Knowledge that leaves a mark

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SEVENTY YEARS
OF THE SLOVENIAN NATIONAL BUILDING
AND CIVIL ENGINEERING INSTITUTE
1949–2019

KNOWLEDGE THAT LEAVES A MARK
Seventy Years of the Slovenian National Building and Civil Engineering Institute 1949–2019

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SLOVENIAN NATIONAL BUILDING AND CIVIL ENGINEERING INSTITUTE IN 2019

The Institute was established in 1949, when the People's Republic of Slovenia founded the Building and Civil Engineering Institute. In 1952, the institute was renamed to the Institute for Testing and Research in Materials and Structures (ZRMK). After Slovenia became independent, new conditions in 1994 warranted the breakup of the ZRMK into the public and private parts. The laboratories and most of the research activities were transferred to the public research institute, the Slovenian National Building and Civil Engineering Institute (ZAG). One of the fundamental objectives of ZAG was to continue the tradition of the research and professional work of the ZRMK, which served since its very establishment as one of the main civil engineering and building institutes in the then Yugoslavia. After more than a quarter century of independent operation, ZAG is successfully navigating the outlined path. We have gained recognition both at home and even more so abroad. Among others, we are an equal and active member of numerous important international associations dealing with the broader area of construction. We should specifically note ENBRI (European Network of Building Research Institutes), FEHRL (Forum of European National Highway Research Laboratories) and EOTA (European Organisation for Technical Assessment). According to the most relevant indicators, we are entirely comparable to the best similar institutes in the European Union.

Throughout this time, ZAG developed successfully, even during the latest economic crisis. The key was to integrate the various fields, from research and professional work, to certification and attestation of the compliance of construction products, and the quality control of the executed works. Investing in new content and working closely with Slovenian and foreign industrial partners really paid off and resulted in numerous new research projects. As a public research institute, we still feel the negative effects of recent austerity measures. In order to remain competitive, Slovenia will have to increase the budget for science and research and will also have to systemically position the area of technology development. Recent data confirms that competition in the European research area is intensifying, following the initial favourable period after joining the EU, which affects in particular partners from smaller countries. Without the proper supportive environment, we will lose our hard-earned status of an effective and technologically strong partner. Smart specialisation mechanisms have partly replaced stable national funding, while some later measures, such as industry-supporting demo projects, are clearly unattractive to research institutions. In order to accelerate technological development in the field of construction, it will be essential to introduce in the public procurement effective mechanisms for the implementation of research results and the incentives for using the cutting-edge expertise.

Scientific and Research and Development Activity

In terms of content and status, the scientific and R&D work are ZAG's key activities. They are mainly carried out in an area which is, in economic terms, among the most important ones. The construction industry in the EU provides 18 million jobs and generates around 9% of the GDP. This number is even significantly higher if we include the associated activities. In Slovenia, its share has dropped in recent years to approximately 5% of its GDP, meaning that there is plenty of room for development. ZAG mostly performs applied research and most of it involves close cooperation with R&D departments from the industry. At the same time, we maintain close contacts with the latest scientific findings in many fields, which has resulted in publications in major international journals. Most of the research is part of international projects, mainly under the various

mechanisms of the Horizon 2020 programme, which proves their scientific importance in the broader sense. We are currently involved in around 80 research projects, two thirds of which are international. At the national level, we are conducting a research programme Building Structures and Materials with the support of the Infrastructure Group-Testing of Materials and Structures.

Buildings and civil engineering structures must meet the prescribed requirements in accordance with the European Construction Products Directive. A special provision applies to buildings that must ensure not only mechanical resistance and stability but also fire safety, adequate hygiene, environment for a healthy life, safety and accessibility in use and noise protection. They must also be energy-efficient and must retain heat. Lately, construction works must also meet the requirements regarding the sustainable use of natural resources throughout their life cycle, i.e. from construction to disposal. In order to meet the above conditions, we must know or develop technological solutions and calculation methods that allow to verify the compliance with these requirements. As a result, our research focuses primarily on the following areas:

- safety and stability of structures, including the prevention of the effects of ageing infrastructure, extreme events such as earthquakes and climate change;
- sustainability of construction works from the environment, circular economy, LCA (life cycle assessment) and construction errors perspectives;
- energy efficiency of buildings, considering health impacts, in particular the appropriate use of new materials and technologies.

Special attention is paid to facilities with specific requirements such as transport and energy infrastructure, landfills, including those for radioactive waste, and cultural heritage sites. We are increasingly focusing on digitalisation and industry or construction 4.0, as we are aware that without them the development of a wider field of construction is no longer possible. We are a partner in the InnoRenew Centre of excellence, which is the only European Teaming project that Slovenia acquired and is coordinated by the University of Primorska. A detailed description of research activities is provided in the following chapter.

Professional Activity and Attestation of Compliance

The second key area, which accounts for roughly one half of the Institute's activity, is professional activities and attestation of the conformity of construction products and executed works. When it comes to the broader area of construction, we prepare technical opinions and analyses as well as perform studies, examinations, measurements, controls, observations, investigation-supported detailed inspections and analyses of buildings and civil engineering structures, transport facilities and traffic infrastructure. We are involved in projects related to the major national road, rail, energy and utility infrastructure. The results of these activities are largely dependent on, and complementary to, the results of scientific research activities.

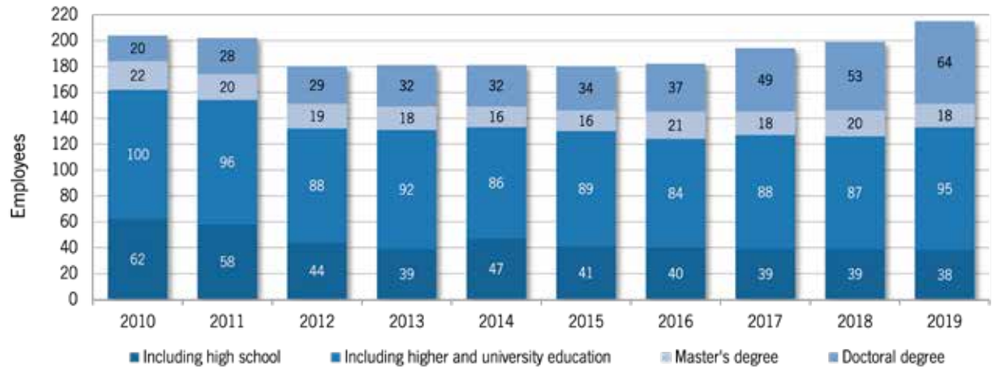
In parallel with professional activities, we certify construction products and issue technical assessments and approvals, calibrate force, torque and hardness meters and perform external independent third party control.

In our work, we follow the requirements of European and Slovenian legislation, actively participate in relevant bodies and frequently represent Slovenia at the European level. Our professionalism and breadth should represent a certain competitive advantage, but for most projects we struggle to tender with other providers. Unfortunately, tenders all too often stipulate deficient technical requirements. This even occurs in areas in which we develop internationally comparable methodologies, technologies and investigation procedures. Despite having more than 500 accredited measurement methods and certification procedures and despite the warnings of the Chamber of Commerce and Industry of Slovenia and the Slovenian Chamber of Engineers, the lowest price is only slowly retiring as the most important or even the only criterion for selecting a service.

This approach is particularly disadvantageous in the determination of the condition of structures and the planning of the necessary remedial measures. Inadequate data in the analysis phase generally increase the costs of measures and lead to uneconomical use of natural and financial resources. This practice and lack of demonstration projects also prevent faster implementation of research results into practice, which in turn hinders the technological progress of Slovenia. The new Public Procurement Act (ZJN-3) unfortunately did not significantly improve the situation in this area.

Employees

Upon the completion of motorway construction a decade ago, the number of employees reached 211 and then gradually decreased by 15% as a result of the reduced volume of routine examinations. More extensive engagement in international research projects, more extensive activity in the fields of technical assessments and certification and opening of new fields, such as cooperation with the automotive and timber processing industry, required to recruit new associates with higher education, usually with a doctorate. There are currently 215 people working for ZAG, 68% of them with at least a university degree, 64 of them with PhDs. In the field of construction, and given the large number of professional activities compared to similar institutes abroad, these are the numbers that we can be proud of.



Long-term human resource planning is a demanding task, especially in light of the long-planned large infrastructural projects, such as the second railway track project, the third development axis and the railway modernisation. As many of the key colleagues who have been with us for decades are retiring, a rejuvenation of the team is a must. This however is a challenge considering the general lack of technical specialists on the market and the uncompetitive salaries in the public sector. Consequently, the public research institutes have difficulties to compete with the private sector employers. I hope that the new research and development law will balance the technical and support activities. It is highly likely that staffing requirements will continue to increase for more complex activities within the Slovenian and international research projects, where knowledge from various fields needs to come together. Similarly, we expect to grow the needs for demanding professional activities that integrate various knowledges in the areas of materials, structures, building physics, geotechnics and traffic infrastructure.

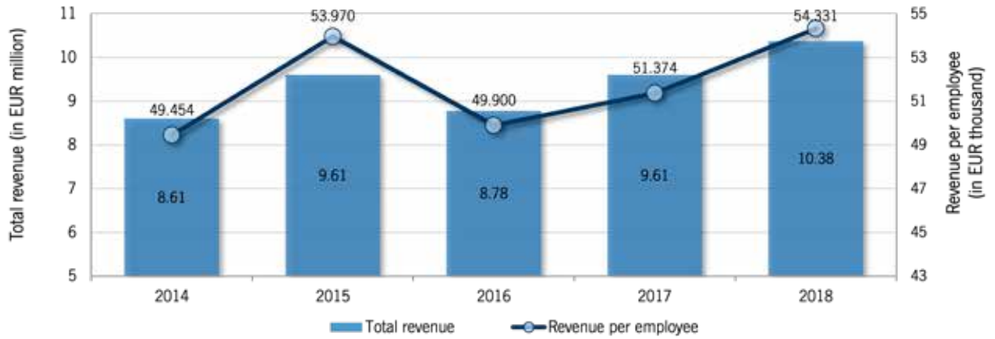
Operations

Throughout its 70 years of operation, the work of ZAG has been based on cooperation with numerous partners, today more and more coming from abroad. Nevertheless, our most important partner remains the state, mainly through our umbrella Ministry of Education, Science and Sport. We generate 15% of revenue from the very successful Research Programme and Infrastructure Groups. Both are the result of competition with other institutes and universities in the area of scientific excellence and are therefore not in themselves intelligible. The remaining three quarters of activities are market-oriented and include research, development and other projects. Other key partners that need mentioning are the Slovenian infrastructure operators, the Motorway Company in the Republic of Slovenia (DARS) and the Slovenian Infrastructure Agency, for which we perform quality control of the construction works and main and detailed inspections of key infrastructure. We have many partners from the industry and work with them either on concrete projects or within strategic research and innovation partnerships or SRIPs.

We are intensively engaged in international cooperation. I can highlight our participation in FEHRL, in ENBRI, and in EOTA. Then, there are also ECTP, the European Construction Technology Platform, ERTRAC, the European Road Transport Research Advisory Council, and Knowledge and Innovation Centre KIC RawMaterials. In most of these organizations, our representatives are appointed to the governing bodies.

Without this kind of active involvement, we would get significantly fewer research projects, which would result in far weaker knowledge sharing and progress, or such progress would be much slower. We regularly actively attend international forums such as workshops, conferences and congresses and participate in committees, associations and boards. These activities are a prerequisite for networking that leads to cooperation and new projects. We have recently signed a few new cooperation agreements with foreign and domestic universities.

The result of these activities is a stable operation that oscillates slightly in relation to the current number of research projects and major activities in the field of control of executed works on infrastructural projects. The moderate annual surpluses from market activities have allowed us to be today just before the construction of the new fire laboratory in Logatec.



Infrastructure

Since the formal establishment of ZAG in 1994, we have allocated 7 to 10% of our operating revenue for the procurement and modernisation of research and testing equipment. A part of the acquisition of this equipment was financed by the Slovenian Research Agency and the European Commission in the framework of research projects. This is why we today mostly own modern equipment that enables our employees to perform quality research and professional activities. In individual highly specialised fields that do not fall into our core activities, we established ties with other research institutions, such as the Centre of Excellence for research and innovation in the field of renewable materials and healthy environments InnoRenew, the Geological Survey of Slovenia, the Institute of Metals and Technology, the Institute for the Protection of Cultural Heritage of Slovenia, the Universities of Ljubljana, Maribor and Koper as well as the National Institute of Chemistry and the Jožef Stefan Institute. In the context of joint research and testing, we also have the opportunity to use the equipment from other ENBRI and FEHRL members.

In 2016, we completed the renovation of the Laboratory for Structures that was co-financed by the European Regional Development Fund. We built an extension to the existing laboratory hall, erected a new reaction wall to test the structural assemblies up to 7 m in height, covered the outdoor crane track and supplemented and updated the technological equipment and software. With this, we have significantly upgraded our testing capacities in the area of structures and building physics.

We are now facing the biggest investment in the last 70 years. After obtaining a valid building permit, a tender for the construction of a new fire laboratory in Logatec is currently under way. It will be completed in 2021. Without it, we would have to gradually suspend the activity of the existing fire laboratory, the only one in this part of Europe. We will purchase the equipment mainly from the dedicated funds of the InnoRenew project and will construct the building from the funds of the umbrella Ministry of Education, Science and Sport and from the savings from past successful business operations.

