra dabas izcelsmes pildvielu kompozītu īpašības", supervisor U.Cabulis (the defence is planned in 2018).
2. Fridrihsone: „Dzīves cikla analīze poliuretānu materiāliem, kas iegūti no atjaunojamām izejvielām". supervisor U.Cabulis, (the defence is planned in 2018).

The following doctoral theses were defended:

1. 6.04.2016. 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.

Outreach:

Outreach for general public was realised within Science night activities (annually organised pan European at the last Friday of each September). This gave a possibly to present research done in

testing labs for more than 500 people. Moreover an opportunity to present project research within national broadcast – LTV-1 was given by broadcast "Vides fakti" on subject of environmentally friendly wood product development for building sustainability: http://www.videsfakti.lv/skatities-raidijumus/?content_id=3de59.

As a year's highlight Latvia Academy of science has announced that one among distinguished researches of Latvia for year 2017 are performed by research team of Latvia sate institute of wood chemistry for developed effective thermal isolation material: polyurethane synthesis based on Latvia grown rapeseed oil. Research team acknowledged: dr.habil.chem. Uldis Stirna, LZA korespondētāj loceklis Uģis Cābulis, dr.sc.ing. Vladimirs Jakušins, m.sc.ing. Miķelis Kirpļuks, m.sc.ing. Anda Fridrihsone

http://www.lza.lv/index.php?option=com_content&task=view&id=4146&Itemid=87

PART 2: PROGRAMME PROJECT INFORMATION

2.1. Project Nr. 3

Title	***Risk consideration for safe, effective and sustainable structures***	
Project leader`s:		
Name, surname	Ainārs Paeglītis	
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)

Objective: ***Development of new methods for risk assessment for buildings and structures to ensure the safe, efficient and sustainable operation***

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.

Core task 1: *To investigate the dynamic characteristics of road bridges in Latvia and to ascertain their impact on construction reliability. To develop the new methods for structural risk assessment, reliability and robustness.*

Task for period 1:	Investigate vehicle and bridge interaction.
Task for period 2:	Vehicle weight and speed impact on the structural dynamic characteristics.
Task for period 3:	Vehicle weight and speed impact on the bridge dynamic characteristics. Approbation of theoretical probability distribution models for bridges in Latvia.
Task for period 4:	Determin the recommended limits of the bridge dynamic characteristics. Estimation of the safety index defined in the Eurocodes for existing bridges.

Core-task 1 activity timetable is given in the Annex Nr.3-A.

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*

Task for period 1:	Development of methods for damage localization in structural elements.
Task for period 2:	Development of methods for evaluation of damage zone in structural elements.
Task for period 3:	Development of methods for identification of damage in sandwich-type structural elements Numerical investigation on pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements
Task for period 4:	Development of a method for pre-stress loss estimation in pre-stressed

	steel reinforced concrete structural elements. Numerical and experimental investigation on multiclass probabilistic classification of damage location in a plate structure.

Core-task 2 activity timetable is given in the Annex Nr.3-B.

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

Task for period 1:	Development of design procedure for load-bearing elements from cross-laminated timber.
Task for period 2:	Development of design procedure for load-bearing elements from cross-laminated timber.
Task for period 3:	Development of design procedure for load-bearing elements from cross-laminated timber. 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 load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure.
Task for period 4:	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 load-bearing structure which consists from the main tensioned members and secondary cross-laminated timber members subjected to flexure.

Core-task 3 activity timetable is given in the Annex Nr.3-C.

Project „Innovative and Multifunctional Composite Materials from Local Resources for Sustainable Structures" 3rd Project published papers:

1. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Chate, A. Experimental structural damage localization in beam structure using spatial continuous wavelet transform and mode shape curvature methods (2017) Measurement: Journal of the International Measurement Confederation, 102, pp. 253-270. **(SNIP>1)**

https://www.scopus.com/inward/record.uri?eid=2-s2.0-85013304475&doi=10.1016%2fj.measurement.2017.02.005&partnerID=40&md5=4e6d656c83426146dc9133cc02665074

2. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Chate, A. Multiple Damage Identification in Beam Structure Based on Wavelet Transform (2017) Procedia Engineering, 172, pp. 426-432.

https://www.scopus.com/inward/record.uri?eid=2-s2.0-85016306328&doi=10.1016%2fj.proeng.2017.02.023&partnerID=40&md5=0f5b96587d8bf84579871b4e55900ab2

3. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Chate, A. Damage identification in beam structure based on thresholded variance of normalized wavelet scalogram (2017) IOP Conference Series: Materials Science and Engineering, 251 (1), art. no. 012089.
4. Kovalovs, A., Rucevskis, S., Akisins, P., Kolupajevs, J. Numerical Investigation on Detection of Prestress Losses in a Prestressed Concrete Slab by Modal Analysis (2017) IOP Conference Series: Materials Science and Engineering, 251 (1), art. no. 012090.
5. 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, 23 (9), pp. 1180-1193. **(SNIP>1)**
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84980416733&doi=10.1002%2fstc.1838&partnerID=40&md5=903a6a4e35760dc9037047314003ffb5

6. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Chate, A. Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares (2016) Journal of Physics: Conference Series, 744 (1), art. no. 012054.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84966430791&doi=10.1088%2f1757-899X%2f111%2f1%2f012005&partnerID=40&md5=ef79106a55600aca5e2849cfb9828a3b
7. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Kovalovs, A., Chate, A., Damage Identification in Polymer Composite Beams Based on Spatial Continuous Wavelet Transform (2016) IOP Conference Series: Materials Science and Engineering, 111 (1), art. no. 012005.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84966430791&doi=10.1088%2f1757-899X%2f111%2f1%2f012005&partnerID=40&md5=ef79106a55600aca5e2849cfb9828a3b
8. Janeliukstis, R., Rucevskis, S., Akishin, P., Chate, A. Wavelet Transform Based Damage Detection in a Plate Structure (2016) Procedia Engineering, 161, pp. 127-132.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84997719815&doi=10.1016%2fj.proeng.2016.08.509&partnerID=40&md5=3ade9e9b3219beb061f2ea6b0f6ee6ea
9. Rucevskis, S., Janeliukstis, R., Akishin, P., Chate, A. Vibration-based approach for structural damage detection (2016) ICSV 2016 - 23rd International Congress on Sound and Vibration: From Ancient to Modern Acoustics.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84987922684&partnerID=40&md5=689a54e80d3c118df5bbfb568c0f5956
10. Wesolowski, M., Rucevskis, S., Janeliukstis, R., Polanski, M., Damping Properties of Sandwich Truss Core Structures by Strain Energy Method (2015) IOP Conference Series: Materials Science and Engineering, 96 (1), art. no. 012022.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84960345051&doi=10.1088%2f1757-899X%2f96%2f1%2f012022&partnerID=40&md5=a58963b76089f9bae3cd190d12a5c2df
11. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Kovalovs, A., Chate, A., Damage Identification in Beam Structure using Spatial Continuous Wavelet Transform (2015) IOP Conference Series: Materials Science and Engineering, 96 (1), art. no. 012058.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84960443038&doi=10.1088%2f1757-899X%2f96%2f1%2f012058&partnerID=40&md5=5dd318a96658ae9a0a8dce6537ae3f3a
12. Mironov, A., Doronkin, P., Priklonsky, A., Chate, A. Effectiveness of application of modal analysis for the monitoring of stressed or operated structures (2015) Aviation, 19 (3), pp. 112-122.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84947058997&doi=10.3846%2f16487788.2015.1104860&partnerID=40&md5=e78f9d2a86660297515bb3957d9a27d5
13. R. Janeliukstis, S. Rucevskis, A. Kovalovs, A. Chate. "Numerical Investigation on Multiclass Probabilistic Classification of Damage Location in a Plate Structure" (2017) Proceedings of the International Conference on Structural Engineering Dynamics ICEDyn 2017.
14. R. Janeliukstis, A. Clark, S. Rucevskis, S. Kaewunruen. "Vibration-based damage identification in railway concrete sleepers" (2017) Proceedings of the SMAR 2017 – Fourth Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures.
15. Paeglite I., Paeglitis A., Smirnovs J. (2015) The Dynamic Amplification Factor for bridges with span length from 10 to 35 meters. // Journal Engineering Structures and Technologies, 2015, pp.1-8 10.3846/2029882X.2014.996254
16. Freimanis A., Paeglītis A., Analysis of yearly traffic fluctuation on Latvian highways, IOP Conf. Series: Materials Science and Engineering 96 (2015)
http://iopscience.iop.org.resursi.rtu.lv/article/10.1088/1757-899X/96/1/012064/pdf.
https://www.scopus.com/inward/record.uri?eid=2-s2.0-84960384889&doi=10.1088%2f1757-899X%2f96%2f1%2f012064&partnerID=40&md5=58423e70b2cb510a5ed77f80c4b99e6b
17. Paeglīte I., Smirnovs J. Dynamic effects caused by vehicle – Bridge interaction. In. 5th International Scientific Conference Proceedings, Vol. 5 Latvia, Jelgava, Latvia University of

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18. Paeglītis A., Freimanis A.Modeling of traffic loads for bridge spans from 200 to 600 meters. In. 5th International Scientific Conference Proceedings, Vol. 5 Latvia, Jelgava, Latvia University of Agriculture, 14-15 May 2015, pp. 15-23. ISSN 2255-7776
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29. Freimanis, A., Paeglitis, A. "Modal analysis of isotropic beams in peridynamics", (2017) IOP Conference Series: Materials Science and Engineering, 251 (1), art. no. 012088, . DOI: 10.1088/1757-899X/251/1/012088
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Participation in conferences:

1. Janeliukstis, R., Rucevskis, S., Wesolowski, M., Chate, A. 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. septembris, 2017, Rīga, Latvija.
2. Kovalovs, A., Rucevskis, S., Akisins, P., Kolupajevs, J. Numerical Investigation on Detection of Prestress Losses in a Prestressed Concrete Slab by Modal Analysis, IMST 2017 – 3rd International Conference „Innovative Materials, Structures and Technologies", 27. - 29. septembris, 2017, Rīga, Latvija.
3. R. Janeliukstis, S. Rucevskis, A. Kovalovs, A. Chate. "Numerical Investigation on Multiclass Probabilistic Classification of Damage Location in a Plate Structure", International Conference on Structural Engineering Dynamics ICEDyn 2017, 3. – 5. jūlijs, Ericeira, Portugāle.
4. R. Janeliukstis, A. Clark, S. Rucevskis, S. Kaewunruen. "Vibration-based damage identification in railway concrete sleepers", SMAR 2017 – Fourth Conference on Smart Monitoring, , Assessment and Rehabilitation of Civil Structures, 13. – 15. septembris, Cīrihe, Šveice.
5. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Chate, 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. jūlijs, Southamptona, Lielbritānija.
6. R. Janeliukstis, S. Rucevskis, P. Akishin, A. Chate, Wavelet Transform Based Damage Identification in a Plate Structure, WMCAUS – „World Multidisciplinary Civil Engineering Architecture Urban Planning Symposium" 2016, 13.–16. jūnijs, Prāga, Čehija.
7. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Chate, Multiple Damage Identification in Beam structure Using Wavelet Transform Technique, MBMST 16 – 12th International Conference „Modern Building Materials, Structures and Techniques", 2016, 26.–27. maijs, Viļņa, Lietuva.
8. S. Rucevskis, R. Janeliukštis, P. Akišins, A. Čate, Vibration-Based Approach for Structural Damage Detection, 23rd International Congress on Sound and Vibration, 2016, 10.-14. Jūlijs, Atēnas, Grieķija.
9. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Kovalovs, A. Chate, Damage identification in beam structure using spatial continuous wavelet transform, IMST 2015 - 2nd International Conference „Innovative Materials, Structures and Technologies", 30. septembris – 2. oktobris, 2015, Rīga, Latvija;

10. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Kovalovs, A. Chate, Damage identification in beam structure using mode shape data: from spatial continuous wavelet transform to mode shape curvature methods, ICoEV 2015 - IFTOMM International Conference on Engineering Vibration, 2015, 7.-10. septembris, Ļubļana, Slovēnija;
11. R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Kovalovs, A. Chate, Damage identification in polymer composite beams using spatial continuous wavelet transform, BPS 2015 – Baltic Polymer Symposium, 2015,16.-18. Septembris, Sigulda, Latvija.
12. Paeglite I., Paeglitis A. (2014) Dynamic Amplification factors of some city bridges, ICSCE 2014: XII Interantional Conference on Structural and Construction Engineering, London, United Kingdom, 22-23 December 2014.
13. Paeglīte I., Smirnovs J. Dynamic effects caused by vehicle – Bridge interaction. // 5th International Scientific Conference of Civil Engineering, Architecture, Land management and Environment, 14-15 May 2015, Jelgava, Latvia.
14. Paeglītis A., Freimanis A.Modeling of traffic loads for bridge spans from 200 to 600 meters. // 5th International Scientific Conference of Civil Engineering, Architecture, Land management and Environment, 14-15 May 2015, Jelgava, Latvia.
15. 10th International Scientific and Practical Conference „Environment. Technology. Resources", Rēzekne, Latvia, 2015, June 18 – 20 ar posteru Stuklis A., Serdjuks D., Goremikins "Materials Consumption Decrease for Long-span Prestressed Cable Roof".
16. 2nd International Conference „Innovative materials, Structures and Technologies" (IMST 2015, 30.09.15. – 02.10.15, Rīga, Latvia) ar ziņojumu Vilguts A., Serdjuks D., Goremikins V. "Design Methods for Load-bearing Elements from Cross-Laminated Timber".
17. 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,
18. Paeglite I., Smirnovs J., Paeglītis A., Dynamic behaviour of pre-stressed slab bridges // 12th International conference "Modern Building Materials, Structures and Techniques", (MBMST 2016), 26.-27.maijs, 2016, Viļņa, Lietuva,
19. Freimanis A., Paeglītis A., Mesh sensitivity analysis for quasi-static simulations // 12th International conference "Modern Building Materials, Structures and Techniques", (MBMST 2016), 26.-27.maijs, 2016, Viļņa, Lietuva.
20. Riga Technical University International Scientific Conference 2016, 14.10.16. – 18.10.16, Rīga, Latvija ar ziņojumu "Inovatīvas viedas konstrukcijas izstrādē ar uzsvaru uz atjaunojamo dabas resursu izmantošanu ar paaugstinātu ilgtspējību un drošumu, kas ir vērstas uz būvniecības un infrastruktūras objektiem ".
21. 12th International Conference „Modern Building Materials, Structures and Techniques", Viļņa, Lietuva, 2016, Maijs 26 – 27 ar referātu "Experimental Verification of Design Procedure for Elements from Cross-Laminated Timber ".
22. 29th International Baltic Road Conference, Tallinn (Estonia), 27 - 30 Aug 2017, A.Paeglitis ar referātu "New opportunities of timber bridges in Latvia".

Master's theses:

1. Kristaps Freimanis, „Nesošo elementu no Z profiliem darbības analīze" (vadītājs Dr.sc.ing. prof. D.Serdjuks) (2015).
2. Jāna Juričuka, „Krustiski līmētas koksnes nesošo elementu darbības analīzē" (vadītājs Dr.sc.ing. prof. D.Serdjuks) (2015).
3. Jānis Mūrnieks, „Koka pārseguma nestspējas palielinājuma analīze" (vadītāji Dr.sc.ing. prof. D.Serdjuks, M sc.ing. asist. A. Kukule) (2015)
4. Tatjana Saknite, „Lokveida koka pārseguma ugunsizturības analīze" (vadītājs Dr.sc.ing. prof. D.Serdjuks) (2015).
5. Inese Virbule, „Trīsstāvu koka karkasa ēkas nesošo elementu darbības analīze" (vadītājs

Dr.sc.ing. prof. D.Serdjuks) (2015).

6. Kristaps Freimanis, „Nesošo elementu no Z profiliem darbības analīze" (vadītājs Dr.sc.ing. prof. D.Serdjuks). (2015)
7. Jāna Juričuka, „Krustiski līmētas koksnes nesošo elementu darbības analīzē" (vadītājs Dr.sc.ing. prof. D.Serdjuks). (2015)
8. Jānis Mūrnieks, „Koka pārseguma nestspējas palielinājuma analīze" (vadītāji Dr.sc.ing. prof. D.Serdjuks, M sc.ing. asist. A. Kukule) (2015)
9. Tatjana Saknite, „Lokveida koka pārseguma ugunsizturības analīze" (vadītājs Dr.sc.ing. prof. D.Serdjuks). (2015)
10. Reinis Tukišs, "Satiksmes drošības pilnveides pasākumu analīze Liepājā") vad. prof. J.Smirnovs). (2016)
11. Mārtiņš Jākobsons, "Satiksmes organizācijas ietekme uz vides kvalitāti Liepājā", vad. prof. J.Smirnovs. (2016)
12. Vaivods Edgars, "Lokveida ceļa mezglu satiksmes drošības līmeņa analīze Latvijā" (vad. prof. J.Smirnovs). (2016)
13. Vaivods Edgars, "Satiksmes drošības problēmu analīze Ogres pilsētā" (vad. prof. J.Smirnovs). (2016)
14. Renārs Krišanovskis "Tērauda tiltu elementu bojājumu ietekme uz konstrukciju veiktspēju" (vad. prof. Ainārs Paeglītis). (2016)
15. Zigmārs Krūmiņš "PPP piemērotākā modeļa noteikšana autoceļa E67/A7 Ķekavas apvedceļa posma izbūvei" (vad. prof. Ainārs Paeglītis). (2016)
16. Linards Malmeisters, „Kompozītā nesoša elementa darbības analizē", vadītājs Dr.sc.ing. prof. D.Serdjuks. (2016)
17. Inga Drobis-Drobiševska, „Ugunsizturības analizē koka lokveida pārsegumam" (vadītājs Dr.sc.ing. prof. D.Serdjuks). (2016)
18. Kaspars Spricis, „Kompozīta stiepta nesoša elementa parametru analīzē" (vadītājs Dr.sc.ing. prof. D.Serdjuks). (2016)
19. Jānis Stepanovs, „Kombinētā tilta konstrukciju darbības izpētē" (vadītājs Dr.sc.ing. prof. D.Serdjuks). (2016)
20. Andris Vētra, "Lokveida ceļu mezglu ietekme uz satiksmes drošības līmeni" (vadītājs prof. Juris Smirnovs). (2017)
21. Roberts Koops, "Rīgas un Valmieras apvedceļu vienlīmeņa ceļu mezglu satiksmes drošības analīze" (vadītājs prof. Juris Smirnovs). (2017)

Bachelor's thesis:

1. R.Ruža "Stīgbetona siju nestspējas izpēte", vad. Prof. A.Paeglītis (2015);
2. R.Martinsons "Ilgtspējīgas koka tiltu laiduma konstrukcijas", vad. Prof. A.Paeglītis (2015);
3. M.Jansons "Ceļa zīmju un apzīmējumu izmantošanas efektivitātes analīze", vad. Prof. J.Smirnovs. (2015);
4. M.Cepurnieks "Satiksmes organizācijas un drošības analīze un iespējamie uzlabojumi Limbažu pilsētā", inženierprojekts "Rostokas ielas pārbūve Rīgā", vad. J.Smirnovs. (2015)
5. Karina Buka-Vaivade „Aprēķina metodiku pārbaude šķērsvirzienā kārtaini līmētam koka elementam. Veselības aprūpes centrs", vadītājs Dr.sc.ing. prof. D.Serdjuks. (2016)
6. Aleksandrs Trokšs-Traško "Šķērssiju nepieciešamības analīze saspriegtos saliekamos dzelzsbetona tiltos (inženierprojekts: Ceļa pārvada rekonstrukcija pār autoceļu V972 Madliena – Lēdmane)", vad. prof. Ainārs Paeglītis. (2016)
7. Andris Vētra "Drošības barjeru lietošanas analīze Latvijā (inženierprojekts: Rāmavas ielas rekonstrukcija Rāmavā, Ķekavas novadā)", vad. prof. Juris Smirnovs. (2016)
8. Jānis Praličs "Tiltu balstu izskalojumi un to radītās sekas (inženierprojekts: Autoceļa P5 Ulbroka-Ogre pārbūve)", vad. prof. Ainārs Paeglītis. (2016)
9. Lauris Spiģeris "Satiksmes drošības problēmu analīze Siguldā (inženierprojekts: Autoceļa A12 posma Rēzekne – Ludza pārbūve)", vad. prof. Juris Smirnovs. (2016)

10. Mārtiņš Cepurnieks "Satiksmes organizācijas un drošības analīze un iespējamie uzlabojumi Limbažu pilsētā (inženierprojekts: Rostokas ielas pārbūve Rīgā, posmā no Zolitūdes ielas līdz Jāņa Endzelīna ielai)", vad. prof. Juris Smirnovs. (2016)
11. Ivars Loits "Dzelzsbetona konstrukciju aizsargkārtas izbūves precizitātes analīze saskaņā ar 2.Eirokodeksu (inženierprojekts: Gājēju pārvads pār autoceļu A5)", vad. lekt. Ilze Paeglīte. (2016)
12. J. Gerasimova "Koka kupola racionāla konstruktīva risinājuma analīze", vad. prof. D.Serdjuks. (2017)
13. L. Lubgans „Koka karkasa elementu nestspējas palielinājuma analīze", vad. prof. D.Serdjuks. (2017)
14. K. Beridze „Konektoru koka kopnes nesošo elementu darbības analīze", vad. prof. D.Serdjuks. (2017)
15. Endija Namsone, "Racionālas formas koka loka tiltu optimizācija", vadītājs, Profesors Ainārs Paeglītis (2017)

The following doctoral theses are being developed:

1. **Rims Janeliukštis** „ Development of damage identification methods for structural health monitoring", scientific supervisors – Professor Dr.sc.ing. Andris Čate and Senior researcher Dr.sc.ing. Sandris Ručevskis, planned to defend in 2018.
2. **Ilze Paeglīte** "Moving load effect on the bridge dynamic characteristics", Scientific supervisor – Professor Dr.sc.ing. Juris Smirnovs, planned to defend in 2018.
3. **Andris Freimanis** „ Risk consideration for safe, effective and sustainable bridge structures", Scientific supervisor – Professor Dr.sc.ing. Ainārs Paeglītis, planned to defend in 2018.
4. **Aivars Vilguts** „ Rational structure of multy-storey buildings from cross-laminated timber", Scientific supervisor – Professor Dr.sc.ing. Dmitrijs Serdjuks, planned to defend in 2018.
5. **K.Buka-Vaivade** „ Increase of effectiveness of tensioned structures by the using of cross-laminated timber", Scientific supervisor – Professor D.Serdjuks, planned to defend in 2021.

Prepared documents describing in Project Nr 3 developed methods, methodologies and recommendations (Annex electronically):

Nr.	Description	Result	Number/ unit of measurement
1	Continuous Wavelet Transformation (CWT) method for localization of damage site and evaluation of damage size in various structural elements. (Deliverable Nr.3.2.1)	Method	1
2	Mode Shape Curvature Square (MSCS) method for localization of damage site and evaluation of damage size in various structural elements (Deliverable Nr.3.3.1)	Method	1
3	Method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements. (Deliverable Nr.3.3.2).	Method	1
4	Modelling of bridge and vehicle interaction, taking into account the type of the vehicle, type of the span structure, and pavement evenness.	Methodology	1
5	Vehicle weight and speed impact on the bridge dynamic characteristics.	Method	1
6	Determine the recommended limits of the bridge dynamic characteristics.	Recommendation	1
7	Approbation of theoretical probability distribution models of bridge loads in Latvia. Analysis of traffic load data.	Method	1

8	Development of mathematical model describing influence of building materials physical uncertainty on load bearing capacity.	Method	1
9	Estimation of the safety index defined in the Eurocodes for existing bridges.	Recommendation	1
10	Data generalization for development of design procedure for load-bearing elements from cross-laminated timber.	Methodology	1
11	An innovative and intelligent structures	Design of optimisation algorithm	1 1

Training and the acquisition of new knowledge, promotion of international cooperation:

1. Rims Janeliukštis, Department of Composite Materials and Structures, 09.01.2017.-20.06.2017. University of Birmingham, Birmingham, United Kingdom – Internship within the framework of the program ERASMUS + . Task - Static loading of the railway sleepers and characterization of cracks using experimental modal analysis and acoustic emissions.
2. Ilze Paeglīte, Department of Roads and Bridges 7.07.2015 - 11.07.2015 and 17.08.2015 - 20.07.2015. Stockholm, Sweden - Royal Institute of Technology in Stockholm (KTH) - Study course "Advanced Structural Dynamics Modelling and Measurements".