In line with the upcoming new financial perspective, we are strengthening our activities in the Eastern Cohesion Region. The existing residential premises where the Maribor branch has been operating since 1972 are no longer suitable. The increase in the number of employees and the relocation of certain testing and laboratory capabilities to Maribor necessitate the relocation to more appropriate premises; we plan to move next year. After the recent reconciliation of ownership between the ZAG and ZRMK d. d., we also intend to revitalise, within our financial capacities, the abandoned premises on the courtyard side of the building on Dimičeva Street.

Conclusions

Despite the recent turmoil in the economy, the ZAG has been operating successfully since its establishment. We are proud that most of the indicators show that we remain comparable to the best equivalent institutes in the developed countries of the of European Union. This is only possible with the great engagement of all the employees, to whom I especially thank for their dedication and engagement. Most of them are simultaneously active in professional and scientific R&D domains, which requires tremendous efforts. I also sincerely thank all colleagues in support activities, without whom the core activities of the institute would be much harder to perform.

The last decade is evidence that knowledge and technological development are essential for the survival of the individual parts of the economy and for the prosperity of the citizens. In this respect, it is crucial that Slovenia, upon accession to the European Union, preserved most national research institutes alongside its important industrial cores. At the international podium, we continue to prove that we are comparable in the field of research to the developed countries. Yet, we struggle when we try to implement the research results into practice. This is why I sincerely wish that science, research and development, and in particular the implementation of new technologies, are supported not only by the Ministry of Education, Science and Sport, but also to a greater extent by other ministries that should make a key contribution to the sustainable development of the Slovenian society.

Ljubljana, 12 November 2019

Assist. Prof. Dr. Aleš Žnidarič, Director

Milestones
1949–2019

1949: The Government established the Building and Civil Engineering Institute of Slovenia. Its primary activities were research, testing and development in the fields of construction and the construction material industry.

1953: The Construction Institute was restructured into the Institute for Testing and Research in Materials and Structures (ZRMK).

1972: In Maribor, a business unit was established to carry out activities in the northern-eastern part of Slovenia.

1984: A seven-storey extension was built to host new laboratories and office spaces.

1986: In the Ljubljana suburb Gameljne, a modern fire laboratory was built.

1991: In the new state, ZRMK was recast into a public institute.

1994: A part of ZRMK was restructured into a public research institute, the Building and Civil Engineering Institute (Zavod za gradbeništvo – ZRMK) and became a member of FEHRL, Forum of European National Highway Research Laboratories.

1996: The Building and Civil Engineering Institute – ZRMK was renamed the Slovenian National Building and Civil Engineering Institute (Zavod za gradbeništvo Slovenije, ZAG). As a partner, it participated in the first international project under the title of PARIS.

1999: The Slovenian Accreditation (SA) and the Swedish Accreditation (SWEDAC) accredited the first eight laboratories. ZAG obtained approval of two research programme groups, Building Structures and Building Structures and Materials, by the Slovenian Research Agency (ARRS).

2000: ZAG became a member of ENBRI, the European Network of Building Research Institutes.

2003: ZAG was designated the Slovenian technical assessment body. Since then, it has represented the Republic of Slovenia in EOTA, the European Organisation for Technical Assessments.

2004: According to the Construction Product Directive (CPD) 89/106/EEC, ZAG acquired the status of an EU notified body (notification number 1404).

2005: The Office for Metrology of the Republic of Slovenia designated ZAG the holder of the reference prototype of the unit “mole” in the field of construction materials. ZAG coordinated its first EU project under the title Revitalization of the Carthusian Monastery at Žiče under the framework programme of CULTURE 2000.

2006: ZAG undertook the management of the national mirror group of conformity assessment body group OUS.

2007: ZAG was granted the quality system certificate according to ISO 9001:2000 by the Slovenian Institute of Quality (SIQ). ZAG was one of the cofounders of the E2B (Energy Efficient Buildings) association.

2008: In partnership with the DDC and DRC companies, ZAG organised the largest European conference in the field of road transport, the Transport Research Arena (TRA). The Office for Metrology of the Republic of Slovenia designated ZAG as the holder of the reference prototype of the units of force, hardness and quantity of matter for cement. ZAG Director Dr. Andraž Legat was appointed the vice president of the FEHRL association.

2009: ZAG was granted funding for the Material and Construction Testing programme by ARRS. ZAG director Dr. Andraž Legat was appointed the president of the ENBRI association.

2011: In collaboration with industrial and research partners, ZAG managed the TIGR competence centre: Sustainable and Innovative Construction.

2012: The Ministry of Economic Development and Technology designated ZAG a technical assessment body. The Slovenian Environment Agency accredited ZAG as a body for noise assessment employing model calculation.

2013: The Ministry of Agriculture and Environment designated ZAG as an approved expert for radiation and nuclear safety. The Ministry of Infrastructure and Space authorised ZAG to issue energy performance certificates. ZAG complemented its activity portfolio as a notified body with identification number 1404 by acquiring the status of a notified body under the Construction Product Regulation (CPR) No. 305/2011.

2014: The Ministry of Infrastructure and Space authorised ZAG for technical inspection of cableway devices.

2016: With European funding, an annex to the laboratory for structures was built. Under a teaming project, ZAG was a cofounder of the centre of excellence for research and innovation in the field of renewable materials and healthy living environment (InnoRenew CoE).

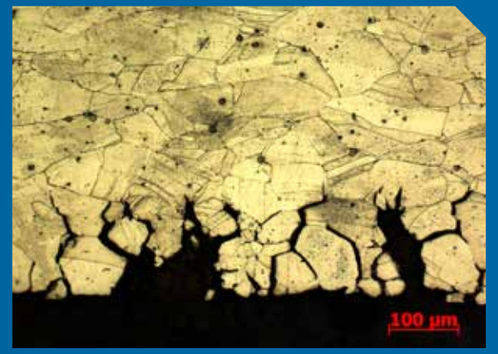
2017: ZAG was one of the cofounders of four strategic development-innovation partnerships- SRIP

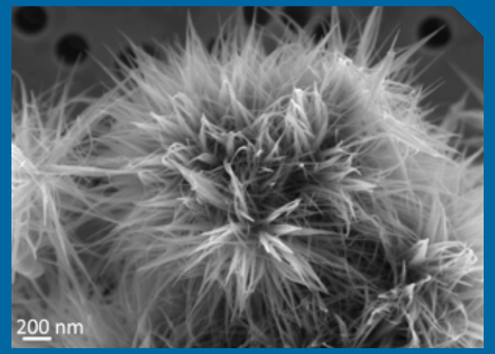
Directors through history

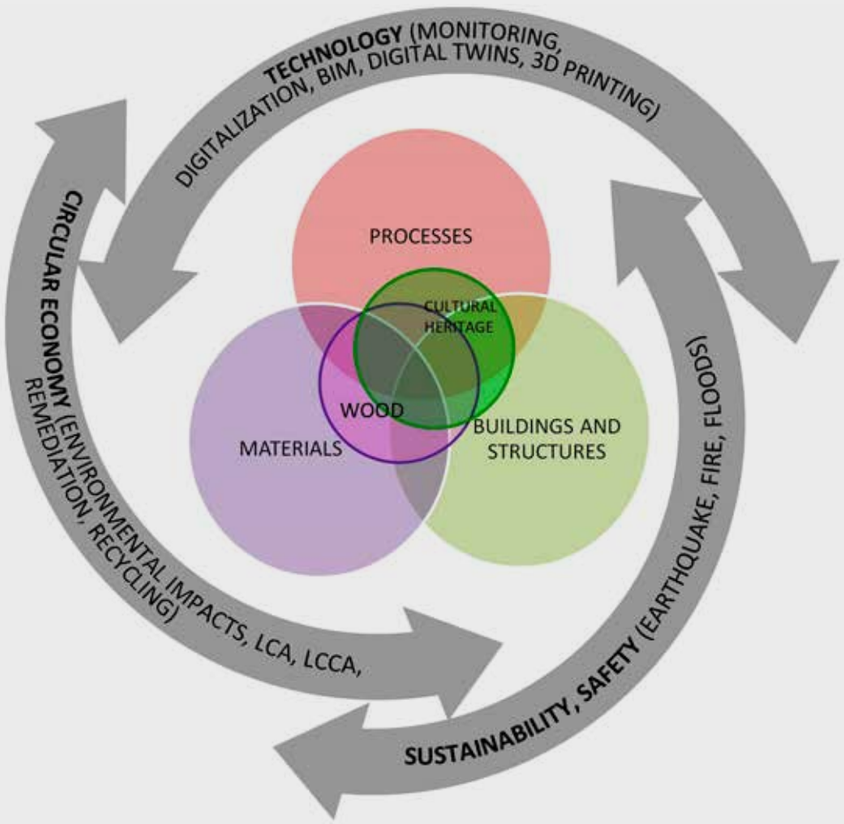
Marjan Ferjan	1949–1951 (Director of the Institute)
prof. **Viktor Turnšek**	1951–1954 (Director of the Institute), 1954–1975 (Director of ZRMK)
Franc Čačovič	1976–1980 (Director of ZRMK)
prof. dr. **Jože Vižintin**	1980–1986 (Director of ZRMK)
Borut Gostič	1986–1992 (Director of ZRMK)
prof. dr. **Roko Žarnić**	1992–1993 (Acting Director of ZRMK)
mag. **Damijana Dimic**	1993–1995 (Acting Director of the IRPK OU), 1995–1996 (Acting Director of the BCV Institute – ZRMK)
acad. prof. dr. **Miha Tomaževič**	1996–2005 (Director of ZAG Ljubljana)
prof. dr. **Andraž Legat**	2005–2019 (Director of ZAG Ljubljana)

Scientific and Research Activities at the Slovenian National Building and Civil Engineering Institute (ZAG)

Since, ZAG (Slovenian National Building and Civil Engineering Institute) is a public research institute, scientific and research activities represent our main commitment. Intensive multidisciplinary activities in the various fields of construction put ZAG on the map as an excellent partner in research. Our main advantage is the successful integration of basic and applied research, which is usually related to actual technical and societal questions. A high-quality and healthy living and working environment, efficient use of natural resources and effective infrastructure are among the most important parameters for a sustainable society. Wider aspects of construction are therefore very important for development of the society.







Main Areas of Research

The objectives of our research follow the need of the sustainable construction where we address new methodologies and technologies, as well as societal and well-being issues. In specific areas outstanding scientific results were achieved, whereas research in other fields was more applied oriented. Most of the areas are, however, closely interconnected in terms of content as well as in technological readiness level. Our research will also in future focus in: stability and safety of structures, including fire safety engineering and protection against natural disasters; development and use of advanced nanomaterials/nanotechnologies in construction products and systems, durability and sustainability of construction elements and systems; use/recycling of industrial and municipal waste; immobilisation of hazardous waste, including the remediation of the environment; modelling of buildings, parts of buildings and building systems to determine their thermal response for their well-being and energy optimisation; life-cycle analyses; methods and technologies for the use of various types and forms of wood, with an emphasis on a healthy living environment; methods and technologies for the renovation of buildings and engineering structures; protection and renovation of cultural heritage; development of measurement methods, including calibration procedures; implementation of digitalisation in the planning, implementation and supervision of construction/technological processes. Our main research areas and their relations can be schematically presented as in figure below.

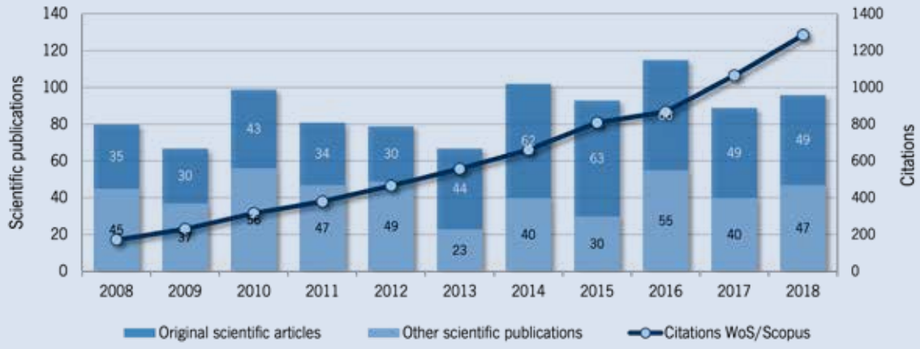
Research programme and Infrastructure Group

ZAG is conducting a research programme entitled Building Structures and Materials (P2-0273) with the support of the Infrastructure Group Material and Structure Testing (I0-0032). Due to the high score provided during the evaluation that was carried out last year, the duration and amount of funding by ARRS (Slovenian Research Agency) were considerably increased. The research programme involves activities in all of the aforementioned areas, where the emphasis is on the scientific approach (technology readiness level – TRL from 0 to 2). It is certainly very important that close links between the topics are established, since individual

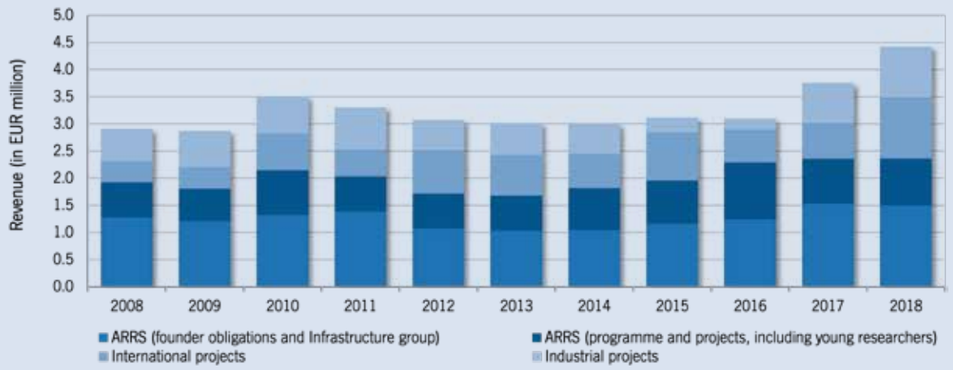
results can be connected and consequently form wider themes. By closer collaboration between various groups of researchers, we achieve also synergies between specific scientific fields. The importance of the results of our research is evidenced by the number of scientific publications and citations, which has grown significantly in the recent years. The chart below shows the number of original scientific articles and citations in the 2008–2018 period (source: COBISS.SI/COBIB.SI database, 30 September 2019).

The Infrastructure Group predominantly acts as a support for the research activities. The ZAG Group is comprised of several teams working on various technical areas, which are heavily diversified. The combination of very high technical expertise enables ZAG to carry out the most demanding tests. The activities of the Infrastructure Group are distributed among organisational units/departments.

- The Department for Structures is involved in research into the response of structures and structural assemblies to typical loads such as dead load, wind and earthquake. The essential part of the equipment therefore includes test devices for the performance of static and dynamic loading that are complemented by measurement devices for various mechanical quantities. Testing is performed in the test hall that is equipped with a foundation for the fastening of elements and two gantry cranes. The system of load-bearing elements with the foundation for fastening enables the erection of various test specimens. The loading of test subjects is performed using a modern electronically controlled servo-hydraulic system with simultaneous loading on several axes. The servo-hydraulic control system ensures controlled dynamic loading that allows the performance of a number of exacting tests.
- Main research topics of the Department for Structures are related to seismic engineering in broader sense. Research activities are related to the study of the response of structures and structural assemblies to typical loads such as dead load, wind and earthquake. The essential part of the equipment therefore includes test equipment for the performance of static and dynamic loading which is complemented by measurement devices for various mechanical quantities. Testing is performed in the test laboratory that is equipped with a strong floor and reaction wall and a number of gantry cranes for sample manipulation. The system of load-bearing elements in combination with the strong floor and reaction wall enables implementation of various complex test setups. The loading of test subjects is performed using a modern electronically controlled servo-hydraulic system with a possibility of simultaneous loading on several axes. The flexible servo-hydraulic control system MTS FlexTest ensures controlled dynamic loading that allows a simultaneous performance of a number of tests.
- The Department for Materials covers particularly microstructural and mechanical characteristics, as well as the long-term stability under various environmental conditions (i.e. temperature and moisture). It should be noted that specific equipment and instruments are unique in this part of Europe. This research infrastructure could be divided into three larger groups: determination of mechanical properties of materials, research of the-long term stability, and equipment for the determination of microstructural characteristics.
- The Department for Building Physics works in the area of acoustics, thermal protection of buildings and fire safety. The equipment is therefore divided into two sets: equipment for the determination of building physics related properties of materials and structures (sound and thermal insulation) and the second set for the performance of various controlled fire resistance and reaction to fire tests.
- The Department for Geotechnics and Infrastructure is involved in research into soil and materials used in geotechnical structures such as embankments, retaining wall structures, dams and road structures. Measurements of deformations and response to various loads are performed on large geotechnical structures. The department operates a geomechanical laboratory and a laboratory for asphalts, bitumen and bitumen products. The Section for Road Maintenance and Management performs measurements of road surfaces.
- The Metrology Department provides the metrological traceability of results for measurement and testing equipment for mechanical and other quantities. It maintains reference measurement standards for force, torque and hardness and actively cooperates with universities and national metrology institute of other countries. As an accredited calibration laboratory, it ensures the comparability and international recognition of calibration results for the Slovenian industry and scientific community.



Graph 1: Bibliographic indicators of research performance (source: COBISS.SI/COBIB.SI database, 30 September 2019).



Graph 2: The funds that ZAG received for the scientific and research activity in the period 2008-2018

National and International Research Projects

Vn parallel with the intensified scientific and research activities, we can notice also a significant increase in the number of national and international research projects. ZAG is currently involved in 79 research projects (29 national and 50 international), which proves high efficiency of our researchers. In this sense is ZAG among the research institutions whose research funding from the EU and the industry is comparable to the co-financing from ARRS. From the status point of view, the most important international project is Teaming InnoRenew (Centre of Excellence for Research and Innovation in the Area of Renewable Materials and Healthy Living Environment), which is coordinated by the University of Primorska. This project assures wider and compatible cooperation with partners in the areas of infrastructure and higher education.

In a large part of the above mentioned research projects, we work closely with Slovenian and foreign industrial partners, where we also highlight the activities within the scope of the Smart Specialisation Strategy. ZAG is active in 4 areas of Smart Specialization: Smart Buildings in Combination with a Wood Chain, Networks for the Transition to a Circular Economy, Mobility, Development of Materials as End Products.

The chart below shows the funds that ZAG received for the scientific and research activity in the 2008–2018 period. The annual funds are divided by the source: ARRS (the fixed part and the Infrastructure Group), ARRS (programme and projects, including young researchers), international projects, and industrial projects (including the cohesion funds).

Following New Trends in Research

Technological parameters and the needs of the society, as well as the environmental conditions are changing rapidly. These fast changes partly define also our research orientations. Multidisciplinary knowledge of our scientists assures necessary flexibility and comprehensive approach in research. In addition, most of our research fields are associated with the key enabling technologies (KET) as defined by the EU: use of nanotechnology, advanced materials and sustainable development.

In relation with global trends, which are observed via our participation in international expert groups and associations, it can be expected that further development on sustainable construction will be driven by the processes presented in the table below.

It is evident that a large portion of the mentioned processes is being addressed as part of Industry 4.0. In our research efforts these trends will receive considerable attention. Sustainable construction is also an essential part of social development: in a way, major infrastructural investments represent the borrowing of resources from future generations. This is why our research activities involve close cooperation with various institutions, mainly universities, and the civil society. Most of the mentioned research will have a distinct impact on people's safety and health, as well as the preservation of natural resources and cultural heritage.

Participation in International Associations

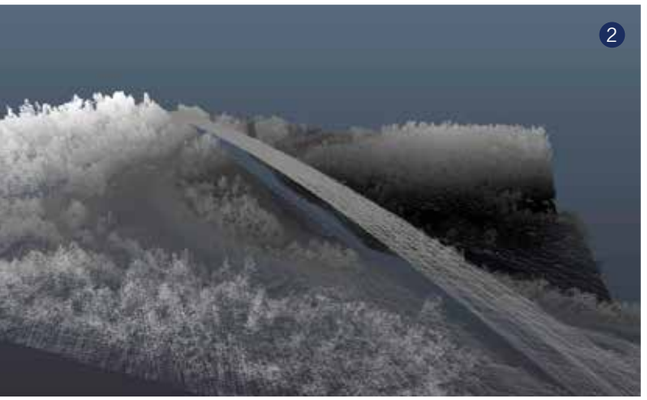
As a result of our multidisciplinary activities and the integration of basic and applied research, ZAG has become highly recognised research partner in Slovenian and EU countries. Within international research activities we collaborate primarily with colleagues from ENBRI (European Network of Building Research Institutes) and FEHRL (Forum of European National Highway Research Centres). Our participation in technological platforms as ECTP (European Construction Technology Platform), E2BA (Energy Efficient Buildings), and ERTRAC (European Road Transport Research Council) also represent close links to new trends in research and technology. Additional value represents cooperation with universities and industry within EIT KIC (European Institute of Technology, Knowledge and Innovation Centre) RawMaterials. In view of most of the relevant indicators (engagement in the EU research space, participation in technical committees, cooperation with universities and the industry), ZAG is close to our counterpart research institutes such as RISE, VTT, EMPA, CSTB, Iffstar, BAM, LNEC, BBRI and BBRC.

assoc. prof. dr. ANDRAŽ LEGAT

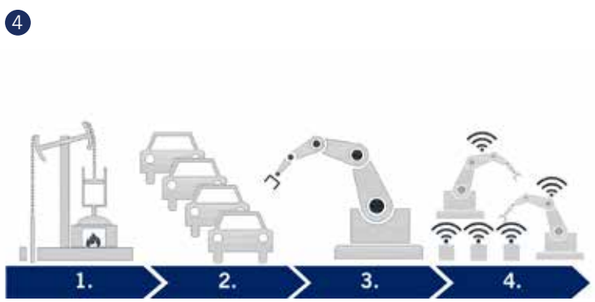
Development of new materials	The emphasis will be on nanotechnology. Even though their application can be first seen in medicine and the pharmaceutical industry, specific technological achievements will with a certain delay strongly affect also the development of construction materials.
Development of electronic elements	Development will be focused into further miniaturisation. Extreme complexity of electronic components will enable the incorporation of a broad range of sensors and distributed measurement systems in buildings, infrastructure and cities.
Development of new processes / production / robotization	Additive manufacturing technologies (3D printing) will move from the metal industry also in the field of inorganic and organic materials. This will make possible creation of materials and products with precisely defined characteristics.
Big data	Artificial intelligence (AI) will enable the arrangement, filtering and classification of large groups of measured data. It will be possible to predict specific responses in the sense of health, well-being, safety and environmental issues. Feed-back information about decision making will be also incorporated.
Process digitalisation	BIM (Building Information Modelling) with databases on materials, products and systems involving mechanical, environmental, aesthetic and other properties will become an inherent part of sustainable construction. Links to robotized construction, demolition and recycling of construction waste as well as to visualisations and maintenance of structures and systems will be established.
Environmental impacts	Comprehensive analysis and mitigation of environmental impacts will become a required integral part of all industrial activities, including construction. Life cycle analyses (LCA, LCCA, L-SCA) will become a general tool for the setup of a circular economy.

Knowledge that creates the future

Digitalisation of the built environment



1. Comparison of thermal and optical images of structures with varying degrees of damage
2. Ravbarkomanda viaduct point cloud (lidar + scanner)
3. View on viaduct Ravbarkomanda from unmanned aerial vehicle
4. Industrial revolution phases



Digitalisation of the built environment

Digitalisation of the built environment in the construction industry is probably just as big of a milestone as the icon of the information age, i.e. the personal computer, was for engineering. Even though most are not aware of this, in the near future the mastery of new approaches will become a pre-condition for cooperation in any project ranging from planning and construction to maintenance and renovation and even demolition.

► Construction 4.0

Digitalisation of the built environment stems from the Industry 4.0 concept. According to said concept, data collected in the real world by sensors, cameras and social networks are used to improve mass produced products. Construction sector is specific in that since it produces unique products. In order to achieve a breakthrough in the implementation of this concept, it is therefore essential for the processes in which data are generated to be digitised. Building information model/modelling or BIM, which deals with the management of information on buildings over their entire lifecycle, is an important but not the central part of digitalisation in construction. Other construction processes such as 3D printing, robotics, digital control of construction sites and infrastructure are also being increasingly digitised. The Slovenian National Building and Civil Engineering Institute has lately been searching for breakthrough areas in built environment digitalisation, including BIM as a concept of better information management and monitoring the damage condition of bridging structures using sensors and unmanned aerial vehicles.

►Better Information Management (BIM)

Communication and cooperation can quickly become critical elements of successful project realisation. BIM is introducing a new concept of information organisation and exchange in the process of planning, construction and maintenance of the built environment. A large quantity of various information required by architects, engineers, supervisors, investors, maintenance personnel and others is generated within this multidisciplinary process. Today, usually data is not collected centrally and is not arranged in a pre-agreed manner as is characteristic of BIM. Solutions are consequently sometimes created spontaneously and are not coordinated with one another up until implementation at the construction site, which is where the list of additional work, corrections, coordination and subsequently costs piles up. If we wanted to manage information more efficiently, each stakeholder in the process would have to have authentic and comprehensive data (better information management). We should see the most interest in BIM from investors, as this approach according to estimates could make building construction up to 20% cheaper while at the same time significantly increasing the reliability of schedules and the quality of construction.

BIM directs decision-making based on design, reconstruction, materials, equipment, management method and other elements much closer to the beginning of

the design process. This may perhaps be one of its problems, as it requires more effort or costs in the initial stages of project design. On the other hand we avoid extensive changes in the later stages of construction, supervision and maintenance, which in turn generates significant savings. Reference projects around the world and at home show that – especially in case of larger investments – BIM is a reasonable next step in the built environment digitalisation process. Public investments can serve as excellent examples of catalysts of technological progress. This has made the use of BIM mandatory in certain EU Member States. It should be noted in this regard that additional investment into better and digital data is required, as such efforts are returned many times over as a result of the construction being more predictable and maintenance being better.

Most of the innovations that await us in the area of the planning, construction, management and demolition of buildings in the built environment are related to BIM technology. Not so long ago, we used to deal with a building's carbon footprint, whereas building designers are now preoccupied with the investor's questions of what is the carbon footprint of two comparable structural system solutions. The norm in the near future will be to prepare comparative parametric analyses of the possible combinations of numerous parameters for the investor. This will subsequently introduce radical changes to the planning process. Using artificial intelligence (AI), the search for optimum solutions will become much more accessible. The provision of quality data about materials and the properties of the element included in the BIM model will thus become essential.

Primerjava termične in optične slike poškodovane konstrukcije

► Digitised Method of Monitoring the State of Constructions

For purposes of regular inspection of the state of bridging structures in Slovenia, we use the methodology developed nearly 30 years ago. The technology is mainly based on the use of the classic visual method, while main and ad-hoc inspections require the use of specialised vehicles or lifting platforms that enable access to all of the important elements of the structure. This method of inspection of constructions – especially structures with long spans that bridge a valley or river – is time consuming and dangerous for inspectors. Because a partial road closure is usually required during an inspection, such an inspection represents a direct cost to the users because of traffic jams. By using drones that have optical, supersonic and thermal sensors installed, in the inspection, the bridging structure state monitoring process can become much safer and effective and the data so collected are more precise and objective. Such an approach to the inspection of constructions ushers in completely new dimensions in the area of efficient infrastructure management and is the next step in the digitalisation of construction.