Within the framework of the project, new methods, approved in enterprises, were developed:

1. "Method of vehicle weight and speed impact on the bridge dynamic characteristics", approbated in the company SIA "Inženierbūve", attestation dated 16.09.2016.
2. "Method of approbation of theoretical probability distribution models of bridge loads in Latvia", approbated in the company SIA "Inženierbūve", attestation dated 11.11.2016.
3. "Determine recommended limits of the bridge dynamic characteristics", approbated in the company SIA "Inženierbūve", attestation dated 16.03.2017.

Training and the acquisition of new knowledge, promotion of international cooperation:

1. Interaction between Institute of Structural Engineering and reconstruction of Riga Technical University and Institute of Civil Engineering of Saint Petersburg State Polytechnic University was developed in frames of the project Competition for Young Researchers Nr. ZP-2017/5 (project financing 3000 EUR).

Participation in new research projects:

1. RTU Scientific project „Interaction between pre-stressed cable trusses and cross-laminated timber decking" Nr. ZP-2017/5.Supervisor – Senior researcher, Dr.sc.ing. V.Goremikins.

Participation in international cooperation projects:

1. COST Action TU1406 Transport and Urban Development. Quality specifications for roadway bridges, standardization at a European level (BridgeSpec)(2014-2017).
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:

Representatives of the project participated in 15 seminars on the development and implementation of the National Research Programme IMATEH.

In 2015, two scientific conferences were organised - IMST "Innovative Materials, Structures and Technologies", on 30.09.-02.10.2015, http://imst.rtu.lv/node/42

In 2017, an international conference was organised - IMST "Innovative Materials, Structures and Technologies" (27.09.-29.09.2017), http://imst.rtu.lv/node/46

Technical and scientific conferences for students were organized in 2015, 2016, 2017 (on

28.04.2015, 27.04.2016 and 27-29.04.2017), http://imateh.rtu.lv/konferences/)

During the 56th and 57th International Scientific Conferences of the Riga Technical University (on 14-16.10.2015, 14.-18.10.2016 and 12-15.10.2017) the participants (Latvian and foreign scientists, students and representatives of the industry, as well as representatives from the scientific commission) were informed about the achievements of the project and the obtained scientific results.

International scientific seminar „Design of Steel and Timber Structures" (SPbU 2015, 21.05.15., Saint Petersburg, Russia) with report about "Design Methods of Elements from Cross-Laminated Timber".

International scientific seminar „Design of Timber Structures by EN 1995-1-1" (SPbU 2016, 24.02.16., Saint Petersburg, Russia).

International scientific seminar „Fire Design of Timber Structures by EN 1995-1-1" (SPbU 2016, 26.03.16., Saint Petersburg, Russia).

International scientific seminar „Design of Timber Structures by EN 1995-1-1" (RTU 2016, 17.11.16, Riga, Latvia).

Detailed information on both the Project 3 and National Research Programme IMATEH is available on the IMATEH website http://imateh.rtu.lv/.

Published popular – scientific papers in journals „Būvinženieris" and "Latvijas būvniecība":

1. Paeglītis,A. (2015) "Koka tilti Latvijā – vēsture un perspektīvas" (Timber bridges in Latvia – history and perspective). // Būvinženieris, December 2015, Nr.47, 156-163.lpp. ISSN 1691-9262.
2. Paeglītis,A. (2015) "Saspriegta stīgbetona siju tilta nestspējas izpēte" (Investigation of pre-stressed reinforeced concrete beam load bearing capacity)// Būvinženieris, February 2015 Nr.42, 102-108.lpp. ISSN 1691-9262.
3. Paeglitis A., Līmēta koka gājēju pārvads pār autoceļu P103 Dobele-Bauska 17.44 km Tērvetē (Lamiated timber pedestrian bridge over road P103 Dobele-Bauska in Tērvete) // Latvijas būvniecība, 2016, Nr.3, 79-85 lpp. ISSN 1691-4058.

The amount of private co-funding and revenues from contract work, based on the results obtained in the Project 3 is EUR 24 530.

Contracts 01.01.2014 - 31.12.2014:

RTU Nr.	Responsible person	Name	Client	Contract price EUR (incl.VAT)	Duration
L8063	S. Ručevskis	Transformatora 330kV izvada un 330kV kabeļa savienojuma drošības vārsta aprēķini	SIA Energoremonts	2000	25.08.14-08.09.14
L8071	A. Čate	Iepriekš saspriegto dzelzbetona konstruktīvo elementu iepriekšējā saspieguma zuduma novērtēšana,izmantojot konstrukcijas dinamiskos parametrus	SIA Sweco Structures Latvija	15000	22.09.14-22.09.15

Contracts 01.01.2016 - 31.12.2016:

RTU Nr.	Responsible person	Name	Client	Contract price EUR (incl.VAT)	Duration
L8278	S. Ručevskis	Telpiskas kopnes no kārbveida profiliem spriegum-stāvokļa aprēķins un eksperimentālā testēšana	AS „UPB"	4080,00	25.04.2016 – 30.05.2016

L8043_16	A.Paeglītis	Ģeorežģu testēšana	SIA "Lemmikainen Latvia	3121.23	29.08.16. – 30.09.16.
L8043_17	A.Paeglītis	Ar cementu saistītu paraugu elastības moduļu testēšana saskaņā ar LVS NE 13286-43	SIA Ceļu eksperts	871.31	1.08.16. – 22.09.16

Contracts 01.01.2017 - 31.12.2017:

RTU Nr.	Responsible person	Name	Client	Contract price EUR (incl.VAT)	Duration
L8373	A. Čate	Ēkas apšuvuma kasetes konstrukcijas termo-mehāniskās uzvedības aprēķins	AS „UPB"	3450,00	26.01.2017 – 28.02.2017

2.3. Description of gained scientific results

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

Tasks for Period 4	Results for Period 4
1.	
1.1. Determination of the recommended limits of the bridge dynamic characteristics	Recomendations

In the 4th period continued work to determin recommended limits of the bridge dynamic cgaracteristics. Dynamic assessment method was developed for 4 most oftem built bridge types, because each type of bridge has different characteristics and parameters that influence its ynamic response.

It was determined that main parameters that influence dynamic performance were the ratio of the bridge span length/ deck height, first natural frequency, static deflection and damping ratio. All parameters can be determined in design phase using FEM model, except true damping ratio of the structure.

It is important to consider criteria that increase bridge dynamic. Those parameters are: bridge is positioned in an angle to the carriageway axis or in a plan radius, carriageway is positioned on the cross-section console, deck structure has one sided slope (or curve).

However, without taking into account all of the criteria mentioned, the evenness of the pavement is the most important, since the uneven bridge pavement, regardless of the bridge's parameters, will result in an increased bridge dynamic.

Tables 4.1. to Table 4.4 are showed recommended limits and criteria for 4 bridge types:

Table 4.1. Assessment table of increased dynamic for reinforced concrete slab bridges

Name:			
Type:	**Reinforced concrete slab bridge**		**Limiting values for increased dynamic response**
System:	Simply supported slab		Jā
Factors that can cause increased dynamic response:	in an angle to the carriageway axis		Jā
Span length/deck height:			>30
Natural frequency:			<3,25Hz vai >6 Hz
Static deflection:			> 4,7 mm
Damping coefficient:			<0,02

Ta**ble 4.2. Assessment table of increased dynamic for pre-stressed concrete beam bridges**

Name:			
Type:	**Pre-stressed beam bridge**		
System:	Simply supported beams		**Limiting values for increased dynamic response**
Span length/deck height:			>19
Natural frequency:			>5Hz
Static deflection:			<3,7mm
Damping coefficient:			>0,02

Table 4.3. Assessment table of increased dynamic for pre-stressed concrete slab bridge

Name:			
Type:	**Pre-stressed slab bridge**		
System:	Countinuose frame bridge		**Limiting values for increased dynamic response**
Factors that can cause increased dynamic response:	Plan radius		Jā
	Carriageway in deck cantilever		Jā
Span length/deck height:			>25
Natural frequency:			>4,3Hz
Static deflection:			4,2 - 4,6 mm
Damping coefficient:			>0,03

Table 4.4. Assessment table of increased dynamic for pre-stressed concrete ribbed slab bridge

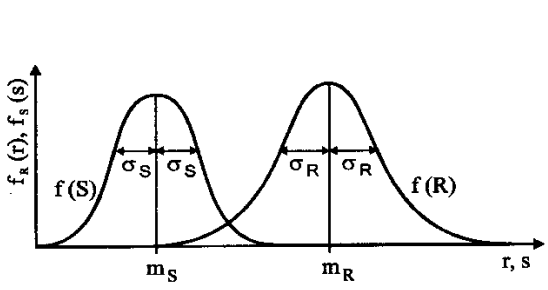
Name:			
Type:	**Pre-stressed ribbed slab**		
System:	Countinuouse frame bridge		**Limiting values for increased dynamic response**
Factors that can cause increased dynamic response:	Plan radius		Jā
	Carriageway in deck cantilever		Jā
	deck structure has one sided slope (or curve)		Jā
Span length/deck height:			>25
Natural frequency:			>3,9 - 4,8Hz
Static deflection:			>5,4 mm
Damping coefficient:			>0,03

1.2. Estimation of the safety index defined in the Eurocodes for existing bridges.	***Recomendations***

To determin safety index and estimation of remaining load carrying capacity of existing bridges a method given in Eurocode 1990 was used. It was assumed that limit state (collapse) for all structure or a part of it happens when material resistance R is equal to the applied load S. Applied lodad is a combination of effects that is applied to the structure at the same time. Hence every limit state can be can be described by the formula: var aprakstīt ar formulu:

$R = S$

For bridges R ans S cannot be straightforward determined, be cause those are random variables. Those variables vam be compared and showed with the corresponding density functions $f_R(r)$ and $f_S(s)$ (Figure 1).



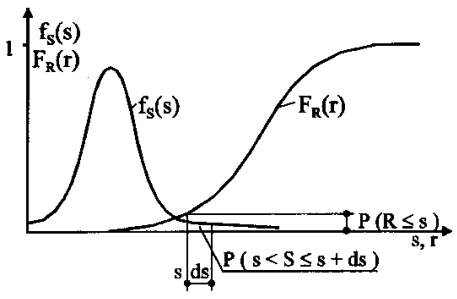


Figure 1 R and S probabilistic functions Figure 2 The probability of collapse

Density functions r and s can overlap (Fig. 1). Such cases are possible if the accidental resistance is less than the magnitude of the applied actions simultaneously and is called the collapse of the structure. Using Figure 1.6, it can be determined that the probability of a collapse depends primarily on the size of the dispersion. With increasing $f_R(r)$ and f_S (s) dispersion, the probability of collapse increases.

The mathematical probability of collapse can be found by using probability density function s and the probability distribution of the resistance r (Fig. 2), which in the interval ds can be expressed in terms of :

$P(s < S \le s + ds) = f_s(s)ds$.

According to the probability distribution function:

$P(R \le s) = F_R(s).$

Assuming the simultaneity of events, the following probability can be calculated: $P\{(s < S \le s + ds) \cap (R \le s)\} = F_R(s) f_s(s)ds.$

The collapse will occur if the left side of the equation is fullfilled, i.e. if the action s is in the interval (s; s + ds) and at the same time the resistance r is less than or equal to the effect. Therefore, it is a conditional probability. To obtain an unconditional probability for a collapse, the previous equation is integrated into all possible s values:

$$P_f = \int_{-\infty}^{+\infty} F_R(s) f_s(s)ds$$

Equation Z = R - S, denotes a security zone. The relationship between the security zone and the probability of a collapse is shown in Fig. 3. The larger the security zone, the smaller the probability of collapse. Two security zones can be distinguished. The central security area, which consists of the distance between the resitance mR and the mean values of the mS action. The nominal safety zone lies between the values Rp and Sq.

If the values of S and R are independent of each other and can be characterized by a normal distribution curve, then Z's characterization is analogous. The mean, standard deviation, and coefficient of variation of the value Z can be determined using the error propagation law:

$m_z = m_R - m_{S;}$

$\sigma_z = \sqrt{(\sigma_R^2 + \sigma_S^2)}$;

$V_Z = \frac{\sigma_Z}{m_Z}$;

If the mean mz value is defined as the multiplication of the standard deviation σZ with the coefficient β:

$m_z = \beta \cdot \sigma_{Z,}$

then the probability of collapse can be described by the equation: $p_f = \int_{-\infty}^{0} f_z(z)dz = F_z(z = 0) = \Phi(-\frac{m_z}{\sigma_z}) = \Phi(-\beta)$;

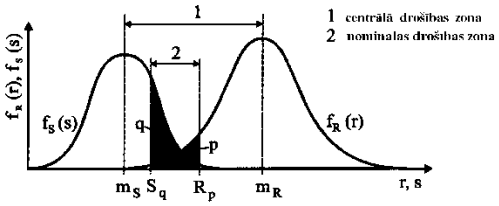


Figure 3 Safety zones

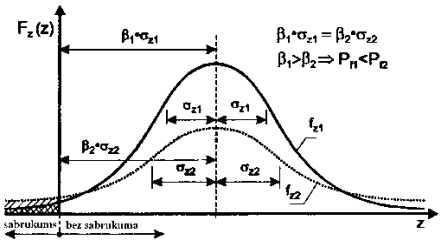


Figure 4 Graphical interpretation of the safety factor for two different dispersion curves

This means that different values of β can be characterized by different safety. As the β value increases, safety increases, so the coefficient β is called the safety factor.

The relationship between the probability of collapse pf and the safety factor β for a period of 1 and 50 years is given in Table 1.

Table 1

Probability of collapse p_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Safety factor β_1 (1 year period)	1.3	2.3	3.1	3.7	4.2	4.7	5.2
Safetu factor β_{50} (50 year period)		0.21	1.67	2.55	3.21	3.83	4.41

For any time period R (expressed in years) over 1 year, the safety factor can be determined by the formula:

$$\beta_R = \Phi^{-1}\{[\Phi(\beta_1)]^R\}.$$

The safety of structures is important because any accident can result in people being affected. The probability of a collapse, compared to other types of activities, that may lead to people being affected, may be assumed to be 10^{-6}. From an economic point of view, the design safety level depend on the cost of the collapse and the cost of the security measures.

In the LV-ENV-1991-1 accepted safety factor β is 4.7 – for ultimate limit state and 3.0- for servicability limit state (for 1 year period).

2.1. Development of a 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 reporting period studies concerning development of a method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements by employing dynamic characteristics of the structure were continued. A detailed study on detection of reinforcement failure in a pre-stressed reinforced concrete hollow floor slab using finite element method software ANSYS was conducted. The purpose of this work was to determine an influence of prestress losses and damage of reinforcements on the dynamic characteristics of prestressed slab made of concrete with different values of Young modulus. Nondestructive experimental-numerical method for detection and evaluation of pre-stress loss in pre-stressed reinforced concrete structural elements is developed by using results of performed numerical parametric study. The method uses experimentally determined dynamic characteristics of structural elements – eigenfrequencies (resonance frequencies) and allows to detect qualitatively the pres-stress loss by comparing eigenfrequency of the damaged typical reinforced concrete structural element with characteristic of reference undamaged element. This method allows also quantitatively evaluate the loss of prestress in case of parallel or previously performed numerical study of the structural element. The sensitivity and effectiveness of the method was analysed by numerical calculations using previously created finite element models of pre-stressed reinforced concrete hollow floor slabs.

2.2. Numerical and experimental investigation on multiclass probabilistic	***Full paper in proceedings of international scientific conference***

classification of damage location in a plate structure.	

In the reporting period a 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 was conducted. In present study, the damage localization methodology for plate structures based on data classification is proposed. A numerical model of composite cantilevered plate is partitioned into 18 zones that serve as class labels in classification process. A point mass of 2 different severities (5 % and 10 % of plate's mass) is applied at 9 points for each of 18 zones to collect more data for each class. Next, the modal analysis is performed and for each event of loading a mechanical strain is recorded from 11 sensors, embedded into the plate. All strain data is collected and passed to the k-nearest neighbors and decision trees classifier algorithms. Classifier models are built and their parameters are optimized to minimize the resubstitution and cross-validation errors. The performance of classifiers is assessed through ROC curves with accompanying area under curve metric and confusion matrices. These metrics suggest a high quality of classification for both, k-nearest neighbors and decision trees. Finally, two artificial damage events through application of point mass are simulated and this information is passed to classifier algorithms to assign a class label to these query points based on trained data. It is found that there is a good agreement between the localization results of both classifiers and these results are in accordance with the actual coordinates of query points for both severities of damage (5 % and 10 %). The research will be expanded further by using carbon fibre reinforced composite plate structure. Dynamic parameters of the plate will obtain experimentally by means of embedded deformation sensors.

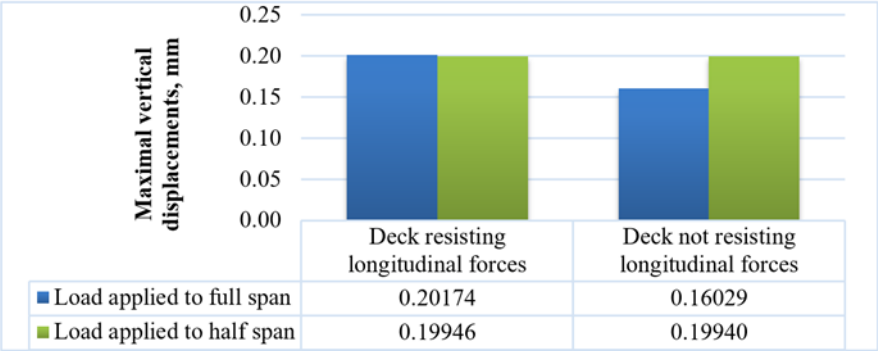
1. The development of the design method of the structural elements from cross-laminated timber	***The method of calculation for bended and compressed-bended constructive elements from cross-laminated timber was offered. Experimental tests of the design method have been carried out, looking at the various static schemes of bended and compressed-bended elements.***

The method of calculation for bended and compressed-bended constructive elements from cross-laminated timber was offered. The design method is based on the LVS EN 1995-1-1 and reduced cross-section method. Four experiment variants have been carried out. Cross-laminated timber panels with cross-section dimensions 350 x 60 mm and span 2 m was selected as an object of investigation. The panels were tested in four point bending by suspending the panels in four points. The panels were also tested in compression and bending by suspending the panel with inclination. The panels were tested up to the collapse in three point bending.

The experiments indicated that the offered design methodology allows predicting the behaviour of bended and compressed-bended element from cross-laminated timber with high precision. The precision of the offered design method is comparable with existing methods such as Gamma method, Shear analogy method, Composite method. The offered method is characterised with reduced labour intensity. The experimentally and analytically received results showed that the difference between results obtained experimentally, by reduced cross-section method and FEM differs in the limits from 0.1 up to 20.23 %. The offered design method is effective for calculation of cross-laminated timber panels in bending and compression-bending.

2. The topology optimisation and obtaining of rational parameters from the point of view of material consumption of the structure from cross-laminated timber	***The optimisation algorithm was developed for the structure with the main load bearing tensioned elements and secondary elements from cross-laminated timber. The topology optimisation was carried out and rational parameters were obtained for the structure from cross-laminated timber.***

The topology optimisation algorithm of the structure from cross-laminated timber was offered. The aim of optimisation is the obtaining of structural parameters which ensures minimum material consumption and maximum allowed stresses in elements and displacements. The optimisation was performed using ANSYS optimisation tools. The pedestrian-bicycle bridge suitable for Latvian conditions was selected as an object of investigation. The selected bridge has suspension structure with cable truss as a main load bearing structure and deck from cross-laminated timber panels. Based on the results received from optimisation, the vertical displacements from the uniformly distributed load could be reduced by 20% while the material consumption remains the same. This reduction is achieved by the ability of the deck to resist compression forces in longitudinal direction.



	Deck resisting longitudinal forces	Deck not resisting longitudinal forces
Load applied to full span	0.20174	0.16029
Load applied to half span	0.19946	0.19940

Figure 1. The maximal vertical displacements with deck resisting and not resisting longitudinal forces.

The material consumption of steel elements can be reduced by 25% by using the deck resisting loads in longitudinal direction for suspension bridge in comparison with the structure with the deck not resisting longitudinal forces.

3. Development of the loadbearing structure of main load bearing tensioned elements and secondary elements from cross-laminated timber.	***The loadbearing structure of main load bearing tensioned elements and secondary elements from cross-laminated timber was developed. Two (2D and 3D) finite element models and two physical models were developed.***

The innovative structure with main tensioned loadbearing elements and secondary elements from cross-laminated timber (CLT) with emphasis on the use of renewable natural resources was offered. The offered structure could be used for building and infrastructure objects. The pedestrian-bicycle bridge suitable for Latvian conditions was selected as an object of investigation. The span of the bridge is equal to 60 m and the width of the bridge is equal to 5 m. The main load bearing element of the bridge is cable truss. It is assumed that the supports are stiff. The deck is based on the stabilisation cables and is made from cross-laminated timber. The CLT deck of the innovative structure behaves not only in bending in transverse direction but also in compression in the longitudinal direction and will take the part of the forces acting in cables, which allows reducing the material consumption of the cables. The offered structure is characterised by the effective usage of high strength materials due to the usage of rational cable truss so as replacement of non-renewable cable material with renewable.

The 2D and 3D numerical models of the bridge were developed. The development of the structure was performed by ANSYS 12.1 software using APDL programming language. For verification of numerical models two physical models of the bridge prototype were developed. The span of the model is equal to 2.17 m and the width of the model is equal to 0.5 m. Two experimental models were developed: the first one for the model with the deck not resisting longitudinal forces and the second one resisting longitudinal forces. The comparison of the numerical models with experimental ones was performed by comparing maximal vertical displacements and forces in stabilisation cables under corresponding loading.

The comparison of the results gained by the numerical and physical models showed, that the

numerical models allows predicting the behaviour of the structure with allowable precision and could be used for modelling of behaviour of the bridge with span 60 m.

2.4. Further research and practical exploitation of the results

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

According to the Core task 1 - "To investigate the dynamic characteristics of road bridges in Latvia and to ascertain their impact on construction reliability. Develop methods for structural risk assessment, reliability and robustness ", research was done to investigate road bridge dynamic responses. The planned objectives are fully met.

Scientific results have been published in 7 SCOPUS peer-reviewed publications and presented at 5 international scientific conferences. According to the tasks 4 methods and 2 reccomendations were developed.

1. Methodology of the bridge and vehicle interaction, taking into account the type of the vehicle, type of the span structure, and pavement evenness.
2. Recommendations – Limiting values of the bridge dynamic characteristics.
3. Approbation of theoretical probability distribution models of bridge loads in Latvia.
4. Development of mathematical model describing influence of building materials physical uncertainty on load bearing capacity.
5. Recommendations - Estimation of the safety index defined in the Eurocodes for existing bridges.

Obtained results are used for Doctoral theses of : Ilze Paeglīte "Moving load effect on the bridge dynamic characteristics" and Andris Freimanis „ Risk consideration for safe, effective and sustainable bridge structures".

Accoring to the project Period 1 Task 1.1 vehicle impact on the bridge deck structure was analysed and Dynamic amplification factors (DAF) determinded. It was found that DAF depend on pavement evenness and vehicle speed. Vehicle driving with speed on 20km/h on uneven pavement DAG increased 1,5 times. Vehicle moving over the bridge with even pavement DAF was less than built in value in Eurocode load model – 1.4. For pre-stressed reinforced concrete bridges DAF values decreased when span length increased with vehicle speed 20km/h over uneven pavement.

Accoring to the project Period 2 Task 2.1 traffic load influence on bridge structure with span longer than 200m was analysed, because Eurocode gives traffic load model for spans up to 200m length. In this research weigh-in-motion system was used, further in text- WIM. System data was gathered from 4 WIM stations owned by VAS "Latvian State Roads". Obtained data was processed and cleaned. Load was calculated by summing up all vehicle loads and dividing them by the span length. This approach was used for spans from 200 to 600 m. Second approach was used in a real scenario. Bridge over Daugava river in Jēkabpils had a finished conceptual design hence this project was used. It was found that for most unfavourable scenario calculated traffic load was lower than ones given in Eurocode. Increasing span length loading decreased. Research was started about data WIM data cleaning to obtain more real data for further research.

Accoring to the project Period 3 Task 3.1 vehicle weight and speed impact on the bridge dynamic characteristics was analysed. Results obtained:

1. Bridge dynamic characteristics (natural frequency, damping coefficient, DAF) deped on bridge material un static system. Moreover, DAF strongly depend on pavement evenness.
2. Increase in vehicle weight does not musch influence DAF and Natural frequency.
3. Vehicle veight over allowed traffic weight does not straightforward increase dynamic response of the bridge.

Accoring to the Task 3.2 application of theoretical probability distribution models for bridges were studied. In the result of the study a method for calculation of loads was obtained.

Accoring to the project Period 4 Task 4.1 recommended values for dynamic characteristics were obtained. Those values will be used for bridge dynamic testing. Results will increase bridge safety.

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.