In addition to the basic data about bridging structures (composition and type of construction, surroundings, dimensions), photographic and thermal images taken from a drone can be used to assess the degree of damage of a construction. Using machine learning methods, e.g. the use of convolutional neural networks, we can perform simple automated damage recognition tasks. When it comes to reinforced concrete structures, the two most relevant indicators are cracking and delamination density.

► Bridging Structure Monitoring

During the reconstruction of the Ravbarkomanda viaduct, the investor recognised the importance of the continuous gathering of data on the state of the bridging structure. The Slovenian National Building and Civil Engineering Institute worked with its partners and building designers to design and set up the largest permanent technical supervision of a motorway bridging structure in Slovenia. More than 200 sensors (acceleration, deformation and temperature gauges) were installed on the viaduct that monitor the response of the structure in real time. We are thus able to assess the severity of the deterioration of damage and reduce the uncertainties associated with the future behaviour of the construction. The effects of traffic loads resulting from the expected increase in heavy freight transport and from the changed traffic regimes are monitored in real time. Changes in prestressing forces in external cables are monitored concurrently. This type of monitoring uncovers certain reserves in the behaviour of the structure, based on which we can perform a more realistic calculation of its actual safety while under traffic loads and the effect on the structure's service life. Vast amounts of data on the state of the structure will be collected over a longer period. The operator will subsequently be able to carry out a more effective strategy of repair and maintenance work on the motorway infrastructure.

Construction of the Future – Wood Construction

1. Wood as a strategic material
2. Classic wooden roof frame – the most widespread use of wood
3. Timber skeleton construction
4. Multi-storey building (cross-laminated timber panels)

Construction of the Future – Wood Construction

Wood is one of the oldest materials used in construction. Availability, simplicity of processing and - if correctly installed - long service life are the advantages that were recognised as far back as our ancestors. They built hand in hand with nature, which is corroborated by the prudent management of Slovenian forests and by closely related cultural and architectural heritage. Even though the rise of the construction materials industry during the industrial revolution and in the decades that followed caused a decline in use of wood, construction using natural materials – mainly wood – is again gaining ground.

► Wood as a Construction Material

The biggest advantage of wood and wood-based construction materials is their ecological acceptability. Calculations of product environmental impact, which take into account the entire service life of a product, show that the use of wood in construction decreases the quantity of CO_2 in the atmosphere and slows down global warming. Its advantage in Slovenia is also associated with local availability, as more than 58% of the national territory is covered by forests – wood is therefore the only raw material that is truly in abundance here. After Finland and Sweden, Slovenia is the third most forest-rich EU Member State, with an annual increment of over 9 million m^3 of wood. The management of Slovenian forests as well as the processing of wood and its use in construction are both a challenge and an opportunity to build hand in hand with nature. Somewhat more than 40% of the timber from coniferous trees is used in construction in the EU if furniture and windows and doors are excluded, whereas in developed countries every 100 m^3 of processed wood represents one employment position in well-arranged forest-wood industries, which should be the goal for Slovenia as well. The potential of domestic forests also represents the national interest – the Action Plan to Increase the Competitiveness of the Forest-Wood Chain defines wood as a strategic raw material and aims to improve the rate of utilisation of the potential of Slovenian forests and raise the added value of wood, improve the competitiveness of the wood processing industry and set up foundations for the development of new wood-based products or new technologies for the use of wood. The Slovenian National Building and Civil Engineering Institute (ZAG) engages as a stakeholder in most of the phases of the forest-wood chain, starting with research of the basic raw material.

► Features of Wood Construction

Wood or wood-based materials are characterised as aesthetic materials with an excellent strength-to-weight ratio. The ratio is essential for modern construction trends – higher, bigger, bolder. Only materials that ensure flexibility of use will be able to compete in the case of taller buildings with the currently most used materials of concrete and steel. Wood construction is no longer limited to single-family houses and ancillary facilities, as investors who develop business, industrial, sporting, educational and tourist buildings are increasingly aware of its potential. Even though building with wood is perhaps no longer the most affordable option, it has one more advantage: high level of prefabrication and consequently shorter erecting time.

► Light-Frame Construction

Prefabricated wood construction that has been developed for decades or mastered by domestic manufacturers is suitable and cost-effective for low-rise buildings. With this type of structures, wall panels are prefabricated in factories; they are made up of a solid wood frame, various sheathing boards (wood-based materials, plasterboards) and insulation materials that fill in the space in the frame and can for exterior walls be additionally affixed to the outer side of the elements. Floor and roof structures can also be prefabricated in a similar manner. The area of frame construction is still developing. New and improved materials as well as new technological procedures are coming to market and the industry is increasingly focusing on optimisation. The Slovenian National Building and Civil Engineering Institute (ZAG) is actively working with established prefabricated building manufacturers both in the area of research and the area of quality assurance.

► Wooden Skeleton Structures

The widespread use of computer numerical controlled machines for the processing of wood has brought back wooden skeleton structures where only load-bearing solid wood or glued laminated timber elements are first prepared and are then placed into a particular grid or raster at the construction site. Gaps are filled in with insulation materials at the construction site, whereby the frame can even be visible depending on the architect's vision and requirements. The limitations of frame and wooden skeleton structures are enhanced using the composites (glued laminated timber, cross-laminated timber panels) or steel.

► Solid Wood Construction

Solid wood construction, which used to be associated with log cabins, has long ago exceeded the limits of simple single-family houses. A solution that is perhaps not the most economical in terms of the efficiency of wood consumption but is very competitive when it comes to bold architectural solutions is solid wood construction using cross-laminated timber panels, which are a composite material composed of a varying number of cross-laminated lamellas that eliminates one of the more important deficiencies of solid wood – anisotropy. Cross-laminated timber panels, as the currently most well-established composites in building construction, are used not only for wall elements but also for floor and roof elements. In Slovenia, we are currently seeing buildings with up to five floors being built, while such structures have up to ten floors elsewhere in Europe. The manufacture of the currently most popular wood composite, which came to market around the turn of the century, is increasing exponentially.

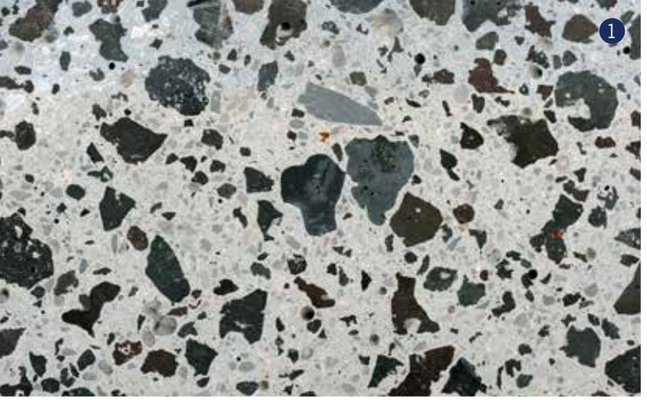
► Hybrid Structures

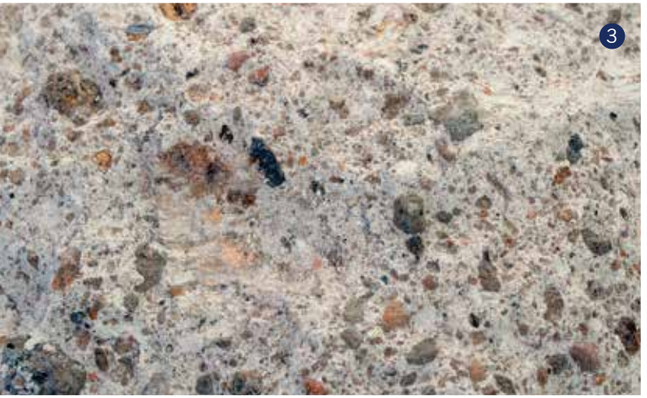
When wooden skeleton or solid wood structures are unable to meet the architects' demands, they are coupled with other structural materials to form hybrid structures. Wood-based materials are most often combined with steel or reinforced concrete, but other combinations are also possible. Different / various materials or structural systems (e.g. combination of cross-laminated timber panels and moment frames) can be combined either only in a certain part of the building or over its entire height. Generally, the connections between individual materials are the critical parts of hybrid structures; these are usually steel connections or connections with adhesives. The aforementioned systems are employed in Europe in buildings up to the height of 70 m (20 floors). Materials in hybrid structures should not be mistaken for materials that need to be installed into a building in order to improve specific essential characteristics, whereby there are currently no alternatives in wood-based materials (e.g. screed to ensure sound insulation or plasterboard to ensure fire resistance). Despite the relatively modest share of tall wooden buildings in Slovenia, the Slovenian National Building and Civil Engineering Institute (ZAG) has recognised the significance of this area and engaged actively in research in timber structural engineering of the future. The Section for Timber Structures of the Slovenian National Building and Civil Engineering Institute (ZAG) is the lead partner of the European Research Project InnoCrossLam (ERA-NET ForestValue funding program), which aims at increasing the competitiveness of cross-laminated timber as a versatile structural material with applications in areas that are not yet addressed in the current and foreseen regulations or guidelines.

► Wood is the Future

The increased share of construction in wood is also confirmed by statistical data that show that investors and building designers are increasingly aware of the advantages of building with wood. The estimates of future construction should by all means account for the fact that the number of the urban population is on the rise and that the spatial constraints in urban environments most frequently only allow building upwards. As a result of the expected higher prices of raw materials, rational use of wood, i.e. ratio between the wood used and the usable floor area or number of floors, will be one of the more important construction efficiency indicators in the future. The concerns from a decade or so ago about cheap and non-durable wood construction have for the most part disappeared. The current state of the art offers numerous wood construction alternatives, however only correctly prepared and built-in wood will be a durable and lasting material that will fulfil the wishes and expectations and will be a synonym for sustainable construction.

Circular Economy in Construction





1. Green concrete with addition of manufactured aggregate from recycled steel slag.
2. Green concrete with addition of recycled aggregate from recycled brick.
3. Geotecnical composite from remediated soil with addition of paper ash.
4. Crushing of mixed demolition waste in-situ.
5. Sampling of geotechnical composite for inspection of installation quality
6. Temporary storage of pretreated polluted soil.

Circular Economy in Construction – Modern Buzzword or Successful Business System?

The construction industry is the largest consumer of raw materials, as it consumes more than 50% of all exploited natural materials every year. The construction industry generates 9% of GDP in the EU and provides more than 18 million jobs. On the other hand, Europe is especially vulnerable in the area of resources, as the net EU share in the annual global production of raw materials is less than 5%, which makes it an importer of raw materials. In a changing world where climate change, rapidly increasing global population and the disappearance of animal and plant species represent a threat of shortages of food, water and other resources, it is the responsibility of each individual and the entire human community to start acting differently – be more responsible towards the planet and future generations.

Effectively making the construction industry green can have a great positive impact because of its size and impact on the environment and resources. The opportunity here lies in the recognition of waste (3 tons per person per year in the EU) as potential raw materials for the circular and inclusive economy as well as the transition from a linear model of consumption, in which products end up in landfills after their concluded life cycle, to a circular model, in which products are not disposed of but rather begin new life cycles in the same or processed form. The recycling society has been the vision of the EU for nearly a decade. The circular economy concept is being set up, whereby material loops are closed at the local level and the quantity of waste that needs to be disposed of is decreasing. The biggest advantages of such an approach in the energy and raw material-dependent Europe are more efficient use of resources, lower pollution, greater competitiveness of the economy and ethical growth that takes into account the limitations of the planet.

Reclaimed tar asphalt, hazardeous waste, becomes inert construction product after permanent binding in concrete

► Waste Recycling in Construction

The need for greater quantities of materials in construction and the large quantity of available waste ensure a mass balance. If waste is not environmentally inert, different binding agents and procedures can be used to immobilise hazardous components permanently. New products are either equal in terms of quality or even better than the conventional ones. We have the knowledge and technology for this, and the legislation governing construction also provides for this: it namely does not discriminate between

materials subject to their origin or name but rather considers their properties, usability and environmental footprint. The European Construction Products Regulation (CPR) that was amended in 2013 introduced the additional basic requirement 7 for construction works that encourages efficient and sustainable use of resources. Construction products from recycled waste can be placed on the market based on harmonised standards or the Slovenian Technical Approval (STS – "Slovensko Tehnično Soglasje").

► Recycling of Industrial and Construction and Demolition Waste

Recycled industrial and construction and demolition waste in building composites can replace natural aggregate and/or traditional binders (cement, lime, bitumen).

An excellent alternative to natural aggregate is manufactured aggregate created from steel slag during the production of carbon steel. Owing to the high level of toughness and micro-roughness, it is considered to be one of the best of the known aggregates. Foundry sand and other industrial sands as well as construction and demolition waste have great potential for recycling into aggregates.

Concrete is the most important construction material, however the production of one ton of cement generates 750 kg of CO_2 (data for EU-28). Lowering the cement content by introducing binders from recycled waste could reduce the carbon footprint of concrete by as much as 20%. The development of so-called "green concretes" using recycled waste (including hazardous materials such as galvanic sludge and tar-contaminated asphalt) and their ethical use is therefore a need and challenge for the concrete production industry as well as a great opportunity.