Scientific results have been published in 12 peer-reviewed articles index by WoS and Scopus, and presented at 11 international scientific conferences. In the frames of Core task 2 three vibration–based damage identification methods have been developed:

1. Continuous Wavelet Transformation (CWT) method for localization of damage site and evaluation of damage size in various structural elements. (Deliverable Nr. 1)
2. Mode Shape Curvature Square (MSCS) method for localization of damage site and evaluation of damage size in various structural elements. (Deliverable Nr. 1)
3. Method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements. (Deliverable Nr. 2)

Also it should be noted that in the frames of Core task 2 Ph. D. student Rims Janeliukštis successfully have finished the research part of his Thesis „Development of damage identification methods for structural health monitoring" (scientific supervisors – prof. Dr.sc.ing. Andris Čate and Dr.sc.ing. Sandris Ručevskis), and it is planned to defend the Thesis in 2018.

Deliverable Nr. 1 proposes two vibration–based damage identification methods (Continuous Wavelet Transformation method and Mode Shape Curvature Square method) for localization of damage site and evaluation of damage size in various structural elements such as beams, plates and sandwich type structures. Required dynamic parameters - vibration frequencies and vibration mode shapes – are experimentally measured by using a scanning laser vibrometer (SLV) or by accelerometers and strain ages. To examine the advantages and limitations of the proposed methods, several sets of numerical simulations considering different levels of damage severity, measurement noise and sensor sparsity were carried out. Numerical simulation were performed by employing a commercial Finite Element Method software ANSYS. Damage identification methods were developed by using MATLAB software. Robustness and effectiveness of the proposed damage detection methods are demonstrated experimentally on the following samples:

1. Aluminium beams containing single damage;
2. Aluminium beams containing multiple damages;
3. Carbon fibre reinforced composite beams containing single low-velocity impact damage;
4. Aluminium plates containing single damage;
5. Railway concrete sleepers containing multiple damages.

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. 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. 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.

Deliverable Nr. 2 proposes vibration–based method for pre-stress loss estimation in pre-stressed steel reinforced concrete structural elements. The method is based on the detailed study on detection of reinforcement failure in a pre-stressed reinforced concrete hollow floor slab using finite element method software ANSYS. By employing the finding of the research a nondestructive experimental-numerical method for detection and evaluation of pre-stress loss in pre-stressed reinforced concrete structural elements is developed. The method uses experimentally determined dynamic characteristics of structural elements – eigenfrequencies (resonance frequencies) and allows to detect qualitatively the pres-stress loss by comparing eigenfrequency of the damaged typical reinforced concrete structural element with characteristic of reference undamaged element. This method allows also quantitatively evaluate the loss of prestress in case of parallel or previously performed numerical study of the structural element. The sensitivity and effectiveness of the method was analysed by numerical calculations using previously created finite element models of

pre-stressed reinforced concrete hollow floor slabs.

One of the tasks for Period 4 was 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. Further research of the Core task 2 will mainly focus on the adaption and expansion of the developed vibration-based damage identification methods (Deliverables Nr. 1 and Nr. 2) and tools for the damage identification in lightweight structures with embedded sensors. In this case dynamic characteristics of a structure are obtained by means of embedded sensors from ambient vibrations of a structure during its service or from forced vibrations by means of embedded sensor/actuator. Thus the developed vibration-based damage identification tools and embedded sensor technology will be used for the development of on-line structural health monitoring methods. Effective solutions for on-line structural health monitoring and damage detection can increase safety, extend serviceability, reduce maintenance costs and define reducing operating limits for structures.

Results of the project Nr. 3 task Nr. 3. The project activities are performed in compliance with the time table. The project aims for the report period and whole project are achieved. This is confirmed by:

- The method of calculation for bended and compressed-bended constructive elements from cross-laminated timber was offered. The design method is based on the LVS EN 1995-1-1 and reduced cross-section method. Experimental tests of the design method have been carried out, looking at the various static schemes of bended and compressed-bended elements. The experimentally and analytically received results showed that the difference between results obtained experimentally, by reduced cross-section method and FEM differs in the limits from 0.1 up to 20.23 %. The offered design method is effective for calculation of cross-laminated timber panels in bending and compression-bending.
- The innovative structure with main tensioned loadbearing elements and secondary elements from cross-laminated timber (CLT) with emphasis on the use of renewable natural resources was offered. The offered structure could be used for building and infrastructure objects. The pedestrian-bicycle bridge suitable for Latvian conditions was selected as an object of investigation. The main load bearing element of the bridge is cable truss. The usage of the renewable structural material for the bridge deck as cross-laminated timber ensures sustainability, or preservation of the environment for future generations. The offered structure of the bridge allowing by the decreasing of the prestressing level easily and quickly replace the worn CLT deck. The offered structure allows decreasing of the material consumption of the cable by 25%.
- The topology optimisation algorithm of the structure from cross-laminated timber was offered. The aim of optimisation is the obtaining of structural parameters which ensures minimum material consumption and maximum allowed stresses in elements and displacements. The topology optimisation was performed by designed algorithm using ANSYS optimisation tools. The 2D and 3D numerical models of the bridge were developed. For verification of numerical models two physical models of the bridge were developed. Two models were developed: the first one with the deck resisting forces in longitudinal direction, the second one with the deck not resisting forces in longitudinal directions.

Scientific importance of the research, the application of the research results

The method of calculation for bended and compressed-bended constructive elements from cross-laminated timber was offered. The design method is based on the LVS EN 1995-1-1 and reduced cross-section method. The offered method allows checking ultimate limit state (ULS) and service ability limit state (SLS) of bended and compressed-bended structural elements from cross-laminated timber so as predicting behaviour under static loading.

The offered method is characterised by reduced labour intensity and sufficient precision in comparison with existing design methods (composite method, combined beam method, shear

analogy method). The design method verification was completed by CLT samples with dimension 2x0.35 m (Fig. 2) and thickness 60 mm. The length to width ratio of the panel is equal to 5.71.

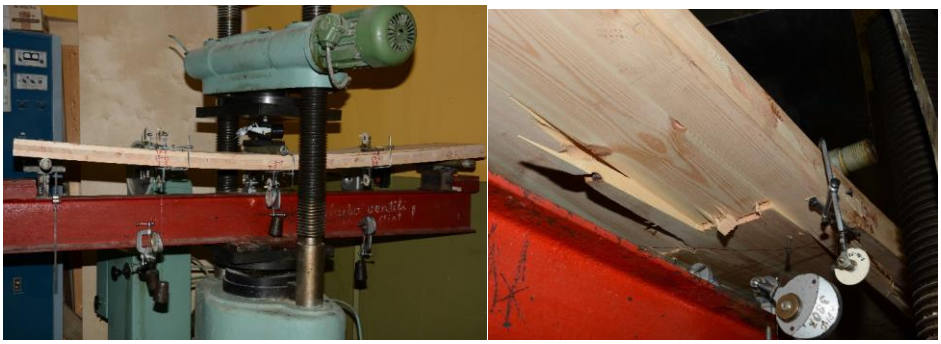
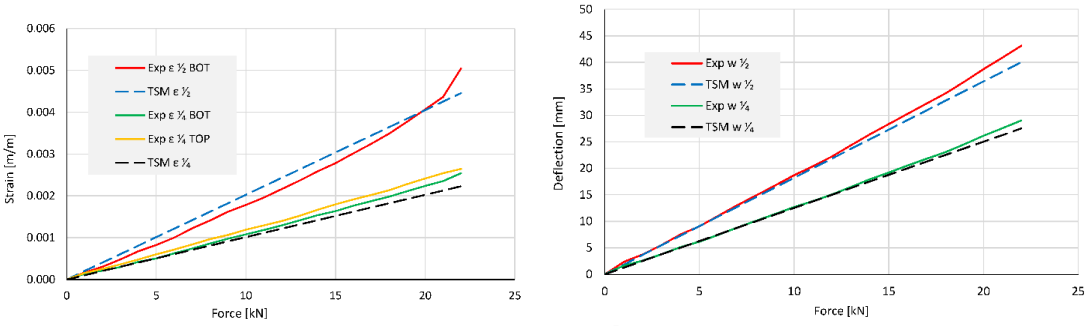


Figure 2. CLT panel before and after collapse.

The experimentally and analytically received results showed that the difference between results obtained experimentally, by reduced cross-section method and FEM differs in the limits from 0.1 up to 20.23 %. The cross-laminated timber panels with dimensions 2x0.35 (Fig. 2) and total width 60 mm were selected as an object of investigation. The dimensions of inner and outer boards are equal to 20x110 mm. The orientation of outer layers of the panel boards is parallel to the panel longest side. The orientation of inner layer is perpendicular to the outer layer boards. The boards are glued together with polyurethane glue under 600 kg/m2 pressure. The C24 timber was used for manufacturing of the panels.



a) b)

Figure 3. Dependence of vertically applied force to a) theoretically and experimentally obtained deformations and b) maximal vertical displacements for CLT panels shown on Fig. 2. Exp w1/2 – the results obtained experimentally at the middle of the span, Exp w1/4 – results obtained experimentally at the one fourth of the span; TSM – results obtained by reduced cross-section method.

Due to simplicity of the offered method and high precision level, the offered design method is declared as effective method for calculation of cross-laminated timber panels in bending and compression-bending.

The designed structure allows decreasing the material consumption of the steel cables by 25%. The medium size pedestrian-bicycle restressed suspension bridge with span 60 m and width 5 m was developed. The deck of the suspension bridge is made of cross-laminated timber panels of C24 timber with span equal to 5 m and width equal to 2 m. The required thickness of the panels based on the serviceability limit state is equal to 180 mm, that corresponds to L5s(40-30-40-30-40) panel. The cable truss with vertical suspenders and coincident in the centre of the span main and stabilisation cables based on the calculation of different types of cable trusses is selected as the most rational one from the point of view of material consumption. The cables of the cable truss are made of steel ropes of steel wires with steel core with an elastic modulus of 100 GPa. The suspenders have a step equal to 2 m. The camber of the main cables is equal to L/10=6m, the camber of stabilisation cable is equal to L/20=3m. The level of prestressing of stabilisation cables is equal to 531.6 MPa, which is equal to 63.3 % of the cable design tensile strength. The cross-section areas of the cables are shown on Fig. 4.

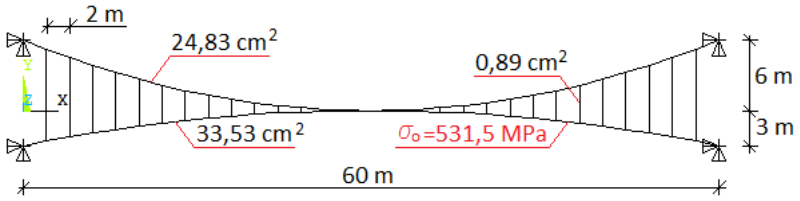


Figure 4. The parameters of the designed suspension bridge.

Two physical models of prestressed cable bridge were developed. The models have span equal to 2.17 m and width 0.5 m. The verification of numerical models was completed using physical models. Two cases were checked: with deck resisting longitudinal compression forces and with deck not resisting compression forces. The camber of the main cable of the model is equal to 1/10 L = 0.217 m and the camber of stabilisation cable is equal to 1/20 L = 0.109 m. The model of the bridge was divided into 14 parts by vertical suspenders with step 0.155 m. The deck of the model is made of 14 panels, which are connected to the stabilisation cables only in vertical direction. The horizontal movement of the deck panels is allowed. The design resistance of the cable is equal to 840 MPa. The WSC type ropes were used for the model of suspension bridge. The prestressing of the stabilisation cables of the models was realized by rotating the nut and moving the rod. The model with the deck not resisting longitudinal forces was prestressed by the load in stabilization cables equal to 905 kg. The model with the deck resisting longitudinal forces was prestressed by the load equal to 907 kg. The deck of the model was made of 6.5 mm thick and 600 mm long five layered plywood Riga Ply sheets. Plywood sheet behaviour is similar to CLT as it is also orthotropic material. The connection of the deck and cables is realized by U-type clamps.

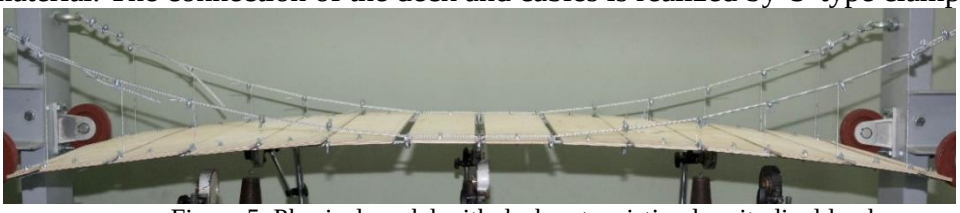
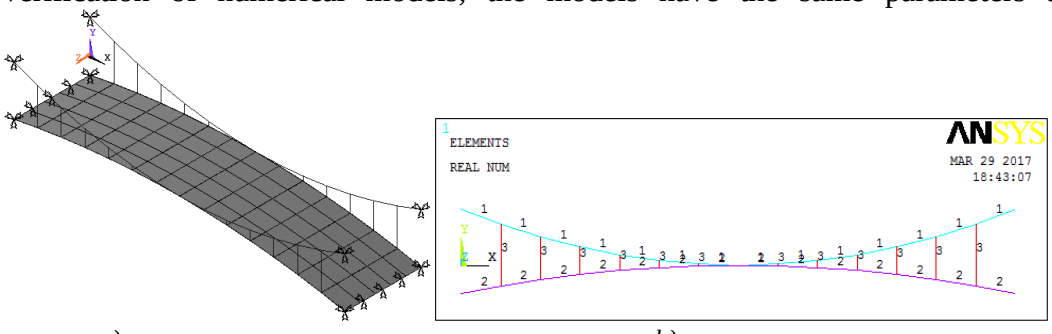


Figure 5. Physical model with deck not resisting longitudinal loads


Figure 6. Physical model with deck resisting longitudinal loads

Two (2D and 3D) finite element numerical models were developed. The development of the models was realized in ANSYS 12.1 software, using APDL parametric programming language. For verification of numerical models, the models have the same parameters as physical ones.



a) *b)*

Figure 7. 2D (a)) and 3D(b)) numerical models of suspension bridge.

Based on the results analytical expressions predicting bridge maximal vertical displacements depending on the applied load were obtained.

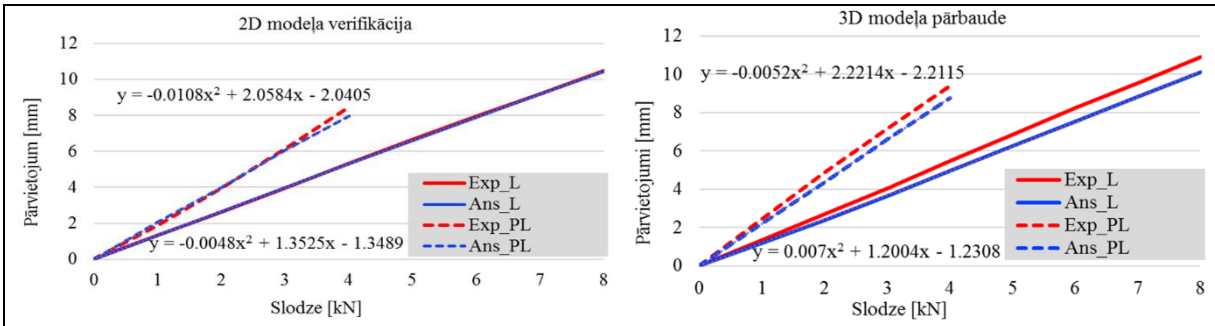


Figure 8. Maximal vertical displacements depending on different loading grades. Exp – experimental results, Ans – ANSYS calculated results, L – load applied to full span, PL – load applied to half span.

The vertical displacements at the centre of span of the model with the deck not resisting longitudinal forces depending on the applied load applied to full span are described by the following expression: y = -0,0108x2 + 2,0584x - 2,0405. The vertical displacements of the model with the deck not resisting longitudinal forces depending on the applied load to half span are described by the following expression: y = -0,0048x2 + 1,3525x - 1,3489.

The vertical displacements at the centre of span of the model with the deck resisting longitudinal forces depending on the applied load applied to full span are described by the following expression: y = -0,0052x2 + 2,2214x - 2,2115. The vertical displacements of the model with the deck resisting longitudinal forces depending on the applied load to half span are described by the following expression: y = 0,007x2 + 1,2004x - 1,2308.

The comparison of results obtained by the physical models and calculated bu numerical models showed, that the developed numerical models can precisely describe the behaviour of the prestressed suspension bridge and could be used for analysis of the bridge with span 60 m.

Based on the comparative calculations of different types of cable trusses the cable truss with vertical suspenders (Fig. 9) is uses as innovative structure allowing decreasing material consumption up to 55% comparing with other types of cable trusses.

Figure 9. Rational from the point of view of material consumption type of cable truss.

Based on the optimization results it was proved that usage of cross-laminated timber panels resisting longitudinal forces as bridge deck allowing decreasing the material consumption of cables. The material consumption of the cables of structure with the deck **not resisting** longitudinal forces is equal to 3.77 t. The material consumption of the cables of structure with the deck **resisting** longitudinal forces is equal to 2.83 t. The offered structure allowing decrease material consumption by 25%.

The applied optimization algorithm is depicted on Fig. 10.

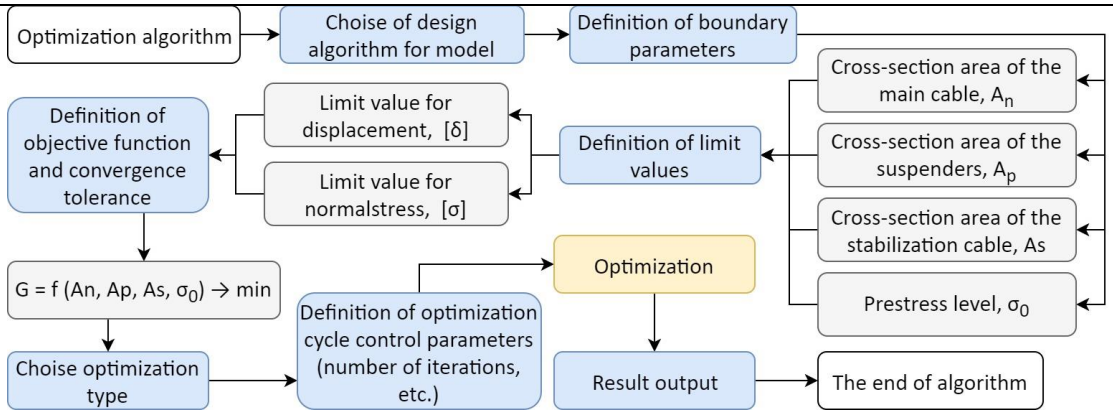


Figure 10. Optimization algorithm

Based on the results obtained by optimization the maximal vertical displacements of the structure with the deck **resisting** longitudinal forces could be decreased by 20% in comparison with structure with the deck **not resisting** longitudinal forces.

PART 2: PROGRAMME PROJECT INFORMATION

2.1. Project No. 4

Title	***Layered wooden composite with rational structure and increased specific bending strength***		
Project leader's name, surname	Jānis Šliseris		
Degree	Dr. sc. ing.		
Institution	Institute of Structural Engineering and Reconstruction		
Position	Senior researcher		
Contacts	*Phone number*		26214882
	E-mail		janis.sliseris@gmail.com

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 varying 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.

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 obtained results by loading up to 1/200 of a span does not exceed 15%).

The calculation method of specific load bearing capacity in bending has been developed. It is based on specific adapted algorithm that generates the input files for ANSYS APDL and optimizes the geometrical parameters of plate depending on aim and restrictions of variables. For example, to provide the same load bearing capacity in bending as birch plywood with thickness of 30 mm (class

E, EN 636:2012+A1:2015) by using global polynomial with obtained coefficients. It has been determined that the required total thickness of plates with cell type hollow core is 14% larger but at the same time the material consumption is reduced for 50%.

Recommendations for production of plates with cell type hollow core have been created in the form of guidelines. They include the design principles of rational geometrical parameters taking into account the geometry and the required load level.

The technological principles for plate with cell type hollow core have been created. They include the manufacturing of cell type hollow core and the plates consisting of such ribs. The method of production of cell type hollow core is based on obtaining the shape of waved rib part with distancing laths and gluing the peaks of waved rib parts to the straight rib part or to these distancing laths. Detailed description of this method is given in applied patents LV14979 and LV15083.

Part of the achieved results have been showed in 13 publications and in 2 valid held patents.

Time frame for the core tasks is given in Annexe 4-A.

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 4 „ *Layered wooden composite with rational structure and increased specific bending strength"* were fully achieved.
All tasks for achieving the project aim have been completed.

2.3. Description of gained scientific results

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

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.	***The set of plate samples have been produced and experimentally investigated to compare with numerical measurements.***
The plate models were created and experimental investigations have been done. Series of plate specimens with thickness of 25 mm and 50 mm have been produced (with practical application in transport industry and furniture production). The plate models for determination of properties in longitudinal directions and related models for determination of properties in transversal direction of ribs were tested. 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. Experimentally determined the load bearing capacity of plates in four point bending by loading up to limit of serviceability limit state (for most typical case according to manufacturing – the thickness of straight rib part 6,5 mm and waved rib part with 4 waves along the span, in confidence interval with probability of 95%). For example, the load bearing capacity in bending for the plates with thickness of 50 mm in longitudinal direction is 2162 ± 55 N·m/m, but in transversal direction of ribs it is 960 ± 33 N·m/m. The difference between calculated and experimentally obtained results by loading up to 1/200 of a span does not exceed 15%.	
4. Recommendations development for design of geometrical parameters of plates with hollow cell type ribs.	***The recommendations have been developed for the design of plate's structure providing the highest possible specific load bearing capacity in bending for given level of load bearing capacity (and/or limited thickness of a plate) in bending.***
Development of recommendations for plates with cell type hollow core have been created in	

the format of guidelines. They include the design principles of rational geometrical parameters of the developed structure. The numerical calculations show that the developed methodologies provide the possibility to calculate the parameters of the plate's structural elements depending on the geometrical requirements of plate, loading type and restrictions. In all cases the structure of the plate and the determination method of structure have been tailored to the required application. It has been determined that it is possible to replace the plywood or cross laminated timber (CLT) providing equal load bearing capacity in bending, and at the same time, reducing mass of structures. Comparing to plywood, by using of plates with cell type hollow core, it is possible to increase the specific load bearing capacity (load bearing capacity to the unit mass) in bending for up to 60%. Plates with cell type hollow core depending on the thickness and the topology of ribs could be used in a wide range – transport industry, furniture production and for structural applications in civil engineering.

5. Recommendations' development manufacturing and 'work in' technology principles and produce plates' demonstration models.	***Developed fundamental principles of manufacturing technology and produced the demonstration models.***

The technological principles for plate with cell type hollow core have been created. They include the manufacturing of cell type hollow core and the plates consisting of such ribs. The method of production of cell type hollow core is based on obtaining the shape of waved rib part with distancing laths and gluing the peaks of waved rib parts to the straight rib part or to these distancing laths. The produced pre-products of hollow ribs are sawn in lanes with the width equal to the thickness of core. Experimental investigations show that the bond pressure has influence on variation of shear and tensile properties of glued connection between skins and ribs – by increasing the bond pressure from 0.3 to 0.5 MPa the coefficient of variation decreases in average for 30% but from 0.3 to 1.0 MPa it decreases in average for 50%. To consider the technological principles a special laboratory equipment has been made for production of plates and pre-product of cell type hollow ribs providing required bond pressure. Three type demonstration models have been created with various structure or consisting element materials.

Prepared documents as deliverables:

No	Tasks	Deliverable	Responsible partner	Status
1	Development of methodology for determination of bending strength and conceptual experimental investigations of plates with cell type hollow ribs	Methodology	Institute of Structural Engineering and Reconstruction	Completed
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.	Methodology	Institute of Structural Engineering and Reconstruction	Completed
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	Tests results of plate models	Institute of Structural Engineering and Reconstruction	Completed
4	Recommendations work out for design of geometrical parameters of plates with hollow cell type ribs	Recommendations	Institute of Structural Engineering and Reconstruction	Completed
5	Recommendations' work out manufacturing and 'work in' technology principles and produce	Technology fundamental principles and	Institute of Structural Engineering and Reconstruction	Completed

	plates' demonstration models	demonstration models		

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 obtained results calculated with this methodology. The difference between calculated and experimentally obtained results by loading up to 1/200 of a span does not exceed 15%
- 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 for maximizing the specific load bearing capacity in bending for given loading case. The difference between calculated and experimentally obtained results by loading up to 1/200 of a span does not exceed 15%
- Plate models with the most typical case of ribs for various thicknesses (25, 30, 50, 100 and 150 mm) of plates have been designed and produced. Experimental investigations have been done to determine the deformability and specifics of fracture depending on the topological structure of a plate. The obtained results approved that the main specifics (depending on plate's structure) of deformability and fracture have been taken into account in the developed model of calculations.
- The developed fundamental principles for manufacturing technology that includes the method of production of cell type core and providing bond between skins and cell type core.
- Provided recommendations as guidelines for the design of rational parameters that harmonize the section stress field with material resistance field of the developed structure.

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 as an input file code in ANSYS ADPL where the geometry of plate, properties of materials and applied boundary conditions are defined in a parametrical way. ANSYS finite element module calculates the stiffness of a plate and stress-strain field by using this code depending on geometry of plates. 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 detailed designed of the plywood consisting parts (ribs and skins) and their behaviour were designed by using 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 δ (displacement jump across the interface) is defined with division in normal δ_n and tangential (shear) δ_t separation. The ultimate normal σ_{max} and ultimate tangential stresses τ_{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 experimental investigations were made to determinate the obtained 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 obtained that stress-displacements curves are non linear behaviour and it is possible to take into account the properties of glued line by design of plates finite element model. 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 thicknesses of skins, geometry of ribs depending on the load and required geometry of a plate with taking into account the behaviour of glued zones (and the stress states in elements of plates and their interfaces) between consisting elements of ribs as well as between ribs and skins. Samples with the most typical case of ribs and various thicknesses (25, 30, 50, 100 and 150 mm) were made (figure 1). to determine the load bearing capacity of plate in longitudinal and transversal directions (according to EN 789).

Figure 1. 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.

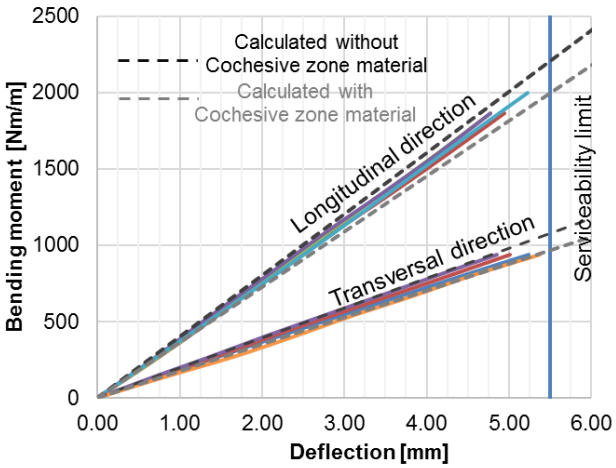


Figure 2. Bending moment – deflection charts (by loading up to serviceability limit) for the plates with cell type hollow core and the thickness of 50 mm in longitudinal and transversal directions. (span 1100 mm; thickness of skins - 4,0 mm; straight rib part- 6,5 mm; waved rib part- 4,0 mm).

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

The calculated deformative characteristics are determined to be in the limits of coefficients of variation for longitudinal direction the mean value of 5% and in transversal direction 9% that show the small dispersion of the plate properties.

If the thickness-to-span ratio remains up to 1/22, then theoretically obtained load bearing capacity from serviceability limit state is 4 times smaller as it is from ultimate limit state, although this ratio decreases by increasing this ratio and at ratio 1/10 the determinant becomes the ultimate limit state. In this case it is the failure of plate's skins. For the transversal direction this ratio remains in level of 4 until thickness-to-span ratio 1/10.

The maximal allowable load levels and the influence on specific load bearing capacity have been determined depending on geometrical parameters of skins and cell type hollow core. The main factor that have the influence on allowable loads that the plate can resist are the total thickness of a plate, thicknesses of skins and the straight rib part as well as the shape of waved rib part. The constant intensity and 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.

The geometrical parameters of plate's structure and the behaviour of joints between ribs and skins should be taken into account for the design of plates. Additional the method of manufacturing of cell type hollow ribs and the technological principles of assembly of plates also have been developed during the project. The method of production of cell type hollow core is based on obtaining the shape of waved rib part with distancing laths and gluing the peaks of waved rib parts to the straight rib part or to these distancing laths. The produced pre-products of hollow ribs are sawn in lanes with the width equal to the thickness of core. The steps that should be done for the production of cell type ribs from standard plywood or other sheet material, have been showed in figure 3.

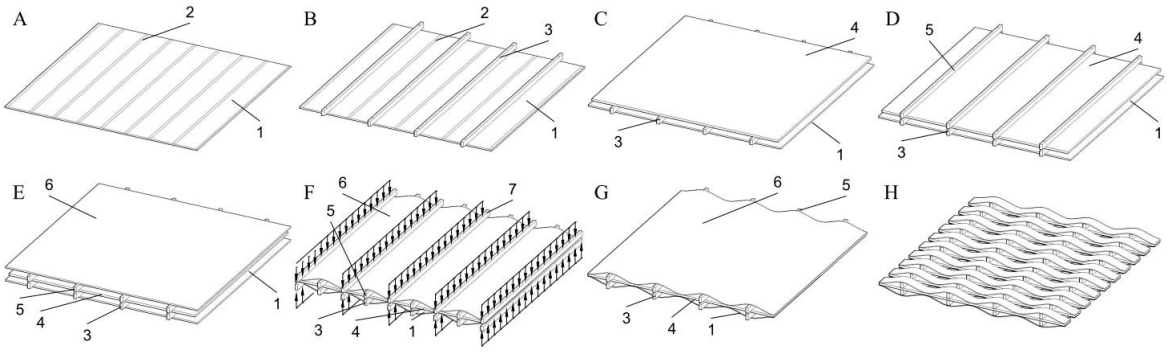


Figure 3. Method of production of cell type hollow ribs

1,6 – plywood sheet for the waved rib part; 2 – applied glue layer; 3, 5 – laths with thickness equal to the maximal height of hollow; 4 – plywood sheet for straight rib; 7 – applied bond pressure for gluing;

The production of plates with cell type hollow core includes these phases:

a) preparation of sheet materials for plate's skins;
b) production of cell type core pre-product and joining the sawn separate rib into blocks;

c) in step b obtained ribs joined together by gluing peaks of near placed ribs which are matched to the dimensions of a plate geometry;
d) lamination of core layer structure achieved in step c at the same time from both sides (bottom and top) with the sheet materials from step a and with the pressure till the bond between core and skins are partly or completely provided.

Figure 4. Part of the equipment for production of cell type hollow core in compressed state

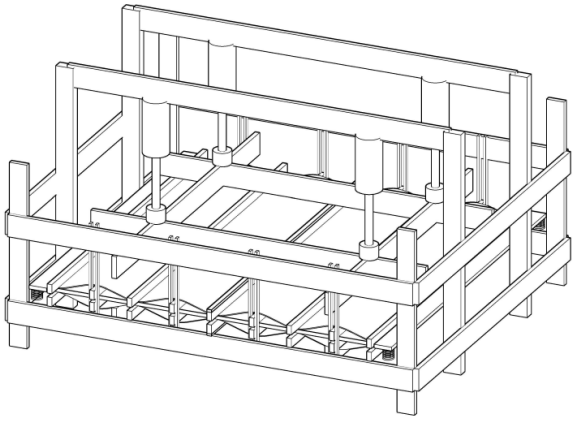


Figure 5. Sketch of equipment for production of cell type hollow rib pre-products

Figure 6. Pre-products of cell type ribs

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 described in patents LV14979 and LV15083. The approbation of technological potentialities and 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 50mm when the straight rib part is 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.

The laboratory equipment (fig 4 - 6) has been made for production of plates and pre-product of cell type hollow ribs. Hydraulic jack (50 kN) was used to apply the load. The dynamometer was used to measure the applied load and to calculate the pressure on plates with accuracy of ±0.01 MPa. The movable plate provides uniformly distribution of pressure along the fixed plane. With this laboratory equipment can be produced plates with dimensions of 1500×850 and thickness up to 250 mm. 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 7. Demonstration model with recycled granulated insulation, without insulation and with polyurethane foam insulation

.

The recommendations for rational design of plates with cell type hollow core have been developed based on developed methodologies for calculations as a guidelines.

Several ribbed plates have been compared to the plywood depending on serviceability limit state. The results showed that ribbed plates have higher specific load bearing capacity – plates with cell type hollow ribs showed up to 50% higher but plates with only straight ribs up to 100% higher as plywood plates (figure 8.).

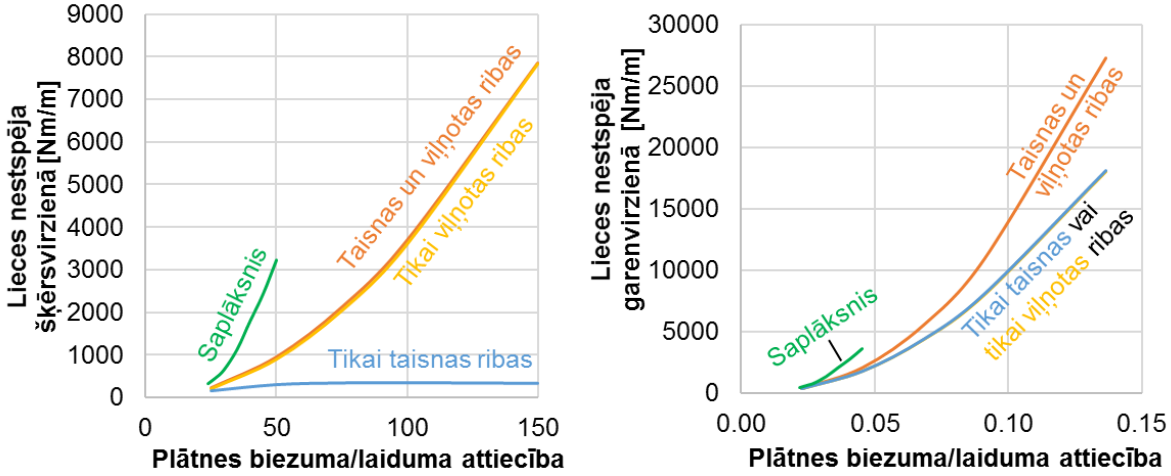


Figure 8. Plywood, plates with straight ribs, plates with waved ribs and plates with cell type hollow ribs. Load bearing capacity A – longitudinal direction; B – transversal direction.

When the load bearing capacity in bending is compared in transversal direction, it has been obtained that the plates with only waved ribs show better results (for about 17 %) over plates with cell type hollow core, because the straight rib part works mostly in longitudinal direction but in transversal direction it has minor influence although the mass of plate increases. When compared to the plates with only straight ribs, the specific load bearing capacity in bending is about 58 % higher for plates with thickness of 50 mm and with the tendency to increase by increasing the thickness or thickness-to-span ratio of a plate (figure 9). The plywood has similar specific load bearing capacity in transversal direction as the plates with waved ribs.

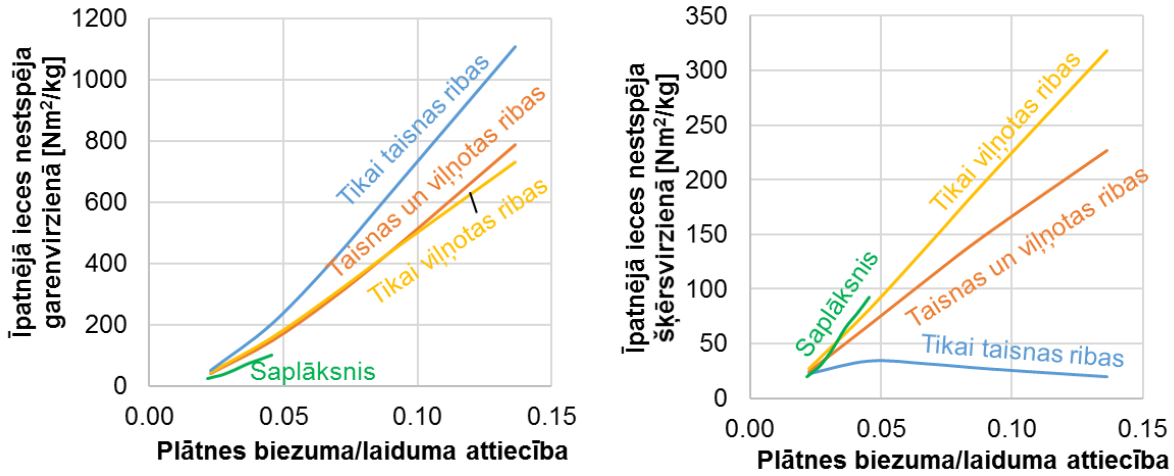


Figure 9. Plywood, plates with straight ribs, plates with waved ribs and plates with cell type hollow ribs. Specific load bearing capacity A – longitudinal direction; B – transversal direction.

It has been established that the outer ply of curved rib part has minor influence on the load bearing capacity (loading till the serviceability limit, in this case 1/200 of a span) of a plate therefore it is easier to produce plates with straight rib part with outer ply direction in longitudinal direction of a plate but the distancing laths and the outer fiber direction of waved rib part in the direction of plates thickness. In that way the reduced stresses in waved rib parts and the reduced compressive forces are required to produce the rib pre-products and make process of production simplified. The recommendations provides not only guidelines for design of geometrical parameters depending on load bearing capacity but also provides the design of heat transfer parameters and the evaluation of plates behaviour in variable moisture conditions.

To expand the practical use of this material additionally to the planed tasks the research about steel joint and the buckling problems were done and could be used as carrying elements of these plates. In additional the influences of temperature and moisture changes on the behaviour of the wood material have been investigated. The special bar type finite elements have been developed which take into account non-linear material properties and crack propagation.

The actuality of these plates and obtained results confirms the achieved first place award at international Invention and Innovation Exhibition MINOX 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).

2.5. Dissemination and outreach activities

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

Participation in international scientific conferences:

1. 3rd International Conference „Innovative Materials, Structures and Technologies", Riga, Latvia, 29.09-30.09.2017.
2. 11th International Scientific and Practical Conference "Environment. Technology. Resources" Rezekne, Latvia, June 15-17, 2017.
3. 12th International Conference "Modern Building Materials, Structures and Techniques" in Vilnius, Lithuania, on 26.05 – 27.05.2016.
4. 5th International Conference "Advanced Construction" in Kaunas, Lithuania on 06.10. – 07.10.2016.
5. 2nd International Conference „Innovative Materials, Structures and Technologies", Riga, Latvia, 30.09-02.10.2015.
6. 10th International Scientific and Practical Conference "Environment. Technology. Resources" Rezekne, 18.06. – 20.06.2015

In the Project „ Layered wooden composite with rational structure and increased specific bending strength" **13 full papers were published or accepted for publishing** (see Annexes):

In scientific journals with SNIP>1:

1. Sliseris, J., Andrä, H., Kabel, M., Wirjadi, O., Dix, B., & Plinke, B. (2016). Estimation of fiber orientation and fiber bundles of MDF. Materials and Structures/Materiaux Et Constructions, 49(10), 4003-4012. doi:10.1617/s11527-015-0769-1 (SNIP 2016 1.533)

https://www.scopus.com/record/display.uri?eid=2-s2.0-84951917178&origin=resultslist&sort=plf-f&src=s&sid=28dc041dbae47f52964087758063be4d&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=7&citeCnt=1&searchTerm=

2. Sliseris, J., Andrä, H., Kabel, M., Dix, B., & Plinke, B. (2017). Virtual characterization of MDF fiber network. European Journal of Wood and Wood Products, 75(3), 397-407. doi:10.1007/s00107-016-1075-5 (SNIP 2016 1.056)

https://www.scopus.com/record/display.uri?eid=2-s2.0-84976318982&origin=resultslist&sort=plf-f&src=s&sid=28dc041dbae47f52964087758063be4d&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=3&citeCnt=1&searchTerm=

In conference proceedings:

1. Frolovs G., Sliseris J., Rocens K., Optimal design of plate with cell type hollow core, IOP Conference Series: Materials Science and Engineering Volume 251, Issue 1, 25 October 2017.

https://www.scopus.com/record/display.uri?eid=2-s2.0-85034435002&origin=resultslist&sort=plf-f&src=s&sid=20af7ca55f5dc9694e72ee826fa1b093&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2855986835100%29&relpos=0&citeCnt=0&searchTerm=

2. Sliseris J., Gaile L., Pakrastins, L. Rocens K. Numerical analysis of behaviour of cross laminated timber (CLT) in blast loading. IOP Conference Series: Materials Science and Engineering Volume 251, Issue 1, 25 October 2017

https://www.scopus.com/record/display.uri?eid=2-s2.0-85034450921&origin=resultslist&sort=plf-f&src=s&sid=f2f54296c162e9e34643ec5dc124af3d&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=1&citeCnt=0&searchTerm=

3. Kukule A., Rocens K. Bending behaviour of insulated ribbed plywood plate during drying of accumulated moisture IOP Conference Series: Materials Science and Engineering Volume 251, Issue 1, 25 October 2017

https://www.scopus.com/record/display.uri?eid=2-s2.0-85034433303&origin=resultslist&sort=plf-f&src=s&sid=5372fec3bc19bde83fe14f037b3e41e2&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2855927991900%29&relpos=0&citeCnt=0&searchTerm=

4. Sliseris J., Gaile L., Pakrastins, L. Rocens K.Non-Linear beam finite element based on extended-multiscale method for modeling of complex natural fiber reinforced beams. Vide. Tehnologija. Resursi - Environment, Technology, Resources Volume 3, 2017, Pages 304-309

https://www.scopus.com/record/display.uri?eid=2-s2.0-85028387902&origin=resultslist&sort=plf-f&src=s&sid=f86c73123ad98393260a904503b6c370&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=4&citeCnt=0&searchTerm=

5. Frolovs G., Rocens K., Sliseris J. Shear and tensile strength of narrow glued joint depending on orientation of plywood plys Procedia Engineering, Volume 172, 2017, Pages 292-299

https://www.scopus.com/record/display.uri?eid=2-s2.0-85016310467&origin=resultslist&sort=plf-f&src=s&sid=024428cf66e2e42c3b7c7c37d6d353b5&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2855927991900%29&relpos=3&citeCnt=0&searchTerm=

6. Kukule A., Rocens K., Lukasenoks A., Frolovs G. Change of Moisture Distribution in Ribbed Plate with Different Opposite Surface Temperatures Procedia Engineering, Volume 172, 2017, Pages 612-619

https://www.scopus.com/record/display.uri?eid=2-s2.0-85016309510&origin=resultslist&sort=plf-f&src=s&sid=d20469def772b59494b55737c247d5f1&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2855927991900%29&relpos=4&citeCnt=2&searchTerm=

7. Sliseris J., Gaile L., Pakrastins L. Deformation process numerical analysis of T-stub flanges with pre-loaded bolts Procedia Engineering, Volume 172, 2017, Pages 1115-1122

https://www.scopus.com/record/display.uri?eid=2-s2.0-85016250149&origin=resultslist&sort=plf-f&src=s&sid=388d9cc02fdb5bc0e746c26e33a485e4&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2836133799800%29&relpos=5&citeCnt=0&searchTerm=

8. 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

https://www.researchgate.net/profile/Jurate_Kamicaityte-Virbasiene2/publication/312231432_Subjective_Identity_of_Kaunas_Cityscape_Research_Results_and_Their_Relation_with_Objective_Indicators_of_Urban_Structure/links/58779c6a08aebf17d3bb9661/Subjective-Identity-of-Kaunas-Cityscape-Research-Results-and-Their-Relation-with-Objective-Indicators-of-Urban-Structure.pdf

9. Frolovs G., Rocens K., Sliseris J. Glued Joint Behavior of Composite Plywood Plates with Cell Type Core, IOP Conference Series: Materials Science and Engineering Volume 96, Issue 1, 2 November 2015, Article number 012048.

https://www.scopus.com/record/display.uri?eid=2-s2.0-84960329140&origin=resultslist&sort=plf-f&src=s&sid=795791af09828ea077af13d62046c5fd&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2855927991900%29&relpos=7&citeCnt=1&searchTerm=

10. A. Kukule, K. Rocēns Prediction of Moisture Distribution in Closed Ribbed Panel for Roof, IOP Conference Series: Materials Science and Engineering Volume 96, Issue 1, 2 November 2015, Article number 012034.

https://www.scopus.com/record/display.uri?eid=2-s2.0-84960461862&origin=resultslist&sort=plf-f&src=s&sid=98f4b800465cc58e1067474db31e056f&sot=autdocs&sdt=autdocs&sl=18&s=AU-ID%2855927991900%29&relpos=6&citeCnt=0&searchTerm=

11. Frolovs G., Rocens K., Sliseris J. Comparison of a Load Bearing Capacity for Composite Sandwich Plywood Plates, Environment, Technology, Resources Volume 1, 2015, Pages 39-45

http://journals.ru.lv/index.php/ETR/article/download/633/609

Applied and 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

The following doctoral theses were successfully pre-defended:

1. 07.09.2017. Organized seminar in framework of Institute of Structural engineering and reconstruction with successful pre defence of G. Frolovs's doctoral thesis "Design principles of rational structure of sandwich plates with cell type hollow ribs" (participants 15, protocol Nr. 1/2017.)

Doctoral thesis within project 4:

1. A.Kukule "Kukule "Behaviour of plywood ribs in various conditions of moisture" (supervisor J.Sliseris)

3 master's thesis and 2 bachelor's thesis have been prepared and defended within Project 4.

Master's thesis:

1. I. Ucelnciece "Impact of snow loads on different types of roof shapes"" Supv. D. Serdjuks un G. Frolovs 2015;
2. A. Žukovska-Kečedži, „ Wind load action depending on the roofs shape" Supv. D. Serdjuks un A. Kukule 2015;
3. A.Levics "Experimental comparison of compressive and flexural strength between 3D printed and monolithic fibro concrete" Supv. J.Šliseris 2016.

Bachelor's thesis:

1. I. Matveja "Validation of plywood panels' comparison and methodology of calculations" Supv. Ģ. Frolovs 2017.
2. G. Švalbe '' Combined office building made of timber (Structural timber frame and three layer timber log construction Supv. J.Šliseris 2017.

New research projects, preparation of project proposals and participation:

The research is partly extended in framework of ERANet project "Development of eco-friendly composite materials based on geopolyer matrix and reinforced with waste fibers" (Budget 18998.40 EUR in year 2017), as well as Riga Technical university grants in academic year 2015./16. for J. Šliseris (8000 EUR) and in academic year 2016./17. for Ģ. 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. Applied project in cooperation with RTU faculty of architecture and Forest and Wood Products Research and Development Institute with project "Smart wood, spatial modelling of glued wood structures and development and testing of joints" in framework of RTU Science and Innovations.

Performance indicators of the program and project promotion:

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 at annual reports in extra organized IMATEH sections in international scientific conferences.

Organized seminars with participation of supporting and other companies which have showed interest about research done in framework of IMATEH Project No. 4.

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/slanains-koksnes-kompozitmaterials-ar-palielinatu-ipatnejo-lieces-nestspeju/).

The cooperation project between RTU Institute of Building and Reconstruction, Fraunhofer ITWM institute and The Baltic-German University Liaison Office was realized in 2014.

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 receives a salary from MeKA for this research.

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 analyse its application ways at enterprises.

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

Tasks of Period 1	*Task 1.* Development of research methods for diagnostics of early destruction of surface of polymer composite materials: the method to research influence of aquatic microorganisms on early destruction of materials. *Task 2.* Development of research methods for diagnostics of early destruction of surface of polymer composite materials: the method to research visual recognition of early destruction using destruction-induced staining.
Tasks of Period 2	*Task 1.* Development of research methods for diagnostics of early destruction of surface of polymer composite materials: the method to research influence of aquatic microorganisms on early destruction of materials. *Task 2.* Development of research methods for diagnostics of early destruction of surface of polymer composite materials: the method to research visual recognition of early destruction using destruction-induced staining.
Tasks of Period 3	*Task 1.* Development of methods for diagnostics of early destruction of surface of polymer composite materials: by 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.
Tasks of Period 4	*Task 1.* To analyse possibilities to apply methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – for manufacturing of polymeric pipes for drinking water. *Task 2.* To analyse possibilities to apply methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – for manufacturing of machinery and engineering constructions.

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

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

The goal of the Project No.5 is fully achieved. 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)

Tasks of Period 4	The main results of Period 4
1. To analyse possibilities to apply methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – for manufacturing of polymeric pipes for drinking water.	***1. The method has been developed.*** ***2. It has been found that in the presence of bacteria, the elastic modulus of polymer pipes changes. Bacteria accelerate the early destruction of the polymer.*** ***3. Mechanical loading of the polymer does not influence concentration of bacteria in water.***

The applicability of the developed *in situ* electron emission spectroscopy (EES) method to detect early destruction of drinking water polymer pipes was analysed. The method was tested taking into account needs of the polymer pipe manufacturer EVOPIPES Ltd.

1.1. Influence of organic substances released from the walls of polymer pipes and chlorine on increase in concentration of bacteria in drinking water.