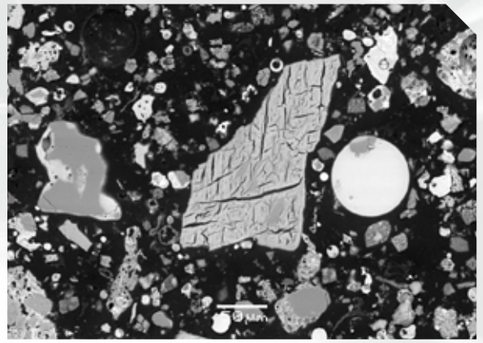
An excellent replacement for part of the cement in concrete is waste in powder form with a binding capacity, either pozzolanic or hydraulic (e.g. ash obtained from coal-fired and biomass power plants, from municipal incineration plants and from the incineration of paper sludge as well as some types of steel slag and gypsum waste from the chemical industry). These types of waste can be a good input raw material for the production of cement clinker. One of the low-carbon and low-energy alternatives to the Ordinary Portland Cement (OPC) clinker with the most potential is the Belite Calcium SulphoAluminate (BCSA) clinker. Owing to the firing temperature of BCSA being lower, its production generates 20–30% less CO_2 emissions, while the use of recycled industrial and other waste contributes to the preservation of natural raw materials. The physico-mechanical properties of such cements are supposedly comparable to Portland cements according to the research performed to date. One big advantage of this binder is that we can use the same technological equipment in its production as we do for the production of OPC.

Lately, the production and use of **geopolymers** or **Alkali-Activated Materials** (AAM) have been on the rise, as they are environmentally-friendly and technically acceptable alternatives to ceramics, cement and concrete. AAM are created through the mixing of a component (in solid state) that contains sufficient quantities of reactive SiO_2 and Al_2O_3, and alkali activators in a water solution that contain, for example, alkali hydroxides, silicates and carbonates. After the dissolution and diffusion reaction, the aluminosilicate matrix solidifies. In addition to natural raw materials such as thermally activated clay (e.g. metakaolin) and natural pozzolans (e.g. volcanic ash), industrial ashes (fly ash, ash from municipal waste incineration, wood ash) and various slags are also potentially usable raw materials. If the alkali activation process is well-known, it is possible to develop new products that serve as a substitute for concrete and micro-reinforced concrete, alkali activated aggregates, foamed insulation AAM, hybrid AAM combined with cement and AAM for repair purposes. In addition to the good technical characteristics, the key advantage of AAM is the use of waste. This preserves natural raw materials and reduces CO_2 emissions.

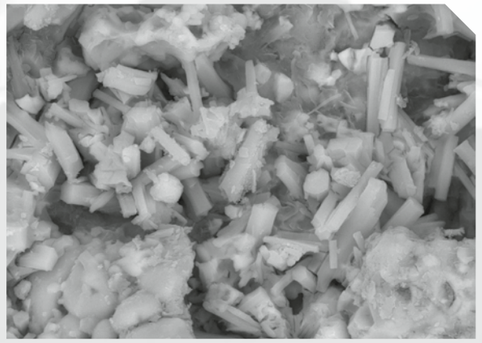
► Recycling of Other Waste

In addition to recycled industrial and construction and demolition waste, numerous other types of waste can be a potential resource in construction. Municipal sludge that is created as solid waste during water treatment is an excellent raw material for the production of geotechnical composites. The use of different types of recycled plastics, waste cellulose and waste plastic fibres is also feasible. An important source of raw materials, both in terms of quantity and quality, is the sediment that occurs in lakes, reservoirs, estuaries

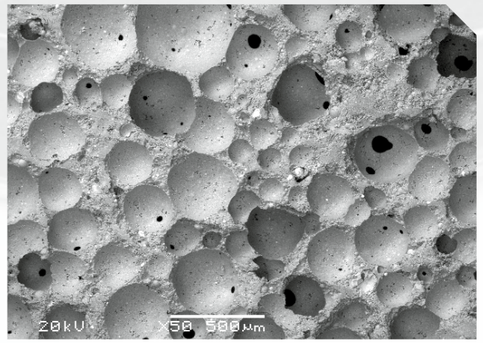
Ash from paper pulp incineration is excellent immobilisation additive



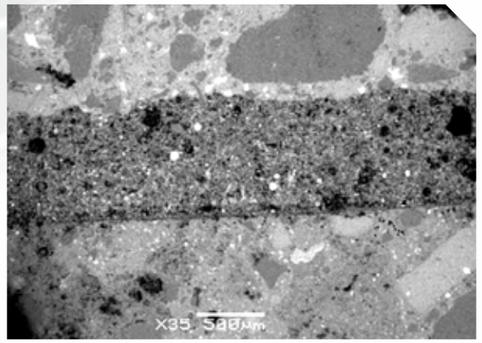
Microimage of hidratation products in cement klinker



Microimage of alkali activated foam



Microimage of alkali activated adhesive



and port areas. Particularly promising are "a la carte" building composites, which consist of several different types of recycled waste in which tailor-made combinations can provide the best possible synergistic effect in the technical, technological and environmental sense. Contaminated soil from numerous brownfield sites in Slovenia, which can be remediated in situ, now appears to be a promising material for some geotechnical applications, especially for the construction of embankments. Such soil is turned into a construction product and incorporated back into the ground using standard procedures for earthworks. When executing earthworks using waste, contaminated soil and lower-quality local soil materials, the use of geosynthetics plays an important role as they allow soil as a natural material to replace concrete and other materials, the production and incorporation of which require more energy and have a greater impact on the environment.

► Celovita obravnava uporabe odpadkov v gradbeništvu

The Slovenian National Building and Civil Engineering Institute (ZAG) is working with waste holders to assess many potential solutions. In doing so, it searches for the most realistic and balanced option in terms of both the nature and quantity of the waste, taking into account the location of potential end users, the current market demand for the product, its carbon footprint, the price of recycling processes and, in particular, the feasibility of the application for standard civil engineering technology, so that new materials can be produced, transported and installed with existing civil engineering machinery and technology. Higher added value of a new product or environmental technology is always welcome but is not an absolute priority. It is also important for the final product not to be harmful to the environment, and that the solutions used are robust – in this way, variations in the quality of the recycled waste can be kept under control, which are generally more extensive than in the case of conventional materials. The research that is usually most successfully transferred into practice is such that the final end user of the construction product is included in the design process from the very start, so that a circular materials loop can be achieved.

► Novi proizvodi za uspešen krožni poslovni sistem

New products made from recycled waste can be a foundation for a successful circular business system, as the cost of waste disposal is on the rise, while construction products made from recycled waste can be more affordable than conventional products and have a lesser impact on the environment. This is considered to be sound recycling and not recycling at any cost. The Slovenian National Building and Civil Engineering Institute (ZAG) provides assistance in designing new circular business models through comparisons of existing and new value chains and analyses of political, economic, social, technological, legislative and environmental factors that can affect the design of a new business model in the local environment. The main consideration in this respect is the valuation of new construction products made from secondary raw materials from the point of view of their entire life cycle. In order to improve transparency and traceability of the waste to product material flows, their functionality in a building and their re-use and recycling, we use tools such as the material flow analysis (MFA) and building information modelling (BIM). Our approaches are based on the most efficient recycling possible, including the extraction of critical raw materials and other economic raw materials, whereby the remainings can be used in construction (zero waste approach). Local closing of material loops and the supply of raw materials mean that circular economy and sustainable construction are no longer only a buzzword but have become an important element in the achievement of global sustainable development objectives.

Laying of asphalt with manufactured aggregate from steel slag

Installation of remediated composite from polluted soil

Instalation of composite layers during revitalisation of mining area

Advanced Materials in Construction

1. Different consolidants before applications: newly developed and patented consolidant (left) in comparison to commercial consolidants (middle and right)
2. Depth determination of consolidant penetration by the use of indicator
3. Colour change measurements after consolidation in Janez Krstnik church at Bohinj lake
4. Determining the efficiency of the consolidation of baroque wall paintings by applying a micro-destructive method
5. Sculpture named "Angel Celebration" from a white UHPFRC (Photo: Petja Novak)

Advanced Materials in Construction

Advanced construction materials encompass nanomaterials for the protection of construction surfaces and application in residential environment, new methods of wood modification to enhance fire resistance, new materials and methods for the protection and consolidation of cultural heritage (historical materials), composites based on renewable and environment friendly fibres, ultra-high-performance fibre-reinforced concrete (UHPFRC) etc.

► Consolidation of Historical Materials

Cultural heritage is an important element in our living environment, hence care for its preservation and protection is of great significance. In this context, we deal with historical materials, i.e. materials falling within the scope of cultural heritage protection. They are subject to degradation processes, which impair their strength or even lead to their collapse. Degraded materials frequently require prior consolidation. To successfully preserve the original, the consolidants must feature a host of extra properties: compatibility with the base material, sufficient depth of penetration, a broad operating temperature range, preservation of the porosity and appearance of the original material, and environmental friendliness. In practice, calcium hydroxide in various alcohols is a particular favourite consolidant. However, calcium hydroxide only reinforces surface layers and has a number of shortcomings, such as shallow penetration depth, whitening of the consolidated surfaces and high sensitivity during application.

At the Slovenian National Building and Civil Engineering Institute, we develop cultural heritage material consolidation procedures. An efficient and simple process of consolidation by applying water-soluble calcium salts has been developed and patented [Patent EP 3004028 (B1), 2017]. Its field of application is the consolidation of different carbonate-based materials such as plasters, mortars, wall paintings, stones etc. The new consolidant is distinguished by its good adhesion properties and the absence of whitening effect on the historical material. The structural strength of consolidated samples exceeds that of untreated ones by far. In comparison with other known consolidation processes, fewer application steps are needed to achieve an equal effect.

The new consolidant has been tested on real historical materials, on monuments of national importance [Pondelak et al., J Cult Herit 28 (2017) 1–8], on wall paintings inside the Saint John the Baptist church at Bohinj lake, in the Franciscan church in Ljubljana, in the Saint Vincent church in Istria, on the Saint Mary plaque column at Radlje ob Dravi etc.

► Nanomaterials in the Residential Environment

The durability and functionality of construction structures and surfaces can be improved by applying newly-developed nanomaterials featuring photocatalytic and super-hydrophilic capabilities in functional coatings.

Applying in-house developed activity measurement methods, the Slovenian National Building and Civil Engineering Institute has demonstrated the efficiency and durability of the developed nanomaterials on various construction surfaces such as roofing tiles, ceramic tiles and facades [Rozman et al., Materials 12 (2019)

1–19; Sever Škapin et al., RSC Adv 5 (2015) 26769–26776]. Their photocatalytic properties promote the decomposition of organic contaminants and purify the surrounding air.

We have modified the surface of organic pigments. A coating, several nanometres in thickness, was applied to the surface of a particular pigment, without affecting the chromatic properties of the pigment [Švara Fabjan et al., J Sol-gel Sci Technol 68 (2012) 65–74; Švara Fabjan et al., Dyes Pigments 127 (2016) 100–109]. Such coatings are distinguished by their long-term chromatic and functional stability.

Wastewater flows with high levels of non-harmful organic substances may also contain harmful contaminants in low concentrations. We have developed a nanomaterial based on mesoporous SiO_2 and photocatalytic TiO_2 that selectively decomposes harmful contaminants [Nadrah, Gaberšček and Sever Škapin, Appl Surf Sci 405 (2017) 389–394].

Mesoporous SiO_2 materials are also an attractive substrate for application in sensorics. By informing the user of the environmental parameters, they may indirectly contribute to improving the living ambience. To this end, we are developing materials based on mesoporous SiO_2 particles with integrated dye to indicate excessive relative humidity of the surrounding. At a certain level of relative humidity, the ongoing process of water adsorption from the gaseous phase into the mesoporous SiO_2 particles triggers specific physical or chemical reactions and thereby a change of colour (Figure 4).

In the future, we will proceed with research in the field of SiO_2 materials to bring them closer to the application stage. Mesoporous SiO_2 will be used in the further development of a relative humidity indicator, as well as for the purposes of indicating the presence of volatile organic compounds and CO_2 in enclosed spaces. In this context, the focus will be both on the research of chemical and physical processes on the surface of the SiO_2 and on the real conditions to which the indicator will be subjected.

▶ UHFPRC – State of the Art Sustainable Cement Composite

Ultra-high performance fibre-reinforced concrete (UHPFRC) is one of the state-of-the-art sustainable cementitious composites distinguished by their high structural strength, exceptional toughness (including under tensile loads) and outstanding durability. It is usually made with pure Portland cement, mineral additives like silica fume and rock powder, chemical admixtures like high-range water reducers, short steel fibres (10 to 15 mm in length) and with or without fine-grained aggregate (up to 4 mm). The composition and properties in fresh and hardened state can be modified to suit the method of pouring and the purpose of application. They are suitable for the thin-layer resurfacing of structural members that are most exposed to environment such as bridge kerb and deck elements, over-pass sub-structures, parts of structures in tidal zone etc. Furthermore, they can be used in renovations and new constructions, as well as for the reinforcement of structural elements of inadequate strength. Due to their relatively high costs, their application is recommended only where they are likely to be financially viable. In this respect, the assessment of the economic viability of application of UHPFRC should not only consider the price of the material, but also: 1) the reduced consumption of materials due to the superior structural strength; 2) reduced duration of construction works due to implementation of different technology and hence, reduced duration of road closures, and 3) in the long term, significant reduction of the number of necessary maintenance works due to their longer service lifetime.