To evaluate the effect of distribution system bacteria and chlorine on polymer material pipes, batch experiments were performed. Glass bottles were filled either with 5 times concentrated tap water (water was passed through 0.1 µm filter and then bacteria were released in smaller water amount using ultrasound) or 20x chlorine dosage (4 mg/l). Then pipe samples were introduced and bottles were placed on an orbital shaker. The suspensions were replaced with fresh ones every 7 days. 'Old' and 'fresh' solutions were analysed using flow cytometry (cells/ml), cultivation on agar plates (CFU/ml) and chlorine concentration.

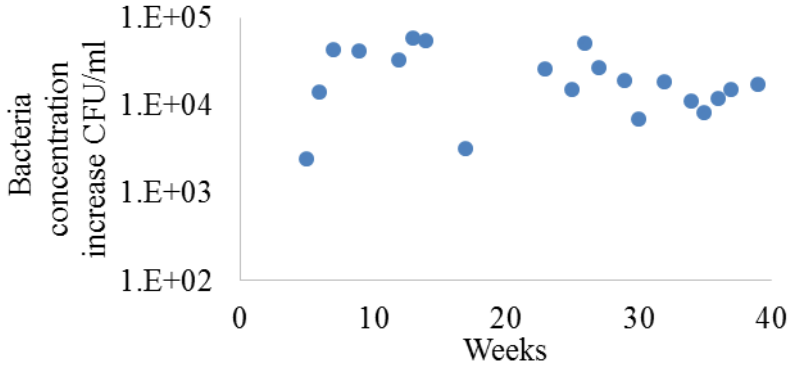


Fig. 1. Increase in concentration of bacteria in water with polymeric pipes.

At the beginning the concentration of bacteria able to multiply (CFU/ml) was $5.23 \cdot 10^3$ per ml, but after 7 days it increased to $1.94 \cdot 10^4$ cells/ml. It is important to note, that similar cell increase was observed also in control samples (without added pipe samples).

The concentrations of the total and free chlorine were 4.40±1.02 mg/L and 3.56±1.13 mg/L respectively. Seven days later both concentrations were 0 mg/L.

The obtained results show that concentration of bacteria in water increases irrespective of presence of pipe samples. The increase in concentration of bacteria may be related to the elevated temperature (20° C room temperature versus 10°C in the drinking water distribution system) or aggregation of organic matter from water.

1.2. Mechanical properties of polymer pipes depending on time of treatment with bacteria or chlorine

Typical force-strain diagram of PE80 pipe is shown in Fig.2. The plastic deformation of the pipes starts at a strain ε=6 %.

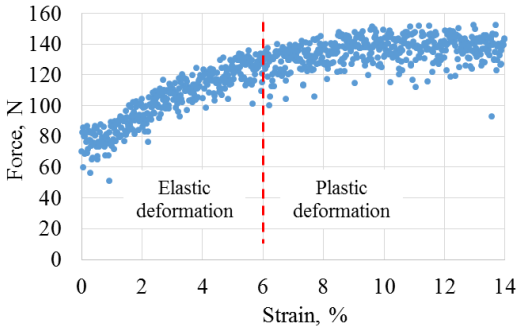


Fig. 2. Typical strain-force curve of PE80 pipe.

To study influence of bacteria on mechanical properties of the pipes, the pipe samples were treated with 5 times concentrated tap water (the bacteria were concentrated using filter) or water with 20 times increased concentration of chlorine (4 mg/l). After treatment with bacteria or chlorine, the pipe samples underwent tensile tests during which photoelectron emission (PE) was measured from the stretch site. PE was excited by illuminating the stretch site with ultraviolet (UV) light. From the obtained elongation-force curves, relative changes of elastic modulus of polymer pipes were calculated depending on pipe treatment time with bacteria or chlorine. The modulus of elasticity increased as the treatment time of pipes with bacteria or chlorine increased (Fig. 3).

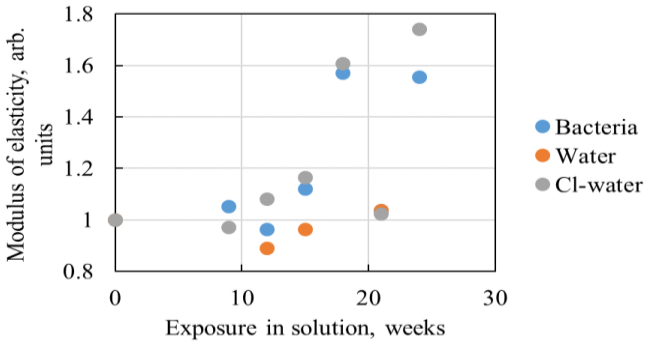


Fig. 3. Relative increase in elastic modulus of the pipes depending on treatment time with bacteria or chlorine

Early destruction of the pipes was studied by analysing changes in PE current in the elastic deformation region (up to 6 % strain). It was observed that the amplitude of PE current oscillations increases with increase in treatment time of the pipes with bacteria (Fig. 4). It the 2016 reporting period, it was shown that the increase in PE current relates to the formation of micro/nano cracks in a material, because electrical potential of a crack surface is reduced compared to the material around it. The obtained results indicate that micro/nano are formed in the walls of polymer pipes under influence of aquatic bacteria.

The increase of PE oscillation amplitude was not observed after treatment of the pipes with chlorine.

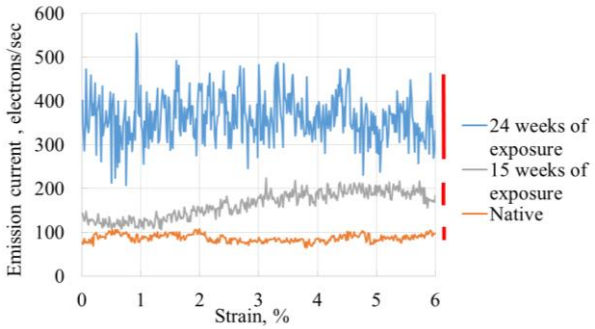


Fig. 4. Amplitude of PE oscillations depending on the pipe treatment time with aquatic bacteria

Based on the obtained results, a recommendation has been developed for the use of the EES method for the detection of early destruction of polymer pipes:

• To study the early destruction, it is necessary to register PE from the loading site of the pipes during their tensile deformation and to observe changes of the PE in the elastic deformation region. Increase in the oscillation amplitude of PE current indicates the occurrence of early destruction (formation of micro/nano cracks).

2. To analyse possibilities to apply methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – for manufacturing of machinery and engineering constructions.	***1. The suitability of the EES method to detect early collapse of composite materials has been demonstrated.*** ***2. The suitability of EES method to determine and regulate mechanical properties (elasticity modulus, strength) of composite materials (by using electromagnetic radiation and charged nanoparticles) has been demonstrated.*** ***3. A patent application about fabrication method of a nanostructured composite with charged nanoparticles has been developed and submitted.*** ***4. A set of mechanical parameters of microcapsules has been determined and a mechanical model has been developed that allows to fabricate smart composite materials that have ability to detect the early collapse visually.***

2.1. Suitability of the EES method to detect early collapse of composite materials exposed to electromagnetic radiation and advanced composites.

2.1.1. Composites exposed to electromagnetic radiation

The suitability of EES method was analysed taking into account needs of the representative of Latvian industry – AVIATEST Ltd. The company tests composite materials for aviation engineering which are particularly employed in electromagnetic radiation conditions (radars, etc: frequency ≥1 MHz [2,3], power 160–1500 W [4]).

Influence of radiation on mechanical properties of composites reinforced with carbon nanotubes (CNT) was analysed. The samples of the composites were exposed to electromagnetic radiation (600 W, 2.450 MHz), and then the elastic modulus was measured. It was determined that both CNT concentration and the radiation exposure increase the elastic modulus (Fig. 5). However, at CNT concentrations above 0.75 % the elastic modulus had a tendency to decrease.

[2] https://en.wikipedia.org/wiki/Air_traffic_control_radar_beacon_system#The_interrogation; 2017.11.16.
[3] https://www.itu.int/dms_pub/itu-r/oth/0A/0E/R0A0E0000710001PPTE.ppt; 2017.11.16.
[4] https://en.wikipedia.org/wiki/Airport_surveillance_radar; 2017.11.16.

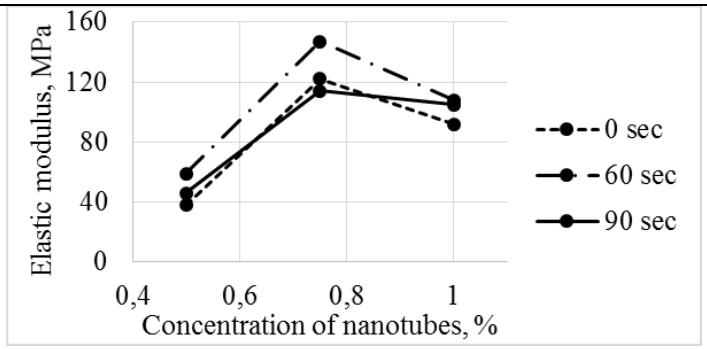


Fig. 5. Influence of exposure of electromagnetic radiation and CNT concentration on the elastic modulus

The approbation of EES method shows that the emission of electrons begins when elastic deformation reaches 1–1.5 % or 30 % from the beginning of the elastic deformation region. The strain corresponding to appearing of emission (ε_E) decreases if the exposure to electromagnetic radiation increases (Fig. 6). However, when the exposure increases from 60 to 90 seconds, the ε_E tends to increase. This allows to put forward a hypothesis that the exposure above 60 sec 'hardens' the material.

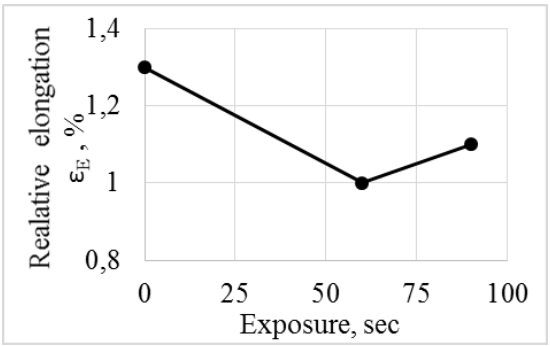


Fig. 6. Influence of exposure of electromagnetic radiation (600 W, 2.450 MHz) on strain that corresponds to the start of PE from ONC-reinforced composite (ONC concentration 0.5 %)

It was also observed that the filtered Fourier image of PE current (frequency 3.5 Hz, filter window ±0.5 Hz) forms antinodes (Fig. 7).

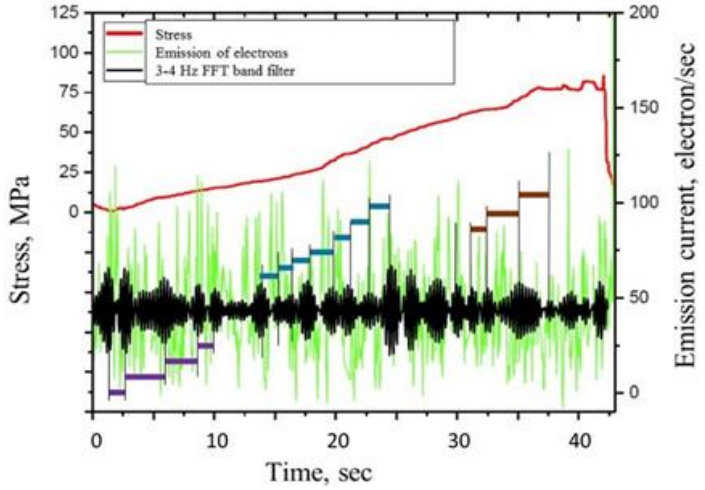


Fig. 7. The antinodes of the filtered PE signal detected during the tensile deformation

The time distances (violet straight segments) between the antinodes recorded at the elongation ε < εE are not equal (random lengths). Upon reaching the εE, the time distances (blue straight segments) between the antinodes become approximately equal. However, as the deformation continues, reaching the inelastic deformation area, the time distances (brown straight segments) are

not equal again.

The following is recommended based on the results achieved above:

1. When composite materials with CNT are designed, the CNT concentration 1% is preferable versus the smaller one. In this case, it is possible to achieve material with increased resistance to high frequency electromagnetic radiation.
2. EES signals about the early destruction of the CNT reinforced composites as follows: increase in PE current; the emission signal filtered Fourier image delivers the antinodes, the time intervals between them being equal at the destruction beginning step (while before and after this area the time intervals are "chaotic").
3. EES method may be suitable for the detection of early destruction of CNT composite material, starting at ~30% from the elastic deformation region, i.e. ~ 70 % before its end.

2.1.2. Application of the method to advanced composites

2.1.2.1. Composite reinforced with electrically charged nanoparticles

Nanoparticles are used to improve mechanical properties of polymer composites. To achieve this, adhesion between the nanoparticle surface and the polymer binder has to be provided. To achieve this, surface of a nanoparticle is being functionalized, for instance, by coating the surface with chemical agent that provides chemical coupling between the nanoparticle and the binder [5].

Following the general adhesion theory[6], the attractive and repulsion forces compete to connect the particle surface to the binder. Because the repulsion employs electrical fields[5] nanoparticles with an electrical charge arranged at their surface could be engaged to design the reinforced composite and control its mechanical properties. Such possibility is demonstrated for the first time in the project.

Silicon dioxide (SiO2) nanoparticles with diameter 10–20 nm were electrically charged with UV radiation. The deposited charge was identified by measuring the photoelectron work function (increase of the photoelectron work function indicates negative charging of the particle surface).

It was identified that positively charged nanoparticles promote increase in the strength (σ) and the elastic module (E) of the composite (Fig. 8).

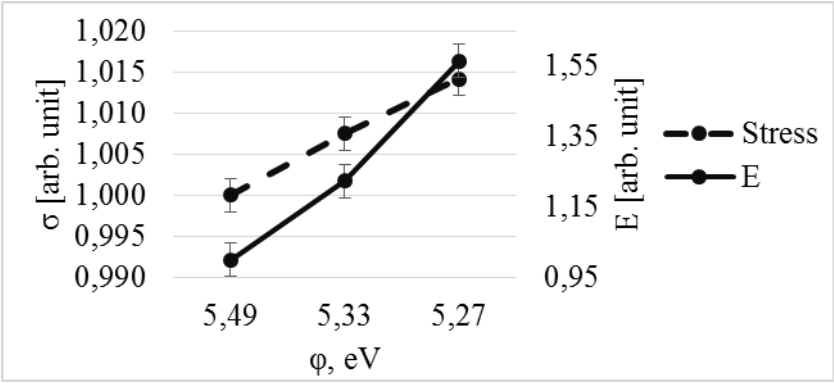


Fig. 8. The correlation of σ and E with the photoelectron work function (φ) of embedded nanoparticles (concentration 1.5%)

The possibility to use EES method to detect early destruction of the described composite was verified. An electron emission filtered Fourier image has the antinodes. Their amplitude increased at ε = 0.02 of the elastic deformation beginning, i.e. at ~ 35% of the total elastic deformation region (Fig. 9). Besides, similar to Fig. 7, the time intervals between the antinodes became approximately

[5] Q.Yuan, R.D.K. Misra. Polymer nanocomposites: current understanding and issues. *Materials Science and Technology. 2006*, Volume 22, Issue 7, 15.

[6] Derjaguin B.V., Landau L.D. *Acta Physic Chimica*, USSR, **14**, 633-642, (1941)

equal, starting at $\varepsilon > 0.02$, that was not the case when $\varepsilon < 0.02$.

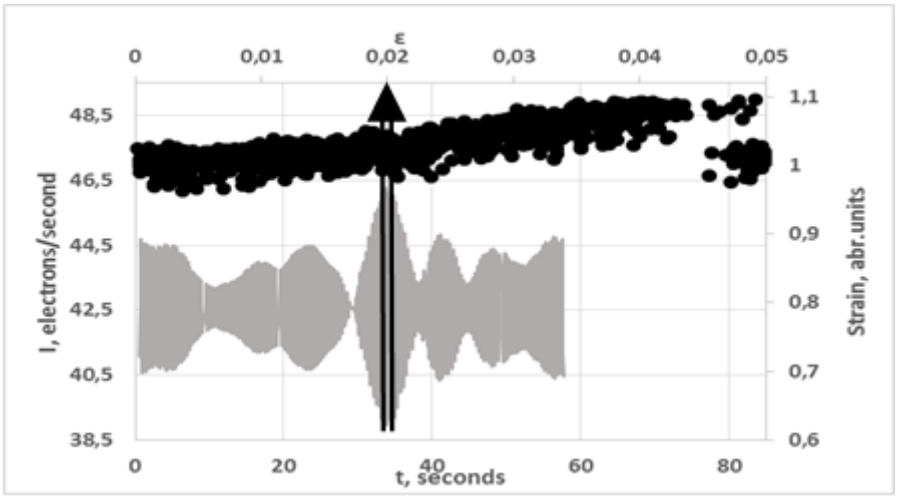


Fig. 9. Filtered (frequency 2.8 Hz, filter window ±0.1 Hz) image of the emission signal and deformation curve for composite material with charged nanoparticles

The following is recommended based on the results achieved above:

1. It is possible to design composite materials reinforced with the dielectric nanoparticles having a charged surface: positively charged nanoparticles increase the strength and the elasticity modulus of the material.
2. EES method could be employed to identify early destruction of the composite reinforced with charged nanoparticles: the emission signal filtered Fourier image antinodes amplitude sharply increases and the time distances between antinodes become equal.
3. EES method is able to recognize early destruction of the composite material reinforced with the charged nanoparticles, starting at ~35% from the beginning of the elastic deformation, i.e. ~ 65% to its end.

2.1.2.2. Composite material reinforced with glass fibres

The suitability of EES method to detect early destruction of the composite reinforced with glass fibres has been tested under condition of multiple loading in the elastic deformation region.

The emission current increases after each cycle of the loading, while each loading had the same mode (Fig. 10). The emission current begins at $\varepsilon \geq 0.4$ %, (at about 30 % from the beginning of elastic deformation); the elongation at which the emission starts does not depend on number of loading cycles.

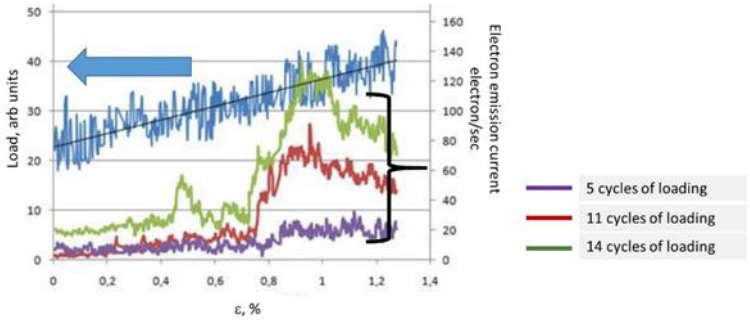


Fig. 10. The emission current in dependence on the number of loading cycles at elastic deformation region

The following is recommended based on the results achieved above:

1. EES method is able to identify early destruction of the composite materials reinforced with the glass fibres: the emission signal increases at ~ 30% from the beginning of elastic deformation region, i.e. ~ 70% before of the elastic deformation end.
2. Multiple loading of the composite materials with glass fibres at the elastic deformation

region increases the emission current after each cycle of loading; this indicates an intensification of the destruction induced by the cyclic loading.

2.2. Suitability of the visual recognition method to detect early destruction of polymer composite materials

2.2.1. Development and verification of the numerical model of mechanical properties of microcapsules

It is known that mechanical properties of the sensitive layer is closely related to the mechanical properties of microcapsules. Prediction of the mechanical properties was performed based on structural principles of mechanics. To calculate the properties of the sensitive layer, the coefficient of volume filling was chosen, which is closely related to geometric parameters of the microcapsules. Using data from SEM, the diameter of the microcapsules was determined. The diameter is in the range of 0.7–12 μm, the shell of the microcapsule is around 0.1 μm.

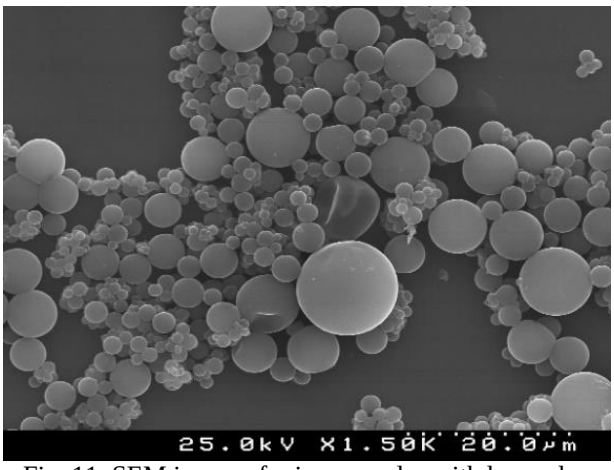


Fig. 11. SEM image of microcapsules with leuco dye


Fig. 12. Tensile testing of the film

To determine the mechanical properties (stiffness and strength) of the microcapsules, the indirect method was used. Properties of a composite (films with integrated microcapsules) with known concentration of the microcapsules were measured. Effective properties of the microcapsules were calculated from the measured data.

The samples – the films with integrated microcapsules had different types of matrix. To prepare the films, a glass substrate was used. Typical thickness of the film was 0.8 mm. After the preparation, the films underwent tensile tests to determine their properties.

Data from the tensile tests were used in further calculations. To determine E-mod of the microcapsules, indirect method – the Rule of mixture, was applied:

Voight model $$E_c = E_f \cdot V_f + E_m \cdot V_m$$

Reuss model $$E_c = \left[\frac{V_f}{E_f} + \frac{V_m}{E_m}\right]^{-1},$$

where E_m is elastic modulus of the matrix and E_f is the one of the filler;
V_m is volume fraction of the matrix and V_f is the one of the filler, $V_m + V_f = 1$.

By applying the Rule of mixture, it is possible to define the theoretical upper limit (Voight model) and lower limit, where the real values are located between the limits. For the experimental data, films with microcapsules were prepared and tested on tensile. After data processing, the correlation between E-mod and concentration of microcapsules in the films was established.

Two cases were analysed:

1) E-mod of the matrix is lower than E-mod of the filler (Fig. 13): $E_m \ll E_f$

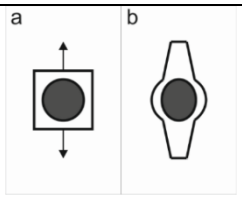


Fig. 13. Before (a) and after (b) the applied load

In his case:

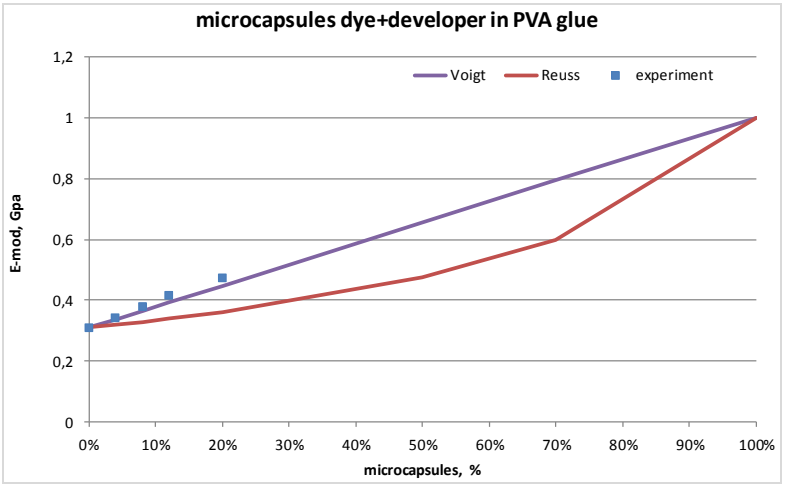


Fig. 14. Experimental (■) and theoretical (–) values: E-mod vs. concentration of microcapsules in the films (PVA glue)

2) E-mod of the matrix is bigger than E-mod of the filler (Fig. 15): $E_f \ll E_m$

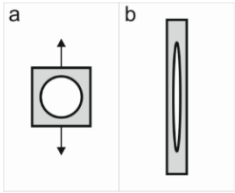


Fig. 15. Before (a) and after (b) the applied load

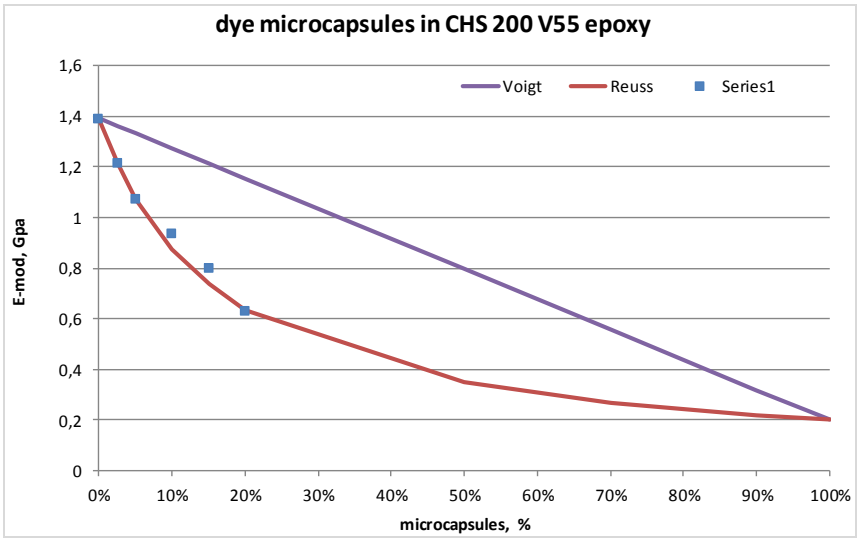


Fig. 16. Experimental (■) and theoretical (–) values: E-mod vs. concentration of microcapsules in the films (epoxy resin)

In the first case better results were observed with the *Voight model*, in the second with the *Reuss model*.

For the direct measurements of mechanical properties of the microcapsules the atomic force microscopy (AFM) was used. Nano indentation allows to determine the maximal force needed for

the rapture of a microcapsule and to calculate E-mod. A typical curve with load till capsule rupture (deformation vs. applied load) is shown in Fig. 17.

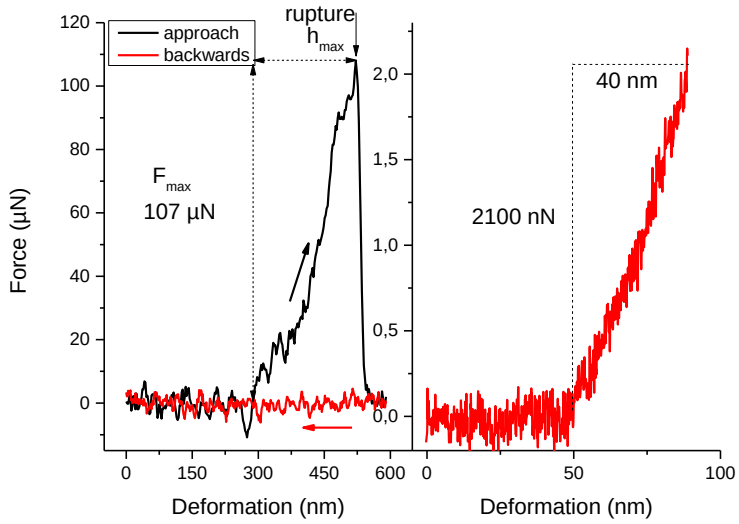


Fig. 17. Typical curve of the nano indentation process: direct contact of indenter with microcapsule

E-mod was calculated by applying the thin shell theory: $E = 0.43*FR/(dH^2)$, where E- mod of microcapsule, d – ½ of deformation, H – shell thickness, R – radius of microcapsule, F – applied load. For the calculations the linear interval of nano indentation process was used. The average value of E-mod calculated from the AFM data is 3.5 GPa.

The results of the reporting period allow to make a model of the mechanical properties of the microcapsules before and after applied load.

The total results of the project allow to manufacture smart composites with integrated ability to change colour in the place of overload in accordance with the requirements of industry. Namely, different methods to manufacture smart composites were developed, threshold of sensitivity and methods to control it were defined, mechanical properties of the material were determined, different parameters for the modelling were determined.

The following Deliverables were delivered (submitted as electronic annexes):

No.	Task	Deliverable	Responsible partner	Status
1.1	Development of research methods for diagnostics of early destruction of surface of polymer composite materials: the method to research influence of aquatic microorganisms on early destruction of materials	Research method for development of diagnostics of early destruction of surface of polymer composite materials using *in situ* electron emission spectroscopy (31.12.2015)	J. Dehtjars, Institute of Biomedical Engineering and Nanotechnologies, RTU	Delivered
1.2	Development of research methods for diagnostics of early destruction of surface of polymer composite materials: the method to research visual recognition of early destruction using destruction-induced staining	Research method for development of diagnostics of early destruction of surface of polymer composite materials using destruction-induced staining (31.12.2015)	A. Aņiskevičs, Institute of Material Mechanics, University of Latvia	Delivered
2.1	Development of methods for diagnostics of early destruction of surface of polymer composite materials: the method for	Method for diagnostics of early destruction of surface of polymer composite materials using *in situ* electron emission	J. Dehtjars, Institute of Biomedical Engineering and	Delivered

	diagnostics of early destruction using *in situ* electron emission spectroscopy; the method for diagnostics of early destruction, based on influence of aquatic microorganisms.	spectroscopy (31.12.2016)	Nanotechnologies, RTU	
2.2	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 (31.12.2016)	A. Aņiskevičs, Institute of Material Mechanics, University of Latvia	Delivered
3.1	To analyse possibilities to apply methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – for manufacturing of polymeric pipes for drinking water	Recommendations on application of diagnostic methods in manufacturing of polymeric pipes for drinking water (31.12.2017)	J. Dehtjars, Institute of Biomedical Engineering and Nanotechnologies, RTU	Delivered
3.2	To analyse possibilities to apply methods for diagnostics of early destruction of surface of polymer composite materials in enterprises – for manufacturing of machinery and engineering constructions	Recommendations on application of diagnostic methods in machinery manufacturing and engineering constructions (31.12.2017)	A. Aņiskevičs, Institute of Material Mechanics, University of Latvia	Delivered

2.4. Further research and practical exploitation of the results

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

The project goal is fully achieved. To achieve the project goal, two novel methods to detect and research early destruction of polymers and composites have been developed, and applications of these methods for the needs of commercial enterprises have been demonstrated.

The first method (the EES method) is based on *in situ* detection of PE from micro/nano cracks that form in a composite material during its early collapse. Micro and nano cracks that form at the beginning of destruction influence electronic properties of the surface. Therefore, to detect the destruction process, it is necessary to study surface electronic properties. The cracks appear chaotically at the surface layer of a material, which makes it difficult to predict the localization of the cracks and to observe the cracking process if the measurements are fixed at a nanoscale. The developed EES method allows to control the surface area at a millimetric scale that covers the whole expected area of crack formation. Nevertheless, the measurements provide information on the processes taking place in surface nano layer.

It was already known that electrons are emitted from the surface layer of a material during mechanical destruction[7]. Energy for the electron emission is provided as a result of crack formation. This type of emission appears without any additional stimulation and can be used to detect the destruction. However, the formation of cracks changes electron density due to the rearrangement of atoms which also affects electron work function (φ). If photons are used to excite the emission of electrons, the emission current (I) depends on φ, especially when photon energy (E) slightly (with accuracy of kT, k – Boltzmann constant, T – temperature in degrees Kelvin) exceeds φ:

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

[7] 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.

Since the exponent $m>1$, a slight change of φ influences the current I significantly. UV light is used to excite the PE.

During 1st reporting period, the equipment that registers PE from a composite sample during its tensile loading was adjusted. Parameters of the optical system were optimised. A method to fabricate samples was developed and the shape of the samples was optimised to perform tensile tests. Experiments were launched on the ability of polymer pipes to leach organic substances which can serve as nutrients for aquatic bacteria into drinking water.

During 2nd reporting period, it was established that changes in PE current in the elastic deformation region indicate an early destruction of the material. These changes can be explained by structural changes in the material due to which intensity of PE increases.

It was found that number of Evian water consortium bacteria and E.coli bacteria increases in water after contact with polymeric pipes. Increase in number of Evian water consortium bacteria is a normal phenomenon because this is a common environment for this type of bacteria. Multiplication of E.coli, however, indicates that polymeric pipes can promote growth of faecal bacteria in case of unintentional or intentional contamination of water supply systems.

During 3rd reporting period, it was shown that it is necessary to make grooves – concentrators of mechanical stress, in the place where the sample is illuminated with UV radiation. In this case, the deformation location coincides with the location of UV illumination. The difference in the registered forces for the samples with the concentrator does not exceed the dispersion of the forces that are recorded for samples without the concentrators. An optical filter was selected which selects corresponding wavelength from the light source's spectrum to provide the condition $E \geq \varphi$. By using AFM Kelvin probe method, it was shown that micro/nano cracks and the surrounding material have different surface electrical potentials. Surface potential of the crack is reduced compared to the material around the crack. The reduced potential promotes increase in electron emission from the crack. This was proved by performing tensile tests and observing increase in PE current. At the same time, sawtooth-shaped oscillations of PE current were observed, which may be related to breaking or restructuring of atomic or molecular bonds during deformation.

The development of a novel epoxy resin composite material with charged SiO2 nanoparticles as a filler was launched. Surface electric charge of the nanoparticles promotes coupling between the nanoparticles and the epoxy matrix, thus improving the mechanical properties of the composite.

It was shown that polymeric pipes leach organic substances into water under influence of elevated temperature (e.g. accelerated aging process of the pipes) and this promotes multiplication of bacteria.

During 4th reporting period, application of EES method to address problems of the industry was studied. Taking into account the needs of AVIATEST Ltd., early collapse of composite materials used under conditions of elevated electromagnetic radiation in aviation was studied. As an example, behavior of a composite material filled with CNT was analyzed simulating the operating conditions in aviation. It was found that the material hardens when exposed to high radiation, and CNT concentration of 1 % improves the radiation resistance of the material. The start of early destruction of the material is evidenced by increase in PE current and by equal time intervals between the antinodes in the Fourier image of PE signal. It is possible to use the developed EES method in the elastic deformation region, starting at 30% from the beginning of the elastic deformation.

It was proved that it is possible to fabricate nanocomposites with charged dielectric nanoparticles as a filler. Positive charge of nanoparticle surface increases strength limit and elasticity modulus of the nanocomposite. A patent application about fabrication method of the nanocomposite with charged nanoparticles was filed at the Patent Office of the Republic of Latvia. To detect early destruction of the nanocomposite with charged nanoparticles as a filler, EES method can be used in elastic deformation region, starting at 35 % from the beginning of the elastic deformation region.

To detect early destruction of a composite material reinforced with glass fibre, EES method can be used in the elastic deformation region, starting at 30% from the beginning of the elastic deformation region.

Taking into account the needs of EVOPIPES Ltd., early collapse of polymeric pipes under influence of aquatic bacteria was studied. It was found that under normal conditions (without mechanical influence or high temperatures), concentration of bacteria in drinking water increases irrespective of the presence of polymer pipes in water. Obviously, the largest amount of organic material is released into water from the pipes due to mechanical stress. However, it was found that elasticity modulus of the pipes increases if the pipes are treated with the water with bacteria for prolonged time. It was also observed that oscillation amplitude of the PE current increases when treatment time of the pipes with bacteria increases. This result shows that micro/nano cracks appear in the walls of polymer tubes under action of aquatic bacteria.

The second developed method employs visual recognition of the early destruction process. Micro and nano cracks act as capillaries that can draw up liquids with high wetting ability. If the liquid has colour, this gives possibility to recognize early destruction and visualise its location. In the Project, this method was implemented for composites for the first time. Two types of microcapsules were integrated into the composite: (1) with low viscosity dye and (2) with a developer. 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.

During 1st reporting period of the project, the technology for integration of the microcapsules into the composite was developed; two types of fabrics were selected – glass fabric for the internal layer, and nylon fabric for external layer. For both types of the layers the technology for impregnation with microcapsules was developed. To integrate fibres into the composite, the vacuum assister resin transfer moulding process was used. The threshold for the colouring of the damaged place was determined, as well as the method for the sensitivity control was developed.

During 2nd reporting period, mechanical properties of the composite with integrated sensitive layer were defined. The kinetics of colour change after applied load was measured, as well as the ability to change colour after applied load at different temperatures was evaluated.

During 3rd reporting period, investigations of parameters of the microcapsules was launched – such as size, determination of the mechanical properties by indirect and direct methods. The obtained results were summarized to simulate mechanical properties.

During the final period of the project, investigations of microcapsules were finished. All parameters of the microcapsules required for the development of the model were defined. Some modelling was performed. The results of the work were summarized making it possible to produce smart composite with the ability to change colour in the place of overload with the required need of application.

In addition, some technical problems were solved, for example, the optimal concentration of microcapsules in smart layer was defined, making it possible to reduce the weight and the total price of the composite.

Possible directions of application of the developed methods:

- Quality control of aviation composites;
- Detection of invisible damage in aircrafts;
- Quality control of boat composites;
- Quality testing of polymer pipes;
- Determination of overload in flak jackets (for example, for military applications).

2.5. Dissemination and outreach activities

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

The results presented below refer to the whole four-year period of project implementation.

The results were disseminated at 11 international conferences:

1. S. Kronberga, J. Dehtjars, I. Kozaks, A. Aņiskevičs. Influence of nanoparticles with charged surface on mechanical properties of a composite material. Riga Technical University 58th International Scientific Conference, October 13, 2017, Riga, Latvia.
2. K. Gruskevica, V. Denisova, I. Kozaks, A. Lobanovs, J. Dehtjars, M. Romanova. The effect of bacteria on the destruction of the drinking water distribution system polymer pipes. *3rd International Conference "Innovative Materials, Structures and Technologies"*, September 27-29, 2017, Riga, Latvia
3. J. Dehtjars, K. Gruškeviča, M. Romanova, A. Aniskevich, O. Bulderberga. Material mechanical micro- nano- scaled features and their impact on human safety. *3rd International Conference "Innovative Materials, Structures and Technologies"*, September 27-29, 2017, Riga, Latvia
4. A. Aniskevich, O. Bulderberga, Yu. Dekhtyar, A. Korvena-Kosakovska, I. Kozak, M. Romanova. 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.
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. Poster No. PO-3-02, *ECCM17 – 17th European Conference on Composite Materials*, June 26-30, 2016, Munich, Germany.
6. E. Chimbars, Yu. Dekhtyar, I. Kozaks, A. Aniskevich. 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.
7. J.Dehtjars, A. Aņiskevičs, O.Bulderberga, M.Romanova, K. Gruškeviča, A. Balodis. Material mechanical micro- nano- scaled features and their impact on human safety. Riga Technical University 57th International Scientific Conference, October 17, 2016, Riga, Latvia.
8. Ē. Dombrovskis, I. Kozaks, K. Gruškeviča, J. Dehtjars. Diagnostic method for early collapse of polymer pipes under mechanical load. Riga Technical University 56th International Scientific Conference, October 14-16, 2015, Riga, Latvia.
9. A. Aniskevich, V. Kulakov. Express procedure for evaluation of durability of complex shape pultruded composite profiles. *Baltic Polymer Symposium 2015*, September 16-18, 2015, Sigulda, Latvia
10. D. Zeleniakiene, V. Leisis, P. Griskevicius, O. Bulderberga, A. Aniskevich. A numerical study to analyse mechanical properties of polymer composites with smart microcapsules for high performing sensing applications. *Baltic Polymer Symposium 2015*, September 16-18, 2015, Sigulda, Latvia
11. A. Aniskevich, O. Bulderberga, Y. Dekhtyar, V. Denisova, K. Gruskevica, T. Juhna, I. Kozak, M. Romanova. Coloured reactions and emission of electrons towards early diagnostics of polymer materials overloading. *2nd International Conference "Innovative Materials, Structures and Technologies"*, September 30- October 2, 2015, Riga, Latvia

Full-text papers were published or are under review process in journals indexed by Web of Science and Scopus data bases:

1. 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(SCOPUS, ***SNIP 2015 2.055***).

http://www.sciencedirect.com/science/article/pii/S1359835X16000336

2. T. Glaskova-Kuzmina, A. Aniskevich, A. Martone, M. Giordano, M. Zarrelli. 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, pp.522-527 (SCOPUS, ***SNIP 2015 2.055***).
http://www.sciencedirect.com/science/article/pii/S1359835X16302822

3. 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. (SCOPUS)

https://link.springer.com/article/10.1007/s11029-016-9568-1

4. 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
5. Yu. Dekhtyar, S. Kronberga, M. Romanova. Towards polymer composite reinforced by electrically charged nanoparticles. International Journal of Adhesion and Adhesives, Elsevier, 10 pp. (under reviewing process, SCOPUS)

One doctoral thesis has been developed:

O. Bulderberga. Polymer composite with damage indication ability: development and determination of properties. Supervisor A. Aņiskevičs. The pre-defence took place on November 17, 2017 at Institute of Material Mechanics of University of Latvia. (The defence is planned in 2018).

Four master theses were developed and defended:

1. Eriks Dombrovskis. Effect of charged micro/nano particles on early collapse of composite material. Supervisor: Dr.habil.phys. Jurijs Dehtjars, RTU, 2017.
2. Anda Pujate. Homogeneity of polymer composite with charged micro- and nanoparticles. Supervisor MSc. A.Homko, RTU, 2016.
3. Inguna Krista Anspoka. Influence of destruction of composite material on electron emission from composite material surface. Supervisor Prof. A.Balodis, RTU, 2015.
4. Irina Golovko. Influence of plastic water supply material on quality of drinking water. Supervisor Asoc.Prof. K. Tihomirova, RTU, 2015.

Seven bachelor theses were developed and defended:

1. Artūrs Lobanovs. Influence of drinking water bacteria on early destruction of polymeric pipes. Supervisor Dr.Sc.Ing. Marina Romanova, RTU, 2017.
2. Rolands Brenčs. Dependance of mechanical properties of composite material with C - nanotubes on irradiation with high-frequency electromagnetic radiation. Supervisor Dr.habil.phys. Jurijs Dehtjars, RTU, 2017.
3. Sanda Kronberga. Influence of nanoparticles with charged surface on mechanical properties of composite material. Supervisor Dr.habil.phys. Jurijs Dehtjars, RTU, 2017.
4. Edgars Čimbars. High-frequency radiation impact on early collapse of composites with nanotubes. Supervisor Dr.habil.phys. J. Dehtjars, RTU, 2016.
5. Anna Korvena-Kosakovska. Early failure of composite material under mechanical load. Supervisor Dr.Sc.Ing. A. Balodis, RTU, 2015.
6. Ēriks Dombrovskis. Diagnostic method for early collapse of polymer pipes under mechanical load. Supervisor Dr.habil.phys. J.Dehtjars, RTU, 2015.
7. Toms Vāvere. Indirect determination of mechanical properties of polymer matrix spherical fillers. Supervisors Dr.Sc.Ing. Andrejs Aņiskevičs, MSc. Olga Bulderberga, UL, 2015.

Patent application was developed and submitted at Patent Office of Republic of Latvia:

J. Dehtjars, S. Kronberga, M. Romanova, Ē. Dombrovskis, I. Kozaks. Fabrication method of a nanostructured composite. (Submitted on December 14, 2017)

Two novel methods were developed and verified in industrial companies:

1. "Method for diagnostics of early destruction of surface of polymer composite materials using destruction-induced staining", tested and verified at Aviatest Ltd., acknowledgement dated with 7.11.2016.
2. "Method for diagnostics of early destruction of surface of polymer composite materials using in situ electron emission spectroscopy", tested and verified at Evopipes Ltd., acknowledgement dated with 8.11.2016.

2.5. Dissemination and outreach activities

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

Information on the results of the Project is posted on the IMATEH website http://imateh.rtu.lv/materialu-meroga-ipasibas-un-to-ietekme-uz-cilveka-drosibu/

Project results were presented at 3 seminars:

1. December 14, 2017. A seminar at EVOPIPES Ltd., Jelgava, Langervaldes street 2a, project participants presented the methods for diagnostics of early destruction of polymer pipes to industry partners and discussed possibilities for further collaboration with the EVOPIPES Ltd.
2. May 31, 2017, Riga. The project results were presented at Innovation Chamber of Security and Defence Cluster (DAK). Potential application of the results in the areas of security and defence was discussed. The DAK Innovation Chamber was attended by representatives of companies, research institutions and government departments interested in cooperating in the creation of high added value products and services in the security and defence sectors. http://www.federacija.lv/lv/pasakumi/drosibas-un-aizsardzibas-klastera-dak-inovaciju-domnica-31maija
3. May 26, 2015. The project results and performance indicators were presented at a seminar **on the research progress of IMATEH Programme** at RTU.

Six seminars were organized within the framework of the project:

1. September 20, 2017. Possibilities to implement project results for identification of human body protection (for example, hidden blows) were discussed with representatives of Riga Stradins University and the National Guard.
2. March 3, 2016. Seminar at AVIATEST Ltd., Riga, Rēzeknes street 1. The representatives of the industry were introduced to the project results and possibilities of further cooperation were discussed.
3. In 2015 four seminars to discuss project results were organized (13.04.2015, 13.05.2015, 10.09.2015, 21.12.2015). Staff of the institutions involved in the project, as well as students who participated in the research and business representatives were invited to attend the seminars.

Three popular science articles were published (in Latvian):

1. December 6, 2017. A popular science article "Scientists offer methods for anticipating the collapse of materials", https://www.rtu.lv/lv/universitate/masu-medijiem/zinas/atvert/zinatnieki-piedava-metodes-ka-agrini-paredzet-materialu-sabruksanu
2. December 6, 2017. Newspaper "Dienas bizness", an article "Latvian scientists develop methods for prediction of an early collapse of materials", http://www.db.lv/ekonomika/razosana/latvijas-zinatnieki-izstradajusi-metodes-ka-agrini-paredzet-materialu-sabruksanu-469612
3. Latvian popular science magazine "Ilustrētā Zinātne" ("Science Illustrated"), Issue of January 2018, article "Early predictions of material collapse – novel methods will allow to notice material damage faster".

Other project dissemination activities:

1. October 2, 2015. The results and performance indicators of the Project were presented during special session of IMST 2015 conference dedicated to IMATEH Programme: J.Dehtjars “Material mechanical micro- nano- scaled features and their impact on human safety”
2. August 16, 2016. Discussion with EVOPIPES Ltd., Jelgava, Langervaldes street 2a, about the results achieved in the project and possibility to implement them in manufacturing of water pipes.
3. December 12, 2017. Latvian Radio 1 programme about science "Known in the Unknown", (“Zināmais nezināmajā”). The topic of the programme "Safety – the main priority in aviation". Prof. Yury Dehtjar tells how aviation security can be improved by timely detection of nano and micro cracks in aviation composite materials. http://lr1.lsm.lv/lv/raksts/zinamais-nezinamaja/drosiba-galvena-prioritate-aviacija.a96383/
4. December 20, 2017. TV programme of LTV7 channel “Life today” (“Dzīve šodien”). Prof. Yuri Dehtjar tells about the methods of prediction of early collapse of materials developed within the project. https://youtu.be/L9VVWoL-mec

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	Kārlis Agris Gross		
Degree	PhD		
Institution	Riga Technical University		
Position	Lead researcher, Assoc. Professor		
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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 a method and criteria for the optimization of metallic material properties to improve the surface treatment and coating for reduced friction and wear of friction pairs including interaction with metal surfaces and ice.***

Task 1: Characterize the metal surface and determine the best test methods
Outcome: At the commencement of the project, it was thought that a smoother surface will support faster movement between metal and ice. Roughness was defined by scratches and so a controlled technique introduced scratches that were characterized by two contact methods (profilometry and atomic force microscopy) and two non-contact methods (light microsopy and electron microscopy). Profilometry was the least sensitive, since the 2 mm probe could not detect very fine scratches. Atomic force microscopy was the most sensitive, but could not imag large surfaces, so the most appropriate method was .ight microscopy. One journal publication was prepared on this topic.

Task 2: Prepare a test rig for determining the reduction in ice-friction in a climate control room modified to operature at subzero temperatures
REPORT: A method for measuring the sliding speed in laboratory conditions
Outcome: The movement of snow on an angled metal plane is complicated since ice is modified as it moves against a metal surface. To determine the most influential factors that promote the easier movement between ice and metal, it was decided to investigat the movement of a metallic block on ice. Earlier experiments have looked at repeated movement of metal over the same ice area in a short time interval, that encourages melting of the ice. To better understand the relative movement between ice and metal, an angled ice track was developed for measuring the sliding time of metal blocks. The climate control room was equipped with a cooling unit for reducing the temperature to -20 ^{o}C. The angled ice plane was equipped with time sensors to determine the speed at the start and end of the ice track. One patent and a scientific article have been prepared.

Task 3: Modify the metal surface and determine the influence of modifications on the sliding speed
REPORT: A recommendation on surface modifications that improve the sliding speed of metal on ice in laboratory conditions
Outcome: The influence of roughness, hardness and hydrophobicity on sliding speed was evaluated. Metal blocks were imparted 4 different levels of harndess and hydrophobicity. Changes in hardness

did not improve the sliding speed. A larger hydrophobicity led to increases in sliding speed, but plain metal still showed the best sliding performance. A change in the surface roughness showed the best results for increasing the sliding speed.

Task 4: Determine the relationship for a sliding a metal object on ice
REPORT: A relationship between sliding over ice and the surface characteristic
Outcome: A relationship was developed to show the relationship for sliding on ice. The importance of contact area was shown at the macro scale and also at the millemtre scale. Information of the microscale contact area is given in Task 3.