In Slovenia, UHPFRC has been successfully applied in the renovation of the Soča river bridge at Log Čezsoški (ARCHES project: arches.fehrl.org) and in the reinforcement of the old railway bridge (ref. https://www.frontiersin.org/articles/10.3389/fbuil.2019.00026/full).

Since composition of the UHPFRC can be modified to meet specific requirements both in fresh and hardened state the material is also of interest in other fields of application. Thus, we have already been involved in the collaboration with the University of Ljubljana. We worked with the undergraduate students and their academic advisor Assoc. Prof. Metod Frilc from the Faculty of Achitecture and with Ms Petja Novak from the Academy of Fine Arts and Design. For the latter we designed a white UHPFRC which was used to cast a sculpture named "Angel Celebration". The sculpture was created as part of the international fine arts academy LindArt at Lendava."

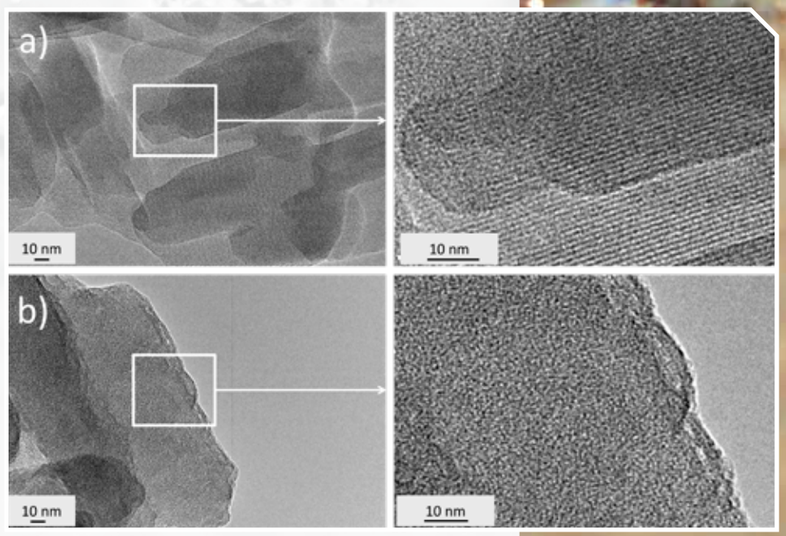


Figure 1: Micrographs of (a) unprotected pigment particles and (b) pigment particles with a SiO_2 nanocoating with electrone microscope [Švara Fabjan, 2012; Švara Fabjan, 2016].

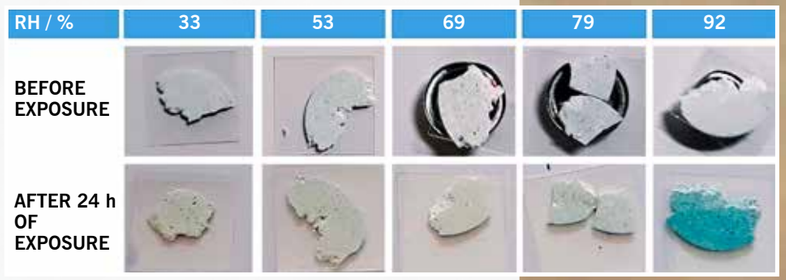


Figure 2: Water adsorption by capillary condensation takes place at relative humidity (partial water pressure) levels above 92% and thus allows determination of the relative humidity in this range.

Earthquakes and Buildings

1. Masonry building models on the shaking table at failure: the house without ties (left) and the house with ties (right)
2. In-situ test of stone-masonry wall, performed in an older building
3. In-situ test of compressive strength of older brick masonry

Slovenia and Earthquakes

Many earthquakes that hit Slovenia in the past confirm the fact that the seismic hazard is present in our country and that this issue should not be ignored. The development of earthquake engineering and the adoption of first codes for seismic-resistant construction in Slovenia was initiated by Ilirska Bistrica earthquake in 1956. This has solidified the belief that seismic-resistant construction is the only effective protection from the impacts of an earthquake. Each building and civil engineering structure has to be sufficiently resistant so as to withstand an earthquake that can be expected at its location without it being destroyed.

► Seismic-Resistance of Buildings and Civil Engineering Structures

The construction of seismic-resistant structures requires a lot of knowledge that is developed and based to a large extent on research. The basis for earthquake engineering research are experiments that are performed in an appropriately equipped laboratory or on a part of an existing building or civil engineering structure. When performing experiments, simulated seismic loads are applied on a building or civil engineering structure, wall or column while the development of damage until failure is monitored. Findings allow us to develop and confirm analytical methods that are then used in structural design. Analytical models are used both for the design of new buildings and for the strengthening of existing ones.

► Experimental Research into Strengthening Systems

The Slovenian National Building and Civil Engineering Institute (ZAG), formerly the Institute for Testing and Research in Materials and Structures (until 1995), carries out fundamental and applicative research into the seismic response of building structures, i.e. mainly masonry building structures. From as early as the 1960s, various scale models of buildings on the shaking-table that simulates seismic action have been tested.

The seismic behaviour of masonry buildings, that are classified as architectural heritage as well as modern construction technologies, has been investigated. The latest strengthening techniques for masonry walls and their effectiveness in the improvement of seismic resistance have been studied. Today, the more capable equipment of the laboratory enables us to test full-scale models, which perform seismic behaviour closer to the actual situation during an earthquake. Based on the destructive tests of structures, the locations of damage are identified and the measures for the improvement of damage propagation are studied.

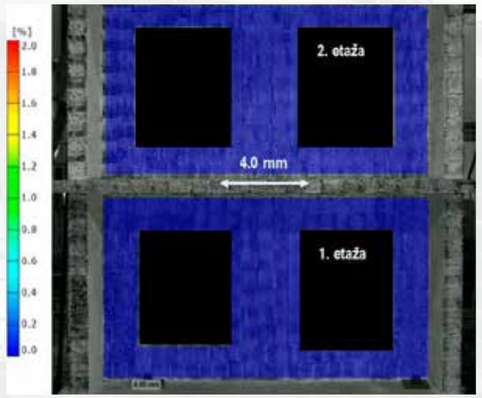
► Let's Prepare for an Earthquake

In order to enable appropriate planning and response to an earthquake, the responsible services must know how many buildings and civil engineering structures will sustain the heaviest damage and where these structures are located. The Slovenian National Building and Civil Engineering Institute (ZAG) has set up a model for the assessment of seismic risk of all buildings in Slovenia, within the scope of the POTROG project, financed by the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief. The model is supported by the use of the Real Estate Register. It is based on the estimates of seismic resistance of typical Slovenian buildings that were built in various

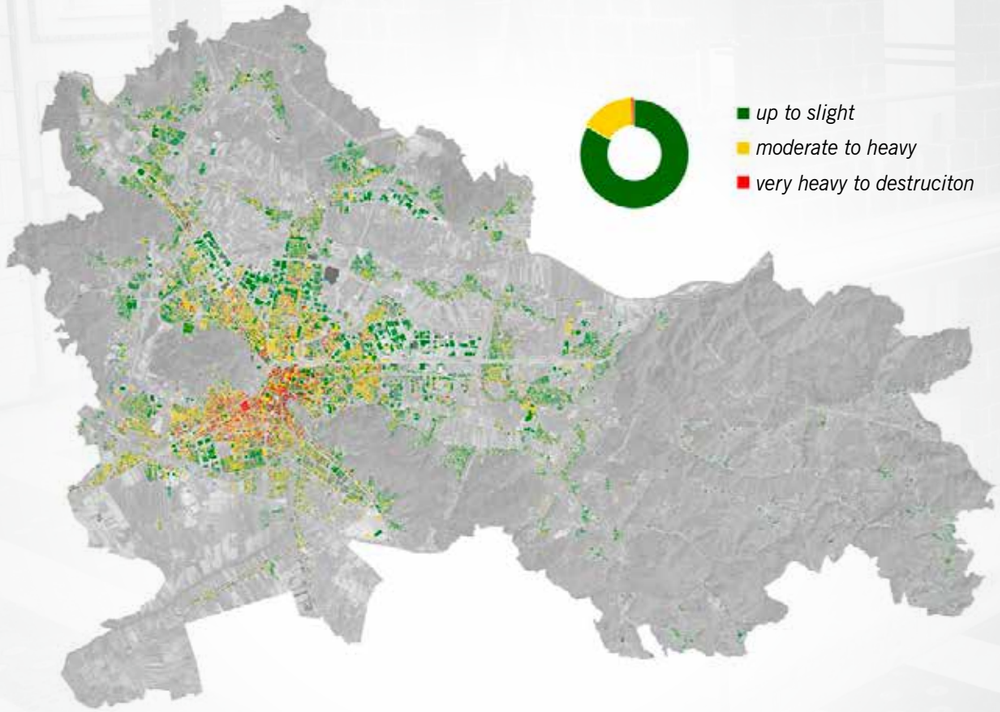
periods, are of different heights and were built using different materials. The seismic resistance of buildings mostly depends on the knowledge and seismic codes that were applied during their respective construction. There is an ever-present misguided belief that there will be no earthquake, that the load-bearing capacity and seismic resistance of buildings are justifiably presupposed and that the structure does not require special attention during reconstruction. In order to improve awareness the web-application "Oceni svojo stavbo" (Assess Your Building) has been prepared within the scope of the POTROG model.

http://www.zag.si/si/organizacijske-enote/konstrukcije/odsek-stavbe-potresno-inzenirstvo

http://potrog2.vokas.si/



Deformations, obtained by optical digital measurements, on the surface of a masonry building due to seismic loading



Spatial presentation of the level of earthquake damage on buildings in a town, obtained by the POTROG model

Seismic test of a full-scale masonry building (top) and diagonal shear cracks on the bottom storey walls (bottom)

The Future of Living in a Sustainable Building

1. Dom24h project (Marles)
2. TIGR4Smart project

The Future of Living in a Sustainable Building

Sustainable construction is a topic that has lately been the subject of intensive debate among various groups of stakeholders: in the industry, at the state level, at universities and mainly among the general public. It concerns each and every person. Despite this or perhaps because of this, we cannot steer this debate easily, as it involves many points of view. If we take a step back and look at it, we can consider sustainable construction in relation to environmental, sociological and cost issues, but this is still not enough. We must also or primarily take into account the health of the people in a building as well as the level of comfort that such a building provides.

► Sustainable Construction Metrics

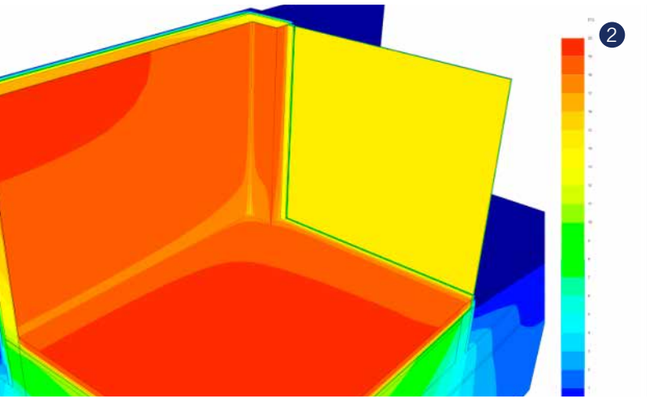
We need to put in place a system for the measurement of the level of sustainability of the construction. This presents us with special challenges such as the question of what is more important, i.e. the environment, the cost or comfort, or the challenge of comparability of individual buildings. We also need to understand that sustainable construction affects the behaviour of the user through consciousness. The topic is truly a complex one. We have been observing extensive efforts (around the globe and at home) lately to survey the level of sustainability in a measurable manner. In Slovenia, we are also seeing buildings that are certified according to different sustainable construction systems (LEED, DGNB or BREEAM) and in accordance with the Level(s) method developed for this purpose by the European Commission in conjunction with its partners. The last method is the direction that the Slovenian National Building and Civil Engineering Institute (ZAG) believes is the one with the most potential for widespread adoption over the long-term, at least in conjunction with the regulations and incentives put forth by the state. The Slovenian National Building and Civil Engineering Institute (ZAG), in conjunction with its partners (in this concrete assignment, these are the ZRMK Building and Civil Engineering Institute and the Ministry of the Environment and Spatial Planning), is therefore engaged in the assignment involving the development of sustainable construction indicators for Slovenia. The assignment is part of the Care4climate (Life+) project. The expected result of the assignment is the adaptation of the Level(s) system criteria to Slovenian circumstances that feature specificities involving the planned use of buildings, construction costs, the attitude of Slovenians towards sustainable construction and the circular economy, etc. In doing so, we address particular indicators such as greenhouse gas emissions associated with the building over its entire life cycle as well as the overall macro-picture, whereby we strive to determine the relative importance of the individual aspects of sustainable construction.

► Smart Building and Smart Home

If we take a slightly broader perspective, we must add the topics of smart buildings and smart homes to the sustainable construction topic. A large portion of the development of concepts and prototypes that will find their way into production has lately been and still is conducted in this parallel field. The coordination of all aspects plays a very important role here. And this is the essence of our research in the recently started Dom24h (Home24h) project, whereby our aim is to identify individual problems in the merging of technologies. This is the first time in Slovenia that we are dealing with the merging of individual technologies or sets of technologies into a single whole. We have tested a part of this already in the TIGR4smart project. We are scaling up the experience gained from the small demo TIGR4smart construction to a building and are even conducting simulations of a mini neighbourhood.