Task 5: Develop a method for improving the sliding of large metal surfsces on ice in real conditions
REPORT 1: A method for determining the sliding speed on a long ice track in real-life conditions compared to laboratory testing.
REPORT 2: A recommendation for modifying the surface to improve the relative movement on ice.
Outcome: A test method for determining the sliding speed was developed on an angled ice track with heavier loads and a larger metal surface area on a longer ice track. This method method will allow the sliding conditions to be investigated at a larer scale. The experiments show that faster sliding is achieved if the metallic surface is abraded with 1500 grade sandcloth under a load of 10 N.

Time frame for the tasks is given in Annex 6.

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

The planned target of the NRP IMATEH Project 6 „ *Modification of metal surfaces for the reduction of friction and wear"* was fully achieved. The planned tasks are completed and the main results obtained.

Three journal articles were planned with a SNIP > 1. One journal article has received this goal, another article is presently under review in Cold Regions and Technology (SNIP >1), and the third article has been redirected to an Open Access journal and is already published. An exceedingly long time was required for the review process requiring a change from the initial plan. An additional two conference papers on different topics from the journal papers have also been written.

2.3. Description of gained scientific results
(Describe scientific results achieved during reporting period, give their scientific importance)

Description of scientific results achieved during reporting period 4:

Tasks for Period 4	Main results
1. Determine how surface modifications influence the sliding speed	***Report: A recommendation on surface modifications that improve the sliding speed of metal on ice in laboratory conditions***

For determining the ice friction, studies can be made by moving ice on steel or steel on ice. Since ice is softer, movement against a harder surface will change the ice surface and also the mass, and so it was decided that more reproducible conditions can be expected from moving steel over ice. Such testing conditions would also provide a safer start into the field of ice-friction that has many unanswered questions. Since many publications have reported on ice friction from movement of metal over ice, then faster progress can be made by comparing out results and also communicating with researchers who have completed those studies.

Three different surface characteristics were changed on steel blocks to investigate the influence on sliding - the surface roughness, the hardness and the hydrophobicity. Firstly, the sliding speed

was determined in the laboratory, and then if a trend was found further tests were made on the field experimnets.

Effect of roughness

Sandpaper was used to impart a roughness to the steel surface, and this was measured with a profilometer. Steel blocks were polished on an autopolisher and then abraded with sand paper by movement in reciprocating direction under a load of 1 kg. To produce a repeatable surface roughness, a guided sides were made on the sandpaper to ensure that the scratches were parallel to each other. The block was moved back and forth on the sandpaper for a total of 10 times. The roughness was measured with a stylus profilometer. Since scratching imparted a waviness and a roughness, the roughness in a random direction could not report the roughness of the ridge at the uppermost part of the surface. It was deemed necessary to scan the entire surface and after locating the ridges, the roughness was then determined along the ridges. Such a reproducible surface roughening operation together with the detailed characterization has not been previously conducted on materials that are then subjected to sliding.

To initiate the study, scratches were made perpendicular to the sliding direction and also parallel to the sliding direction. As expected, the sliding speed was slower with perpendicularly made scratches. This is explained by the combination of waviness and roughness that together lead to a greater friction on ice, a lower acceleration and hence a lower velocity.

The roughness of the sandpaper and the scratches left on polished metal was determined for sandpapers from a number of suppliers. Two types of backing were chosen – cloth and paper. The roughness of a Klingspor 600 grade sandpaper was Ra = 0.17 microns, but the same grit grade 3M and Radex cloth backed surfaces were Ra = 0.08 microns. Abrading polished steel from the different sand supporting abrading surfaces produced totally different levels of roughness. A rougher surface was produced from sandpaper than the cloth-backed sand abrasive. It was decided to prepare surfaces only with cloth backed sand abrasive.

A new testing arrangement was made in a modified climate controlled room for measuring the tilt angle to initiate sliding, and the sliding speed. A cooling unit was introduced into a climate chamber for freezing at sub-zero temperatures down to -20 ^{o}C. An angled ice plane was equipped with four optical sensors for measuring the sliding speed.

The tilt angle to initiate sliding was determined for a steel block abraded with 600 grade sandpaper and a polished steel block. Tests were conducted on two different days. Two different blocks were selected to determine whether the test results were obtained on more than one block. On day 1 (results in blue), the tilt angle necessary to initiate sliding was always lower on the polished surface, Fig 1. On day 2, a lower tilt angle was only found with one of the blocks. The variability in the results did not show a clear difference in the results.

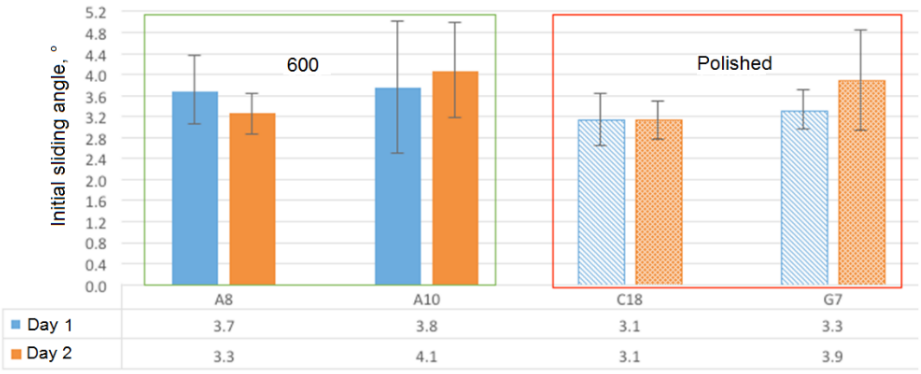


Figure 1. The sliding tilt angle for 600 grade sandcloth and a polished surfaces. Results from the 1st day are in blue, but 2nd day in orange. The labels A8, A10, C18 and G7 refer to the block identification.

The effect of surface roughness was then assessed on the sliding speed. Blocks were abraded with 320, 400, 600, 1500, 2000 and 3000 sandpaper or polished on an auto-polisher to determine

the effect of roughness on sliding speed, Fig 2. The roughness parameter roughness R_{Sm}/S_a, that represents the contact surface showed the critical measure that was required to achieve the best sliding conditions. If R_{Sm}/S_a > 100, then further improvements in the flatness of the surface asperities did not show a faster sliding speed.

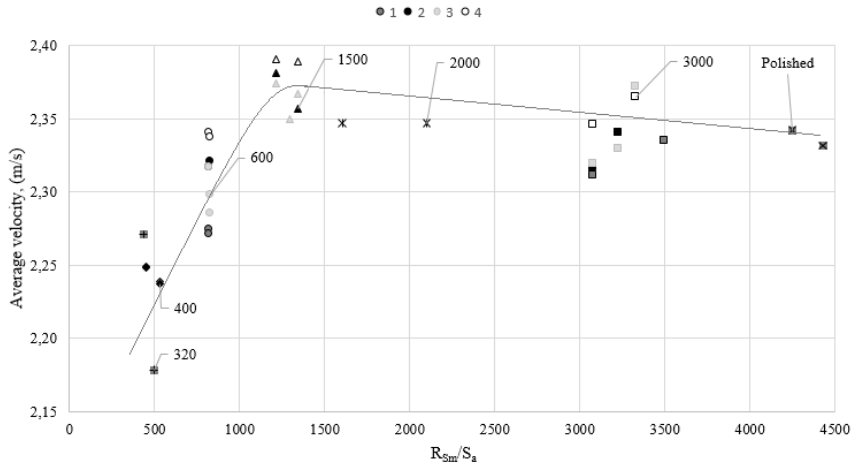


Figure 2. Sliding speed as a function of roughness R_{Sm}/S_a produced by different grades of sandcloth, shown on the curve. Different marker fills indicate different experiment days.

Effect of hardness

The steel blocks were heat treated for changing the hardness to see the effect on sliding speed over ice at -7 ^{o}C. The initial hardness of blocks was 370 HB and it was increased to 435 and 490 HB, for an approximate 25% change in the hardness. Three different steel blocks showed different patterns, and since the results were not repeatable, it was determined that there is no predictable influence of the hardness on sliding speed.

The effect of contact angle

Since the contact angle is best changed with polymers, then standard polymers were chosen for the first step to investigate the influence of contact angle on sliding. Four different polymers were chosen to give a range in contact angle between 72 degrees to 95 degrees, Fig 3. The tilt angle, and the sliding speed were determined. It was found that surfaces with a higher contact angle, initiated sliding at lower tilt angles. If the material initiated sliding more easily, then it was presumed that a higher sliding speed would result. The tests on sliding speed showed that solid surfaces with a higher contact angle slid faster.

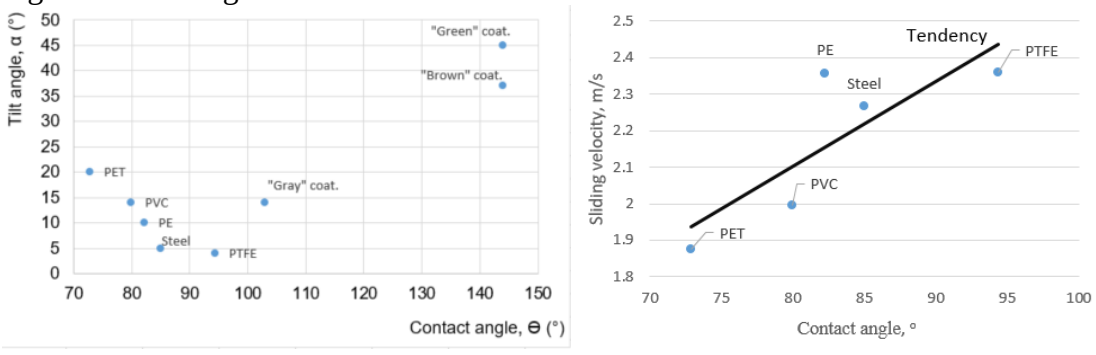


Figure 3. Sliding on ice with contact angle shown as a) the tilt angle at which sliding is initiated, and b) the sliding speed. A comparison is made with steel. For the tilt angle, two superhydrophobic surfaces are included with a contact angle of 145 ^{o}.

Superhydrophobic surfaces involve both a contribution from the solid surface and also from the microstructing of the surface, and so the effect of microstructuring was investigated. The base composition provides a maximum contact angle between 100 and 110 degrees. Further increases in angle are achieved with microstructuring. We chose to apply a thin layer of two hydrophobic powders to the metal surface. The particle size was 8 μm for the finer powder and about 120 μm for

the coarser powder. The tilt angle of the superhydrophobic surfaces, with micro-structured surfaces, was significantly higher than the flat surfaces. This suggests that the contact angle influence is secondary after the roughness.

From the assessment of roughness, hardness and contact angle, it was shown that the most influence is caused by the roughness, followed by contact angle. The hardness did not show any influence on sliding over ice.

This outcome has been summarized from a 30 page report written in Latvian consisting of 24 figures and 7 tables.

2. Determine how surface modifications influence sliding over ice and determine the mathematical relationship	***Report: A relationship between sliding over ice and the surface characteristic***

Experimental results from the laboratory tests on sliding speed of modified surfaces on ice have provided the basis for developing relationships between sliding speed and the surface characteristics. These results showed that the load, the contact area and the coefficient of friction influence the sliding speed, and so mathematical relationships will be provided for each of these aspects.

The model has included several values that have been calculated theoretically, such as the thickness of the water layer and the viscosity of the water. The other parameters are more clear, such as the applied load and the contact area, A.

The sliding velocity, v can be expressed as $$v = \frac{h \cdot \mu \cdot F_N}{\eta \cdot A}$$

where:
A – contact area;
h – thickness of the water layer;
v – sliding velocity;
η – water viscosity;
F_N – applied load;
μ – coefficient of friction.

The contact area has only been previously considered as the macro contact area in contact with the ice. This has been changed by changing the radius of the slider in contact with ice. By introducing a curvature, less of the metal slider is in contact with ice. At the skeleton push-start facility, a 1 meter long slider on a sled made to less contact with ice has led to a faster speed, Fig 1. This trend is observed for both polished surfaces and scratched surfaces.

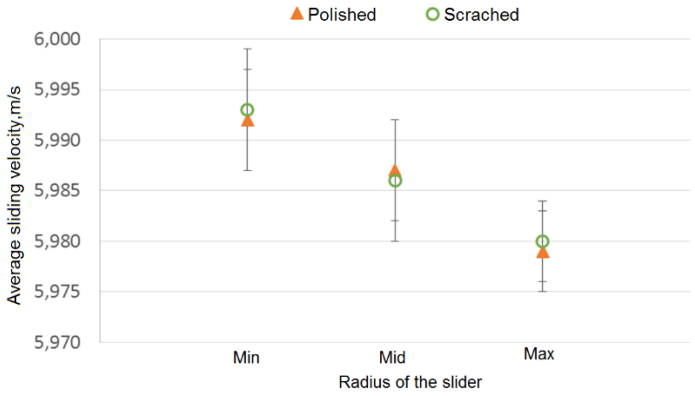


Figure 1. A smaller radius of curvature provides a faster sliding speed.

In the laboratory test, curvature of the metal block can also be present. This curvature arises from automatic polishing, where the sides and corners of the metal block are preferentially removed, leaving a central raised section. The stylus profilometer has measured this as the geometry of the surface, Figure 2. Assuming that 5 microns of the surface top layer interacts with the ice (Kietzig et al. 2010), about 40-70 % of the surface then interacts through the water layer. The rounded metal

blocks have about a 10% variation in the contact area that has a small influence on the sliding speed, Fig 2.

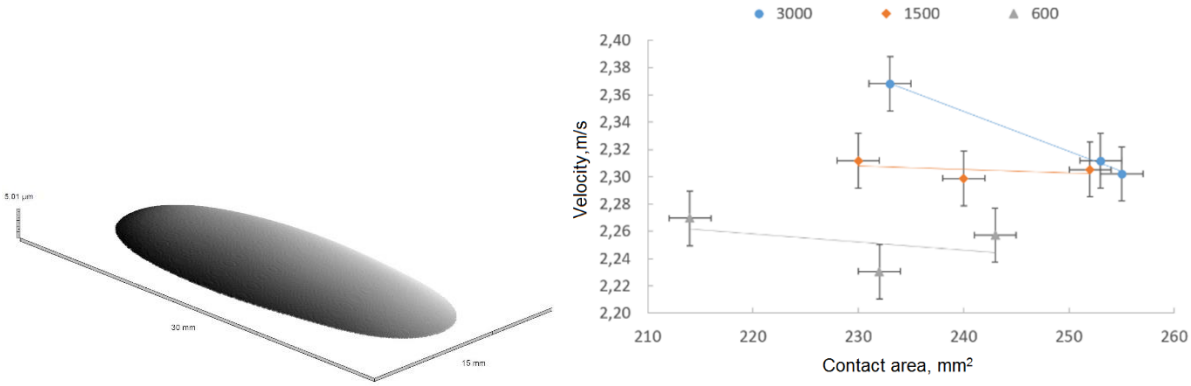


Figure 2. The central raised top 5 mm section of an auto-polished metal block, and an illustration of how the contact area alters the sliding speed.

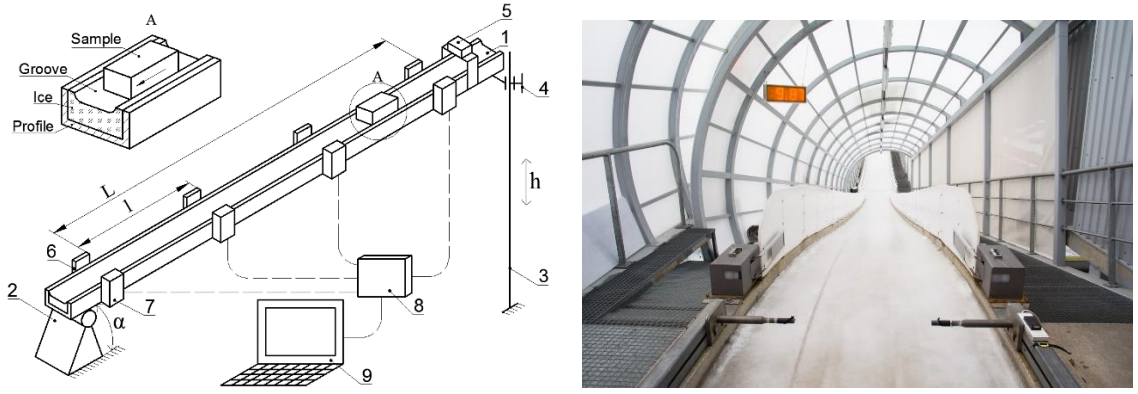
The contact angle was also found to have an influence of the sliding speed. The linear relationship, from four data points found that the sliding velocity could be determined by multiplying the contact angle by 0.022 and then adding 0.36 m/s. The small gradient suggests a small influence of the contact angle on the sliding speed, but this may be useful secondary effect.

This outcome has been summarized from a 10 page report written in Latvian with 8 figures and 8 equations.

3. Determine the correlation of sliding speed in the laboratory and in the field experiment	***Report: A method for determining the sliding speed on a long ice track in real-life conditions compared to laboratory testing***

The purpose of this task was to develop a method for measuring the sliding speed along a 24 m angled ice plane and to compare the trends with those obtained from laboratory tests. The skeleton push-start facility was chosen for conducting these measurements, protected from the wind, sun and snow, only allowing entrance of air from the grating at the bottom and through a small opening at both end of the push-start facility. This provided free circulation of air to attain conditions similar to those outside the enclosure, but at more uniform conditions.

The sled was released at the start position by removing a pin to allow the sled to start sliding by itself. Just like in the laboratory, four sets of sensors at the side of the ice track logged the time at which the sled moved past set positions. This data was used to determine the velocity at the start and at the end of the 24 metre distance.



(a) (b)

Figure 1. Sliding speed tests along a) a 3.5 m ice track in the laboratory, and b) a 24 m ice track at the skeleton push-start facility.

Before initiating the investigation, the repeatability of velocity measurements was determined on the first day of testing. The small 0.15% error, measured from 30 runs, is significantly smaller

than the error stated in previous investigations. Compared to the 2.5% to 4% error reported by Hainzlmaier (Hainzlmaier, 2005), the 2.2% error from the linear tribometer by Hasler et al. (Hasler et al., 2016), and the 1% error from the bobsleigh push-start facility reported by Poirer et al (Poirer at el. 2011), the error is at least 7 times smaller. The larger error was attributed to the human error; this study did not involve the human factor and so has a smaller error from many repeat experiments. To remove the influence of the operator, a sled was secured with a rope and a sliding pin removed to allow the sled to freely slide down the angled plane.

The average sliding velocity was faster for polished surfaces, and increases with temperature. This observation is consistent with previous observations (Kietzig et al. 2010). A 0.2 m/s improvement (3% increase) in the average sliding velocity occurs after an increase in air temperature from -15 °C to 0 °C, Fig 2a. Changing the temperature, however, is not a practical solution. A change in the sliding velocity is better achieved by altering the surface roughness. Polished metal surfaces showed a markedly faster sliding velocity, especially at colder temperatures. Rougher surfaces had a lower sliding velocity. The sliding velocity for rougher runners was 1%, 0.4% and 0.16% slower at -15 °C, -10 °C and a 0 °C, respectively.

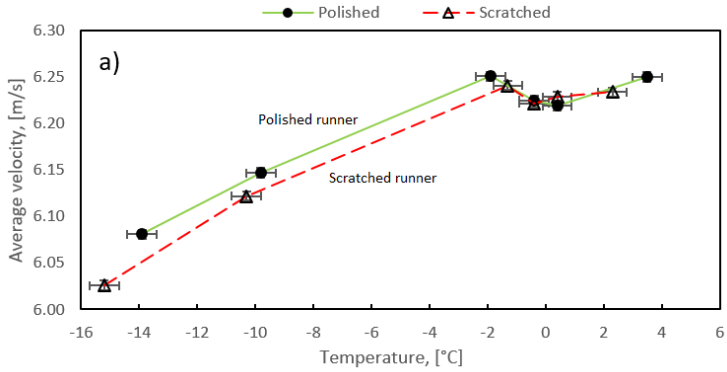


Figure 2. The average sliding velocity for polished and rough runners over a temperature range of -15 ^{o}C to +2 ^{o}C along a 24 m ice track. Solid green curve show trends for the rough runner, dotted circles group together experiments from the same day

The effect of pressure was studied by placing a 10 kg or a 20 kg weight on the sled with polished or scratched runners. The sliding velocity for the scratched runner is displaced to the left (illustrated with a triangle), but the polished runner displaced to the right of the test temperature (illustrated with a circle), allowing an easier comparison for the scratched and polished runners, Fig 3.

The average sliding speed increased with temperature, as previously reported, and does so for the different loads. This is to be expected since assuming a negligible change in the friction, a heavier load will provide a greater acceleration and a resulting higher speed. In all cases, the polished runner slid faster than the roughened runner, Fig 3. A 30% increase in load (from 30 kg to 40 kg) gave ~ 0.3% increase in the sliding speed. A 60% increase in load (from 30 kg to 50 kg) approximately doubled the increase in the speed, but this was only noted at -10 ^{o}C for both scratched and polished surfaces.

Previous investigations on the coefficient of friction found a minimum at about -5 ^{o}C, and little variation in the results (Kietzig et al. 2010). This work found a maximum sliding velocity at an air temperature of 0 ^{o}C, and clearly showed lower sliding velocities at different temperatures. Consequently, the measurement of sliding velocity provides more discernable results to show the influence from temperature, load and surface roughness.

In the laboratory test, the sliding velocity also changed with temperature. Testing at colder conditions (-13 °C) led to a lower sliding velocity, at intermediate temperature (-8 ^{o}C) showed a highest speed, but at -3.0°C a reduction in the sliding velocity was noted, Fig 4. This observation on the change in velocity with temperature in the laboratory is the same trend found in the field test, on the 24 m long ice track. Others have also reported the same trend, as shown in Fig 4.

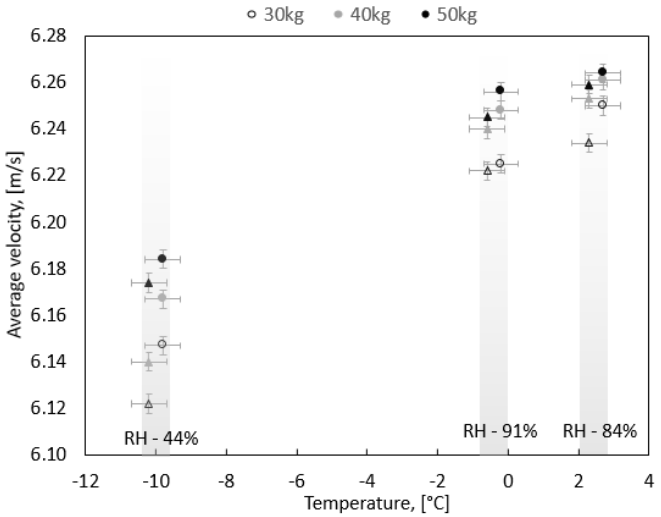


Figure 3. Influence of load on the average sliding velocity showing faster sliding under greater loads and at warmer temperatures along the 24 m ice track. (Δ) – scratched, (O) – polished surface.

We also found an agreement in the trend with polished and rougher surfaces between laboratory and field tests. Smoother surfaces showed a tendency to slide faster than rougher surfaces at sub-zero temperatures, as seen in the data of Figure 2 and Figure 4.

Further developments are presently being made to use the same temperature measuring device for both laboratory and field tests, so as to provide an independent measuring system for tests conducted in two locations.

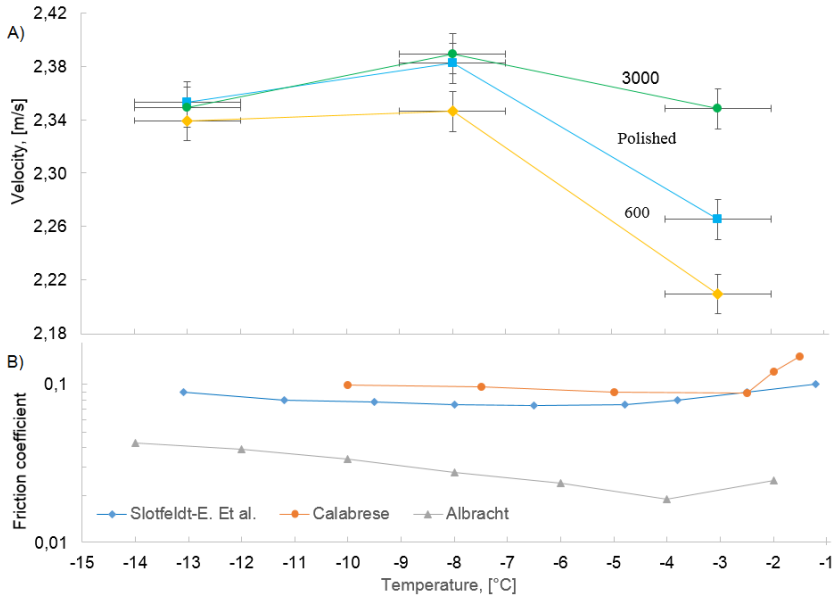


Figure 4. Influence of temperature on the average sliding velocity from laboratory tests, compared to the ice friction [reported by Kietzig et al. 2010]. The ice-friction and velocity is shown together as a comparison.