Buildings – Healthy and Comfortable Living

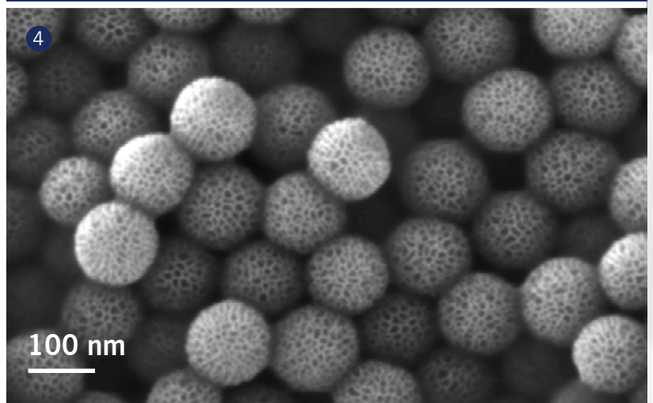
1



2

1. Recording with thermographic camera
2. 3D model of a part of a building with simulations of temperature distributions
3. Noise measurements of indoor installations
4. Electron microscope micrographs of different types of SiO_2 particles

3



4

Buildings – Healthy and Comfortable Living

Buildings are designed to serve humans and, therefore, they must meet all their needs, including physiological and psychological needs. Since people spend more and more time indoors, even more than 90%, the quality of a living environment is of particular importance. Even more so, our demands concerning the quality of living are steadily increasing. We expect an indoor environment to meet high criteria in terms of well-being and not to exert any harmful impacts on the user's health. On the contrary, an indoor environment must act in a stimulating and creative way in order to contribute in a positive way to well-being and productivity. In this context, building envelope materials and components are of particular significance in connection with other building elements and energy utility systems. All these constitute an indoor environment capable of establishing conditions for fulfilling the occupant's well-being, as well as efficiently controlling such conditions.

► Parameters Affecting Health

An occupant's well-being is affected by parameters such as temperature, humidity, air quality and movement, sound and light. When highly intensified, either individually or in interaction, these parameters may have significant impacts on the occupant's health, in particular in the case of the young or vulnerable population. It is for this purpose that it is important to identify, know, control and eliminate any potential sources of negative impacts on the occupants' well-being, or the intensity of sources that are harmful to occupants' health. Lately, the impacts of newly developed nanomaterials have been the focus of study in this field.

Maintaining Thermal Comfort

Like all other stakeholders in the process of the creation of a built environment, experts and researchers at the Slovenian National Building and Civil Engineering Institute strive to advance building concepts and to develop novel building materials, components and systems to contribute to human well-being. On both the application and theoretical levels, we have, for some time now, been dealing with elements of maintaining thermal comfort, including the coupled hygro-thermal parameters of an indoor environment. We successfully employ our know-how and experience in both direct-order projects and in the scope of different research and development projects such as BRIMEE, Q-AIR and Cost-Effective. In the scope of research and collaboration with the industry, we are involved in the macro- and micro-level development of thermal insulation materials and construction products for building envelopes. We test, analyse and evaluate the energy performance and thermal response of buildings, their structural elements and details. In conjunction with other factors, they significantly contribute to the levels of indoor surface temperatures and, in turn, to the maintenance of thermal comfort. We deal with processes of the humidity transport in materials and structures, in particular at the level of details, which still await research. Namely, the consequences of the unforeseen and uncontrolled build-up of humidity in materials often contribute to negative impacts on the occupants' comfort.

Relative Humidity in the room

Relative air humidity has a notable impact on thermal comfort and thereby on the quality of living. Excessively high or low levels of relative air humidity may even lead to certain risks. Thus, high relative air humidity combined with relatively low indoor surface temperatures may lead to a build-up of condensate and thereby provides optimum conditions for the development of moulds on construction surfaces, while excessively low relative humidity may potentially result in human respiratory system infections. Therefore, the experts at the Slovenian National Building and Civil Engineering Institute are involved in the development of special indicators of relative humidity based on mesoporous SiO_2 particles. The material properties achieved by modifying the parameters of synthesis allow indication in a particular range of relative air humidity.

Indoor Air Quality

Indoor air quality is a further significant factor in human comfort. In this segment, the key issues that we address are associated with the build-up of radon from the ground in the enclosed rooms on the building's ground floor. The issue of radon in buildings is addressed by analyses and laying down different measures for the avoidance or mitigation of concentration of this gas. Air is, obviously also polluted by other emissions, such as carbon dioxide (CO_2) exhaled in various concentrations depending on our current activity. Likewise, rooms are exposed to pollutants originating from the preparation of food or space heating, while a further unfavourable factor is the presence of allergens and solid particles. Air quality is particularly influenced by volatile organic compounds (VOC) that may be present in certain construction products or fittings. The improper selection or installation of materials and products, in particular finishing layers or furniture, paints, coatings, glues and others not in direct contact with air, may lead to the emission of substances potentially harmful to health. This, too, is a field that, in recent times, has become a topic of intensive study and engagement for us.

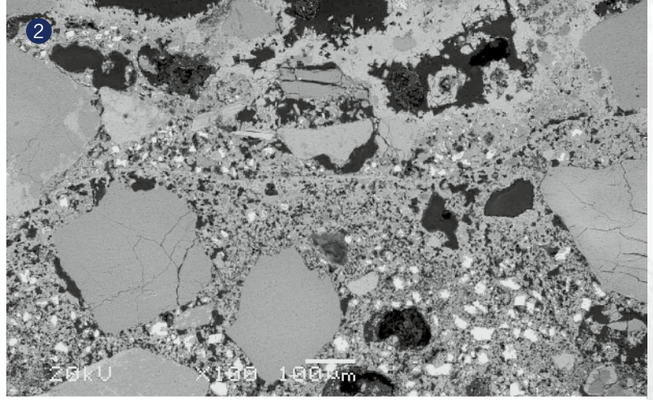
Sound in the Living Environment

In terms of sound in buildings, factors with significant impacts on the occupants' well-being and health are sources of noise within the buildings and in the surroundings, and protection against noise. In this field, the Slovenian National Building and Civil Engineering Institute has recently been involved in particular in building a collaboration with industrial partners, in the development and implementation of construction elements and structures to provide protection against noise. Such was our collaboration in the TIGR4smart project: we participated in the development of a sound insulation panel, of sound insulation improvements for facades consisting of sandwich facade elements and sound insulation improvements of modular residential units. Similar collaboration with industrial partners also takes place in the context of direct orders.

Light in the Indoor Environment

We should not overlook a further indoor environment parameter, namely light. Light has a significant influence on the physical, physiological and psychological condition of humans. An artificial indoor environment usually severely curtails the supply of daylight and affects its distribution across rooms. This is partly offset by artificial light, but to a very limited extent, since it cannot replace all the key properties of daylight. Experts at the Slovenian National Building and Civil Engineering Institute, in collaboration with industrial partners, are involved in the development of innovative luminaries and light sources. We also engage in research into the human perception and sensing of light, its impacts on the occupant's health and quality of living, the photo-biological impacts of LED light on humans and parameters depending on their age.

Water – Air – Soil



1. Pitting and general corrosion in the interior of a cast housing of a water meter made of brass
2. Dissolution of cement coating on the walls of a water tank chamber
3. Pilot system for recycling of waste waters
4. Example of soil contamination: area of the Old Zinc-works in Celje
5. Corroded galvanised pipe from cold water distribution
6. Example of the remediation of contaminated soil with the immobilisation procedure using paper ash
7. Concrete water tank

Water – Air – Soil

What is the link between air, soil and water? Everyone wants to breathe clean air, live in a clean environment and drink good quality water. The water that we drink can be contaminated by the materials through which it passes. Often elevated concentrations of the radioactive gas radon in the interiors of old, dilapidated buildings and basements can be detected. Moreover, soil pollution as a result of human activity can importantly affect the health of living beings.

► Water

The quality of drinking water is influenced by many factors, such as the type of raw water and its geological background, water treatment substances as well as the materials used in the water distribution system. The quality of drinking (potable) water at its source depends primarily on the environment and external environmental pollution; at the end user point, however, it depends on the type and quality of the water distribution system materials that come into contact with water. Even though water is chemically and biologically pure at the source, treated water can be subject to conditions in the water distribution system that can diminish its quality and subsequently affect people's health. The deterioration of drinking water quality in the distribution system is therefore still one of the main problems, because the materials of the water distribution system are usually the main factor that affects the quality of drinking water at the tap.

Complex interaction occurs between drinking water and materials that can lead to the deterioration of the quality of water as well as the deterioration of materials. The main recognized interaction mechanisms between the drinking water and the materials are (1) leaching of substances from the materials (2) corrosion and (3) microbial activity in biofilms formed on the material surfaceThe use of unsuitable materials for the contact with drinking water could lead to biological, physical and chemical hazards that can potentially have a negative effect on human health. We can find elevated levels of lead, chromium, nickel, iron and arsenic in water that leach out of the materials that are in contact with drinking water.

Drinking water distribution system with numerous types of materials constitutes a complex network of uncontrolled physical, chemical, and biological reactors that can produce significant variations in water quality. The water comes into contact with cement materials (concrete impoundments, water tanks), steel pipes or pipes with an internal cement lining and plastic pipes (polyethylene; water distribution), while it runs from the water mains onwards through the water meter (brass) along plastic pipes (polyurethane), galvanised steel pipes, copper pipes or stainless steel pipes.

The Slovenian National Building and Civil Engineering Institute (ZAG) is actively engaged in research of degradation of materials in contact with drinking water. In accordance with the Recommendations for the Assessment of the Suitability of Materials and Products that Come into Contact with Drinking Water, ZAG pro-

vides certification of metal, organic and cement materials and combined materials that come into contact with drinking water.

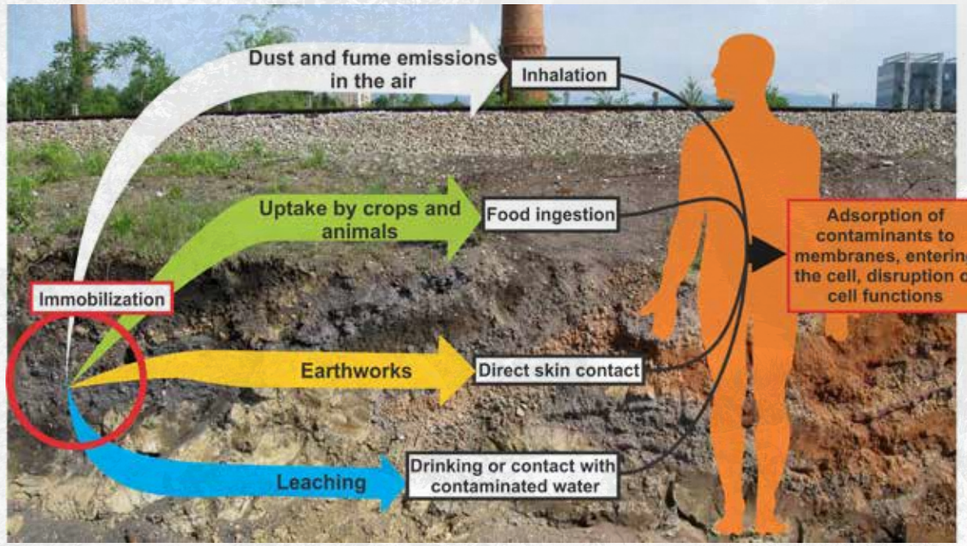
http://www.zag.si/si/naslovne-teme/pitna-voda

► **Air** (Radon in a Living Environment)

Radon (chemical symbol Rn^{222}) is a colourless, odourless and tasteless radioactive gas. It is a decay product in the uranium U^{235} decay chain. We inhale it every time we breathe, because it is present in the air. Radon alpha decays into radon decay products. Even though the reach of an α particle is small, α-decay that occurs in the lungs can cause mutations of the genetic material of the lung cells and subsequently induce the development of lung cancer. Radon itself represents a high risk for the development of lung cancer, while smoking further exacerbates the risk. We can make an assessment that radon causes approximately the same number of deaths as traffic accidents in Slovenia. This is why the radon issue is so highly relevant. Alpha particles react with the tissue and can be hazardous to health in case of prolonged exposure. Radon enters the body by breathing, i.e. through the mouth and nose.
The risk of the development of lung cancer as a result of prolonged exposure to radon in enclosed environment increases significantly at concentrations above 100 Bq/m^3. The European Commission adopted the Basic Safety Standards Directive on Radon in 2013. The threshold value in dwellings may not exceed 100 Bq/m^3, while this value is 300 Bq/m^3 for work premises. Natural background radiation fluctuates by around 10 Bq/m^3. It is important to emphasise that, if we are talking about radon concentrations in the air, there is no safe threshold.

The Slovenian National Building and Civil Engineering Institute (ZAG) is making preparation in the area of radon and partially also measures for the elimination of this problem in the living environment.

Schematic presentation of the transfer pathways for contaminants that are cut off by a remediation process.



It is important to know that even though there are more and less problematic areas in terms of radon concentrations, it is not possible to forecast based on the building's location alone whether problems involving this gas will occur in the building. The radon problem can also occur in new constructions but is more pronounced in older buildings. The Institute deals with the rehabilitation of buildings faced with the radon problem and plans protection against these problems in new constructions. We work with the Ljubljana Institute of Occupational Safety, perform radon concentration measurements with the Jožef Stefan Institute and propose solutions based on long-term measurements, the age of the buildings and living habits. We also work actively on the preparation of international background work for the performance of building rehabilitation.