The work outlined above is taken from Lungevics et al. “An ice track equipped with optical sensors for determining the influence of experimental conditions on the sliding velocity”, Latvian J. Phys. 55(1) 2018, and Jansons et al. “Measurement of sliding velocity on ice, as a function of temperature, runner load and roughness, in a skeleton push-start facility” under review by Cold Science and Technology.

4. Investigate how surface modifications influence the sliding on ice over longer distances	***Report: Recommendation for modifying the surface to improve sliding over ice***

Influence of organic films on the sliding speed

Three types of organic films were chosen to determine the influence on sliding speed. The materials included solid material films, viscoelastic materials such as waxes or fluids.

The contact angle of water seemed to show a similar trend on the longer ice-track as in the cold laboratory. PVC with the lowest contact angle showed the slowest sliding speed, and PTFE with the highest contact angle showed the fastest speed, Fig 1. A pattern was observed between surfaces modified with a polymer film, however bare metal showed the highest speed. The use of superhydrophobic surfaces was not successful, since the microstructure dug into the ice and anchored the metal runner preventing it from sliding.

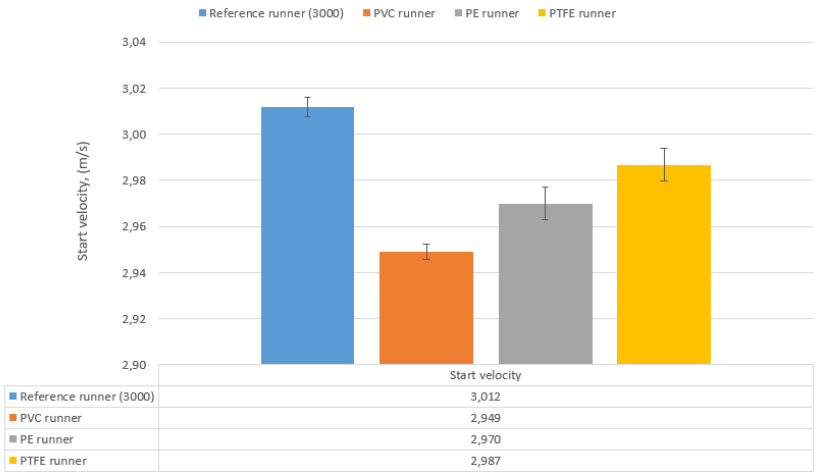


Figure 1. The influence of thin films from PVC, PE or PTFE on the sliding velocity.

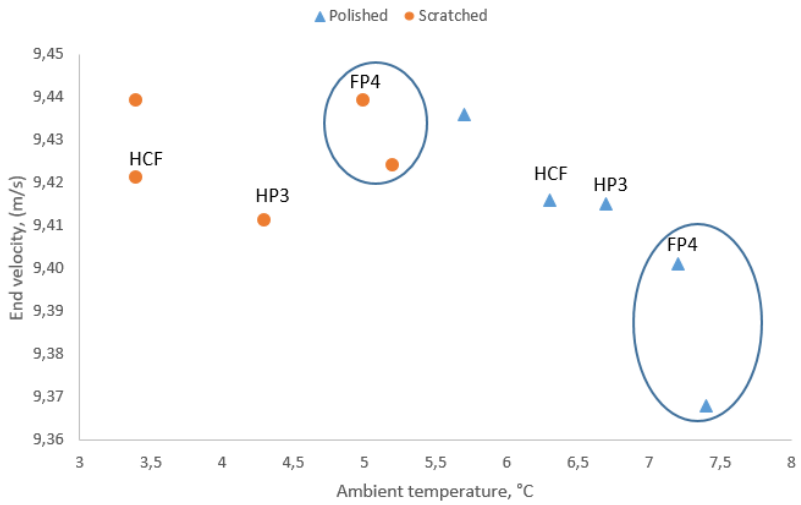


Figure 2. The effect of HCF oil, HP3 liquid paraffin and FP4 wax on the sliding speed.

Speed waxes and hydrophobic surfaces were investigated to see the contribution on sliding

speed, not on downhill skiis, but on metal runners. A HCF oil, a HP3 liquid paraffin and an FP4 wax were applied to runners. The FP4 film on the metal runner gave the fastest speed, both at the start, and also at the end, Fig 2. The marginal increase in speed, although higher, does not make a large difference to be noticeably better.

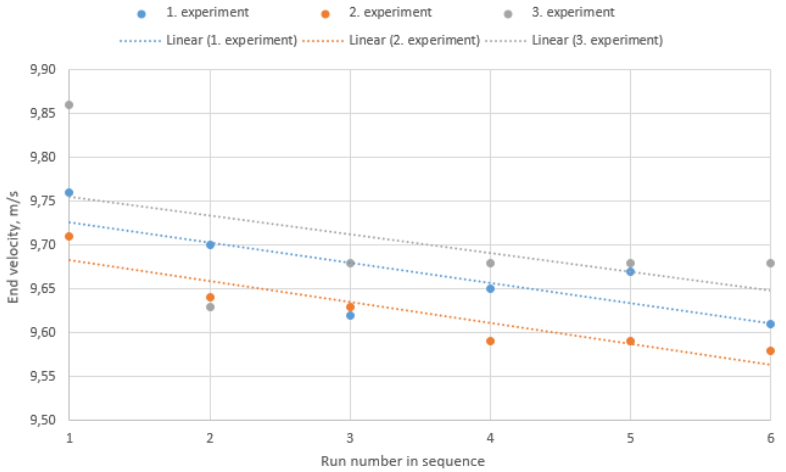


Figure 3. The sliding speed of a metal runner coated with de-icing solution for up to 6 runs, showing that the benefit is no longer present after 3 runs.

De-icing solutions, commonly used on aircraft to lower the chances of ice formation, were investigated for the interaction against ice. The sliding velocity initially was high, but decreased with every run, showing a trend to only last on the surface for 2 to 3 runs, Fig 3. The experiment was repeated three times and showed the same trend nearly every time.

Effect of roughness on slideability

Investigation of roughness on ice friction previously looked at large roughness values and big increments in the roughness, but this work addressed smaller changes in roughness over a narrow range for a beneficial effect. By reference to the laboratory studies, that showed a detrimental effect from sandcloth coarser than 600 grade, we decided to compare a hand polished runner, and a runner abraded with 600 grade sandcloth. At colder temperatures, that is dominated by a solid on solid interaction, a smoother metal moved more easily over solid ice. At warmer temperatures, where a liquid film is expected, the smooth metal slid slower due to the adhesive affect of the water film. The low roughness on the 600 grade sandpaper abraded surface slid faster. It is this surface preparation that can lead to improved sliding on ice.

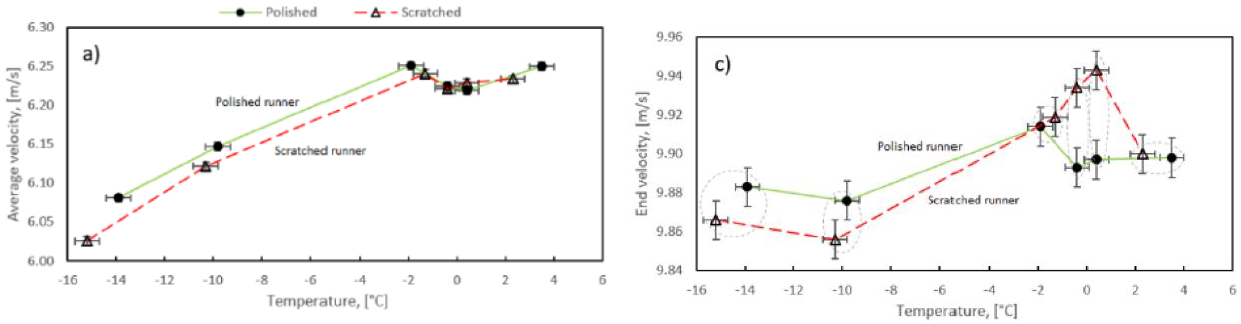


Figure 4. The average sliding speed and the end velocity for polished and roughened metal runners at a range of temperatures.

The study of metal runner sliding speed on ice showed that hydrophobicity was of secondary importance, but the main benefit arose from a change in roughness.

This outcome has been summarized from an 18 page report written in Latvian with 11 figures and 4 tables.

Documents describing the methods, recommendations, reports etc. developed within the Project 6 (electronical copies attached):

No.	Tasks	Deliverable	Responsible partner	Status
1	Develop a method for measuring slip under laboratory conditions	Report: A method for measuring the sliding speed in laboratory conditions (31.12.2015) Annex 6	K.A. Gross, Institute of inorganic chemistry, RTU	Finished
2	Modify the metal surface and determine the influence of modifications on the sliding speed	Report: A recommendation on surface modifications that improve the sliding speed of metal on ice in laboratory conditions (30.06.2017) Annex 6	K.A. Gross, Institute of inorganic chemistry, RTU	Finished
3	Determine the relationship for a sliding a metal object on ice	Report: A relationship between sliding over ice and the surface characteristic (30.09.2017) Annex 6	K.A. Gross, Institute of inorganic chemistry, RTU	Finished
4	Develop a method for determining the slip under real track conditions, in comparison with laboratory equipment	Report: A method for determining the sliding speed on a long ice track in real-life conditions compared to laboratory testing (30.06.2017) Annex 6	K.A. Gross, Institute of inorganic chemistry, RTU	Finished
5	A recommendation for a modification of metal surface to improve gliding in track conditions, application of the material	Report: A recommendation for modifying the surface to improve the relative movement on ice (30.12.2017) Annex 6	K.A. Gross, Institute of inorganic chemistry, RTU	Finished

2.4. Further research and practical exploitation of the results

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

Project nr. 6 started out to address the safety of pedestrians against free falling ice from ice-laden roofs, and blossomed to provide broad ranging benefits for scientific research, industry and society. This project has made contributions to the scientific community, developed a new sub-zero testing laboratory, provided a new test method for a company in Austria, given a valuable new tool to the sporting industry in Latvia, and strengthened a core group for further research on ice related research. This national grant has seeded developments in a number of areas, and led to a European funded project for continued developments on ice-friction research. The completed activities have satisfied the purpose of the national grant to kick-start new fields of inquiry for a contribution to science and society.

The following report will:

1. explain *new methods* that have arisen from this project,
2. describe a new *test capability for testing ice-friction in a laboratory*,
3. show the *correlation of the laboratory test with a field test* for ice-friction studies,
4. disclose how different *surface modifications change the ice-friction*, and
5. show the methods for changing the ice-friction

This project has introduced *four new test methods*; two methods for characterizing material surfaces, one method for a laboratory scale test to evaluate friction between ice and metal, and one

method for field testing friction between ice and metal over a distance of 24 metres. As a result, new capabilities have been established at Riga Technical University in sub-zero temperature conditions to investigate how material surfaces can be held against ice, and how materials slide more easily over ice. This is valuable for improving the safety for pedestrians on ice covered terrain and for wheel based transport. The value extends to the transportation industry for easier movement in ice-laden waters, and to the sports industry for faster movement over ice.

A new test facility was made to determine the *ice-friction at sub-zero temperatures in a laboratory* along a 3.5 meter long ice plane. An angled plane has been produced with time sensors for measuring the ice-friction at sub-zero temperatures. The sub-zero temperatures extend the operational temperature range of the climate control laboratory. Previous ice-friction test methods have been controlled not allowing the free movement of objects over ice. Friction has only been reported during movement. A test arrangement for increasing the angle of a plane has allowed the measurement of static friction - the resistance that must be overcome before an object starts sliding. A new angled plane with time sensors has been made for evaluating the ease or sliding down an angled ice track. Instead of just providing an average speed or the total time for sliding, the use of four sets of sensors have enabled the velocity to be determined along three distance of the ice track. This new capability has led to a Latvian patent, and a scientific article "An ice track equipped with optical sensors for determining the influence of experimental conditions on the sliding velocity" accepted for publication in Latvian Journal of Physics and Technical Sciences (Open Access, Scopus).

A quality control method has been developed for evaluating polished surfaces and maintaining the spatial distribution of scratches over the surface. A comparison has been made between light microscopy, atomic force microscopy, scanning electron microscopy and profilometry. A fast evaluation procedure has been developed to count the majority of the scratches. The scratch depth that is identified by light microscopy has been determined by atomic force microscopy. This new procedure is described in a journal article "A comparison of quality control methods for scratch detection on polished metal surfaces" accepted for publication in Measurement (Scopus, SNIP > 1). A new light microscope has been purchased for the quality control of polished metal surfaces, and equipped with a cold-stage will support the characterization of ice surfaces.

Previous investigations of ice friction on rough surfaces (R_a from 0.1 to 2.6 μm) only reported the roughness value given by the measurement tool. No detail was provided on the roughness profile. Our study looked at smoother surfaces (R_a from 0.007 μm to 0.17 μm) and analyzed the roughness at a deeper level to determine the roughness measure that can be related to ice-friction. A criterion of contact was determined to have the best correlation with ice friction. Instead of R_a as a general roughness measure, the Criterion of contact uses parameter ratio R_{Sm}/S_a which if > 1000 always gave the best sliding conditions. Values less than 1000 incrementally provided worse sliding conditions. The outcome found at the microlevel was in agreement with a model from a macroscale that showed the importance of the contact surface in determining the sliding speed. This information has been disseminated in a conference publication "A surface roughness measure that best correlates to the ease of sliding" at the Engineering for Rural Applications conference in 2016 (Scopus).

Similar trends in ice friction occur in the laboratory and the field test indicating a *correlation between the laboratory test and the field test*. A field-test for testing ice friction was developed at the skeleton push-start training facility that has a 24 m long angled ice plane. This has been conducted to find the correlation of ice-friction between the laboratory test and the field test. Just like in the laboratory, the testing facility had four sets of optical sensors to report on the sliding times. The precision is higher than the system used in the laboratory. The same starting arrangement was used where the object is allowed to start sliding without the influence from the operator. This is the first such test, since other tests either place the object under a load and therefore do not allow free movement or provide an initial starting velocity before measurements are made on the ice-friction or sliding velocity. The same trend in the sliding speed with temperature was found in the laboratory test and the field-test, showing faster sliding at warmer temperatures. This is explained

by the water layer that forms on ice at temperatures closer to 0 ^{o}C. The load has been found increase the sliding speed; a greater increase in sliding speed is found at lower temperatures where a block-ice interface is formed, but a smaller increase occurs from the block-water interface. The influence of roughness has comparable trends in the laboratory and the field. A journal publication has been submitted on the field-test in June, 2017 to Cold Regions and Technology (Scopus, SNIP > 1). Answers to the reviewer questions have been provided, and the revised manuscript titled "Measurement of sliding velocity on ice, as a function of temperature, runner load and roughness, in a skeleton push-start facility" is presently being reviewed.

The effect of three different *surface modifications was tested for the influence on ice-friction*. The roughness, the hardness and the wettability of the surface by water was investigated for the influence on sliding over ice. Blocks were hardened by a heat treatment, polished and then slid down the angled ice-track to look for changes in sliding speed. No trend was found to relate the hardness to the sliding velocity. The surface roughness of polished metal was changed with sandpaper. It was found that abrasion with coarse sandpaper led to slower sliding speeds, but abrasion with sandpaper grades greater than 600 grade had insignificant effect on the sliding speed. The wettability showed a linear trend with the sliding speed. Surfaces with a smaller wetting angle showed slower sliding speeds. Superhydrophobic surfaces did not provide the anticipated increase in sliding speed. The micro-structure of superhydrophobic surfaces that increases the wetting angle has a tendency to mechanically interlock with ice and so does not offer further increases in sliding speed, but has the opposite effect. A publication on the effect of wetting angle on the sliding speed is in progress. The effect of wetting angle on sliding speed has been reported in a bachelor degree research project.

From the investigation on roughness, hardness, and wetting angle, it was found that the best *method for controlling ice-friction* was surface roughness. Surfaces with raised rounded asperities at the micro-scale showed higher sliding speed. The question is under further investigation to determine the importance of the size and the shape of these asperities on the sliding speed. It is clear that an increase in size of the asperities leads to mechanical penetration into the ice, but the effect of smaller scale asperities will not be sufficiently large to cause anchoring, but facilitate another mechanism for easier movement over ice. This is supported by a tendency for polished surface show a possible slightly lower sliding speed.

The inquiry into conditions that facilitate sliding of ice, or sliding over ice require a deeper analysis from a materials perspective. The investigations have been predominantly steered from a mechanical engineering perspective, but more detailed investigation required a materials engineering approach to scrutinize the material surface and evaluate the effect of micro-topographical features and microstructure on the sliding speed. This forms the basis of the European project that was successful in acquiring funds that is supporting continued efforts for further investigating ice-friction in the multidisciplinary project titled "The quest for disclosing how surface characteristics affect slideability" (Project Nr. 1.1.1.1/16/A/129; Total budget: 594 054.28 EUR). These projects continue to develop the research infrastructure at sub-zero temperatures that led to a new field of investigation involving more detailed investigation on the characteristics of ice. A deeper understanding of ice can potentially lead to new insights from the ice perspective in learning how ice can change the ice-friction.

2.5. Dissemination and outreach activities

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

Full-text scientific papers:

1. Z. Butans, K.A. Gross, A. Gridnevs, E. Karzubova. Road safety barriers, the need and influence on road traffic accidents. Proceedings of 2nd International Conference "Innovative Materials, Structures and Technologies", IOP Conference Series-Materials Science and Engineering, 2015, Volume 96. (Scopus)

2. E. Jansons, J. Lungevics, K.A. Gross. Surface roughness measure that best correlates to ease of sliding. Engineering for Rural Development, Volume 2016-January, Pages 687.-695., ISSN 1691-5976. (Scopus)
3. J.Lungevics, E.Jansons, K.A.Gross. An ice track equipped with optical sensors for determining the influence of experimental conditions on the sliding velocity. Latvian Journal of Physics and Technical Sciences, 55 (1), 2018. (Scopus, Open Access, *Accepted for publication*)
4. E.Jansons, J.Lungevics, K.Stiprais, L.Pluduma, K.A.Gross. Measurement of sliding velocity on ice, as a function of temperature, runner load and roughness, in a skeleton push-start facility. Cold Regions Science and Technology. (SNIP>1; *Corrected according to reviewer's comments*, *Under 2nd review*).
5. K.Gross, J.Lungevics, L.Pluduma, J.Zavickis. A comparison of quality control techniques for scratch detection on polished metal surfaces. Measurement, 2018. (SNIP >1; *Accepted for publication*)

Scientific magazine publication:

1. 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 (133), p.12.

Participation in conferences:

1. Z. Butans, K. A. Gross, A. Gridnevs, E. Karzubova. Road safety barriers, the need and the impact on road traffic accident mechanism. *2nd International Conference "Innovative Materials, Structures and Technologies*, September 30.- October 2., Riga, Latvia.
2. J.Lungevics, J. Zavickis, L. Pluduma, K. A. Gross. *European Material Research Society (EMRS) Conference "EMSR Fall meeting 2015",* 15.-18.09.2015, Warsaw, Poland**.**
3. E. Jansons, J. Lungevics, K. A. Gross, Surface roughness measure that best correlates to ease of sliding, *15th International Scientific Conference Engineering for Rural Development,* 25.-27.05.2016, Jelgava, Latvia.
4. E. Jansons, J. Lungevics, J. Rudzutis, K. A. Gross, Use of inclined plane with additional time measurements for investigating surface slidability on ice, *The 12th International Conference Mechatronic Systems and Materials 2016*, 3.-8.07.2016, Bialystok, Polija.
5. J. Lungevics, K.A. Gross, Metāla virsmas modificēšana berzes un diluma samazināšanai, *Rīgas Tehniskās universitātes. 57. starptautiskā konference,* 14.-18.10.2016, Riga, Latvia.
6. K. Stiprais, K.A. Gross. "Polimēru virsmas enerģijas ietekme uz slīdamību pa ledu", *RTU 58. studentu zinātniski tehniskā konference,* 28.04.2017, Riga, Latvia.
7. J. Lungevičs. "Virsmas tekstūras parametru izvēle berzes pāra metals-ledus raksturošanai", *RTU 58. studentu zinātniski tehniskā konference,* 28.04.2017**,** Riga, Latvia.
8. E. Jansons. "Berzes pāra metals-ledus slīdamības pētījumi Siguldas treniņu estakādē", *RTU 58. studentu zinātniski tehniskā konference,* 28.04.2017, Riga, Latvia.
9. K. Stiprais, L. Pluduma, H. Sansonetti, K.A. Gross. "Influence of polymer contact energy on the ease of sliding over ice", *2rd International Conference "Innovative Materials, Structures and Technologies*, 27.-29.09.2017, Riga, Latvia.
10. J.Lungevičs. Slīpās plaknes izmantošana ledus berzes izpētē". RTU 58. starptautiskā zinātniskā konference (sekcija: Inženiertehnika, mehānika un mašīnbūvniecība), 12.10.2017, Riga, Latvia
11. E.Jansons. "Nerūsējošā tērauda slīdēšanas pa ledu likumsakarību pētījumi, izmantojot liela mēroga slīpo plakni". RTU 58. starptautiskā zinātniskā konference (sekcija: Inženiertehnika, mehānika un mašīnbūvniecība), 12.10.2017, Riga, Latvia

Participation in scientific seminars:

1. Scientific seminar about optical microscopy: *"Meeting of s-SNOM practioners"*, 9.-11.06.2015, Garmisch, Germany.
2. 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.
3. One of the largest international tribology meetings in Europe: 44th Leeds Lyon Symposium on Tribology, 04.-06.09.2017, Lyon, France.

Defended Master's thesis:

1. J Lungevičs, Evaluation methods of surfaces with a lower friction and wear. Supervisors J.Rudzītis and KA Gross. June 2016
2. E Jansons, Influence of surface roughness on the sliding of metal on ice. Supervisors J.Rudzītis and KA Gross. June 2016

Defended Bachelor's thesis:

1. K Stiprais, Chemical modification of metals for lowering the friction. Supervisor KA Gross. June 2017

The following doctoral theses are developed:

1. J.Lungevičs, A method for predicting tribological properties of materials used in mechanical engineering. Supervisor: J Rudzītis, KA Gross (to be defended in 2019)
2. E.Jansons, Development of criterion that determine the slidability of metal on ice. Supervisor: J Rudzītis, KA Gross (to be defended in 2019)

Latvian patents:

1. J.Lungevičs, E.Jansons, K.A.Gross, K.Stiprais. Sliding property determination device and method ("Slīdēšanas īpašību noteikšanas iekārta un paņēmiens", P-17-25, submitted on 21.04.2017):

New methods that have been accepted/tested in various companies:

1. Method for measuring the sliding speed is acknowledged by Latvian Bobsleigh and Skeleton Federation (letter dated with 05.10.2016).
2. The inclined plane device (developed within Project 6) and measuring method is acknowledged by V-Research GmbH, Austria (letter dated with 04.12.2017).

New research projects:

Based on the results of the Project 6, a European Regional Development Fund project was submitted and awarded:

1. "The quest for disclosing how surface characteristics affect slideability" (Project Nr.1.1.1.1/16/A/129), 01.04.2017. – 31.03.2020, Total budget: 594 054,28 EUR

PART 3: INFORMATION ABOUT PROGRAM FINANCE

The short information about the use of program finance

		1. period	2. period	3. period	4. period
1000–9000*	EXPENSES – IN TOTAL	**175654.00**	**254830.00**	**255574.00**	**413942.00**
1000	**Remuneration**	**107764.40**	**210352.00**	**198410.16**	**331608.76**
2000	**Goods and services** (2100+2200+2300)	**50017.89**	**50241.46**	**46564.43**	**77425.15**
2100	**Study, work and official missions, official and work trips**	5878.70	16137.74	12317.01	14395.99
2200	**Services**	20700.43	31275.62	22258.59	52680.33
2300	**Stock, materials, energy resources, goods, office supplies and inventory**	23260.64	2828.07	3054.45	7259.34
5000	**Establishment of core capital**	**17871.70**	**3985.95**	**850.00**	**4908.09**

Annex 1-A

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

Annex 1-C

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														X

(deliverable)														
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 assesment 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

Annex 3-B

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	X	X	X	X	X	X	X	X	X	X	X	X	X	X

doctoral and masters thesis														
6. Publications, Scopus														

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