► **Soils** (Remediation)

Soil remediation is a complex procedure or process for the improvement of the ecological state of degraded soil. There are 345,000 contaminated sites evidenced in the EU where soil is contaminated with potentially toxic elements and substances. Contaminants from soil can be transferred to living organisms by various pathways and there they can cause negative effects on health. The risks associated with soil contamination need to be eliminated through the application of permanent, environmentally and economically acceptable remediation methods.
Our Institute performs research of the remediation methods of contaminated soil from contaminated degraded sites by implementation of immobilisation. Using this procedure, through the addition of natural (clay, zeolites), artificial (cement, lime) or recycled materials (ash, steelmaking slag), we can obtain an inert construction product, which is be used in situ to revitalise a degraded site.

Organizational units

Laboratory for Stone, Aggregates and Recycled Materials

The Laboratory for Stone, Aggregates and Recycled Materials was established in order to ensure the complementarity of good practices, experience and engineering knowledge in the area of the testing of these materials. Today, we build on this through our research works, especially in areas that are currently relevant from the points of view of the environment, circular economy and sustainable construction. The laboratory currently employs 22 people. The core of the laboratory is represented by an interdisciplinary team of people covering the areas of geology, construction, the environment and chemistry.

Activities:

- Investigation of natural geological materials (aggregate, stone and other inorganic materials) for applications in construction
- Investigation of artificial materials (agglomerated stone) and materials made of recycled waste (recycled and manufactured aggregate, geotechnical composites) for applications in construction
- Rehabilitation of brownfield sites using recycled materials and remediation of contaminated soil
- Performance of analyses for the industry as part of the quality development and control (SEM/EDS, porosity, 3D analyses using a microtomograph)
- Inspection of buildings for the presence of asbestos
- Assessment of environmental impacts of recycled materials using life cycle analyses (LCA)
- Expert assessments, opinions, controls, inspections and consulting

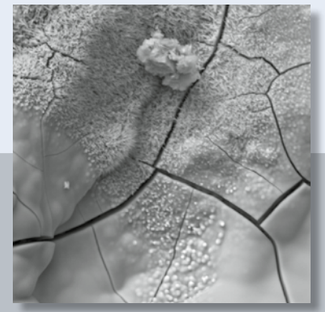
Research and development:

- Methods and technologies for the remediation of soil and water
- Cascade recovery with the extraction of critical raw materials
- Use of recycled waste in building products for civil engineering and building constructions
- Development of circular models and business systems
- Life cycle analyses (LCA, LCC and S-LCA)
- Digitalisation of construction (BIM) and the monitoring of flows from waste to building product
- Microtomography of materials and 3D image analysis
- Research into materials and the preservation of cultural and industrial heritage

Major items of equipment:

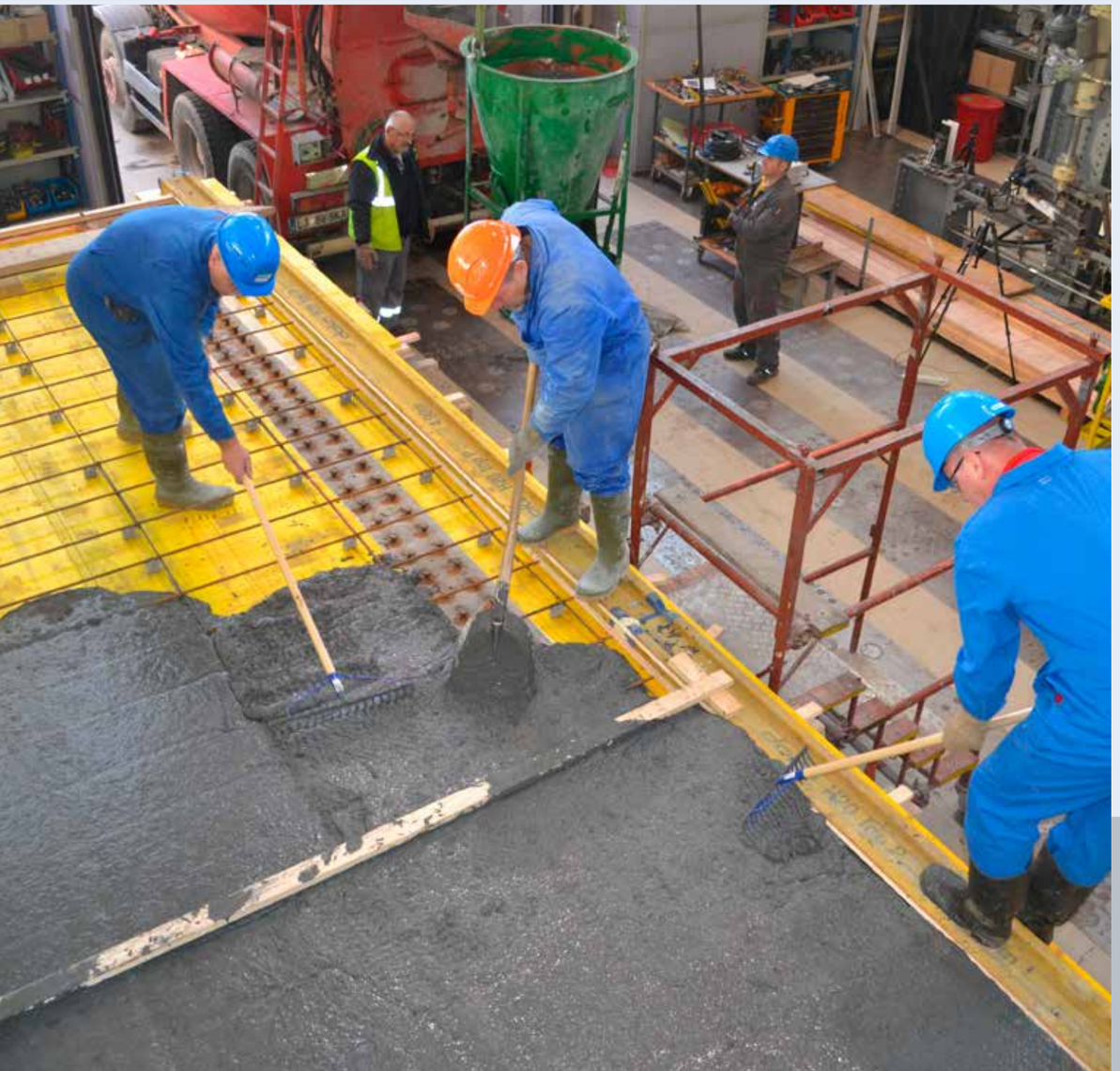
- X-ray computed microtomography system MicroXCT400 with an environmental chamber
- X-ray diffraction analyser (XRD)
- ICP-MS
- Microscopy system
- Isothermal Calorimeter
- Rheometer
- Chambers for the simulation of environmental impacts
- Porosity and size measurement system
- Set of equipment for determination of mechanical-physical properties
- Environmental evaluation software

Head of the laboratory: *Assistant Professor Ana Mladenovic, PhD (Geology) • E-mail: ana.mladenovic@zag.si*



Laboratory for Concrete

The Laboratory for Concrete is equipped with modern equipment for testing, research and development in the area of concrete and concrete technology. The laboratory provides technical and professional support to manufacturers and users faced with problems or issues relating to various types of concrete, their preparation, installation and certification of quality.



Activities:

- Control of the quality of concrete, concrete products and other cement composites
- Control of the quality of executed concrete pouring operations
- Concrete tests and analyses
- Concrete product testing
- Inspection, opinions, expert reports
- Education

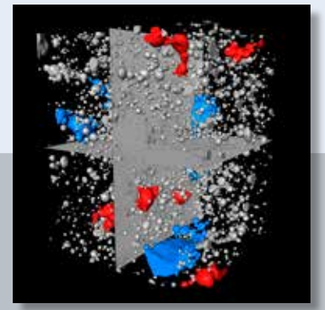
Research and development:

- Research in the area of special concretes and other cement composites (self-consolidating, micro-reinforced, high performance and drainage concretes)
- The use of recycled waste in concrete
- Research of advanced concretes and mortar for fast, durable and sustainable renovation and protection of reinforced concrete structures

Major items of equipment:

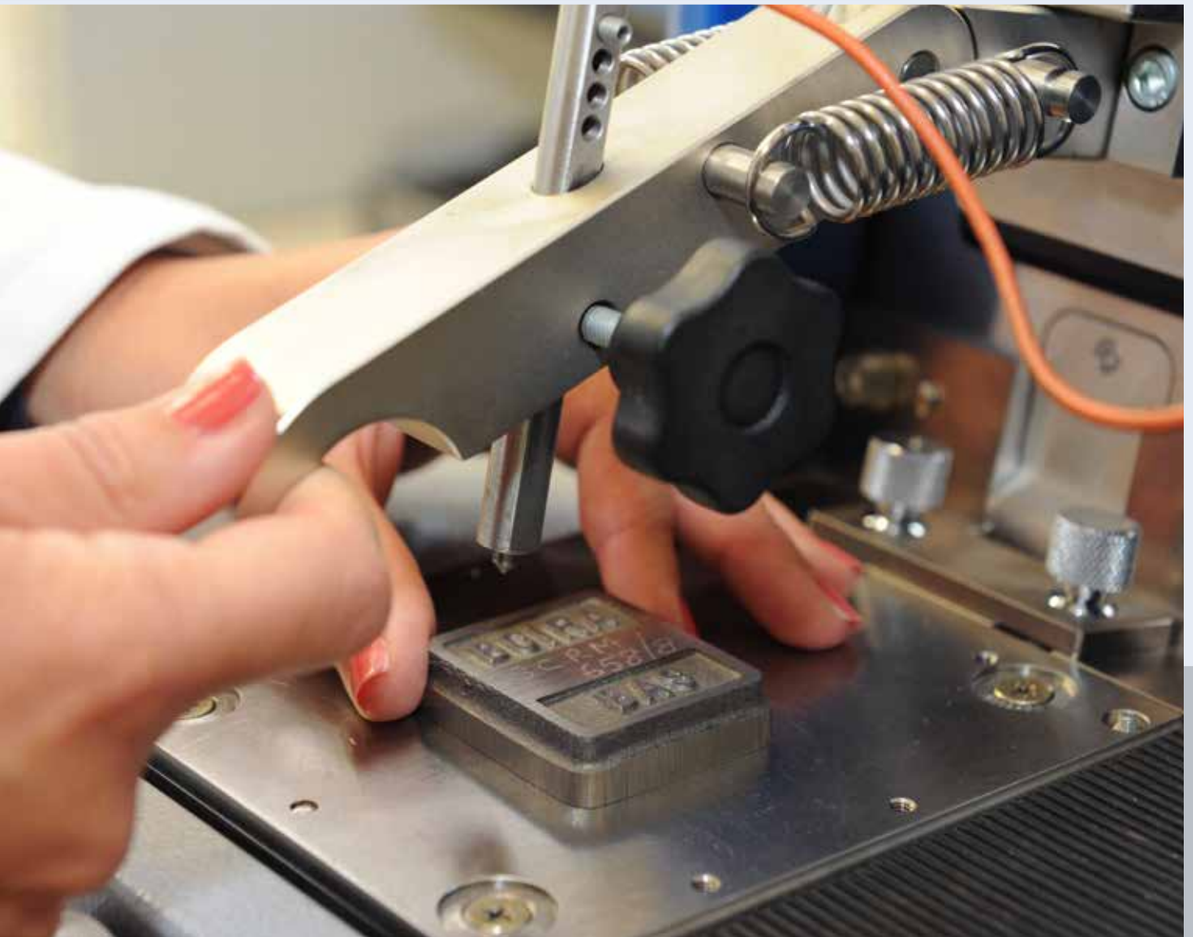
- Torrent air permeability tester
- Equipment for the measurement of pore characteristics in fresh concrete (Air Void Analyser AVA 3000)
- Confocal-metallographic microscope for the determination of pores characteristic size distribution in hardened concrete (according to SIST EN 480-11)
- Rheometer for measuring rheological properties of SCC concrete
- CO2 chamber for rapid determination of concrete resistance to carbonation
- Equipment for measuring autogenous shrinkage
- Acoustics emission monitoring system (Physical Acoustics)
- Equipment for testing SCC concrete (L-box)
- Isothermal calorimeter for concrete hydration heat measurement

Head of the laboratory: *Aljoša Šajna, PhD (Civ. Eng.) • E-mail: aljosa.sajna@zag.si*



Laboratory for Metals, Corrosion and Anti-Corrosion Protection

The Laboratory for Metals, Corrosion and Anti-Corrosion Protection brings to bear its professional excellence and keeps in step with innovations in the area of research and development using state-of-the-art research equipment. We provide technical and professional support in the area of metals, corrosion and their protection. We work with the industry, companies and individuals facing problems or issues related to metals. The laboratory employs researchers and experts from various fields (metallurgy, chemistry, mechanical engineering, physics, construction) who are engaged in numerous domestic and international research projects, professional associations and working groups.



Activities:

- Assessment and testing of metallic materials, products and systems
- Assessment and testing of anti-corrosion protection of metallic and non-metallic coatings
- Non-destructive investigations of defects and damage to metal elements as well as to welded and other types of joints
- Assessments, opinions, expert studies, inspections and control inspections
- Consulting in the areas of corrosion and anti-corrosion protection
- Education

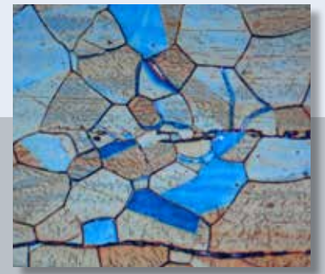
Research and development:

- Development of sensors for the monitoring of corrosion in various applications: steel in concrete, automotive industry, extreme conditions in hydrometallurgy
- Monitoring of corrosion processes in various environments
- Corrosion in water distribution installations
- Mechanisms of local corrosion processes - stress corrosion cracking and repassivation mechanisms in various metallic materials
- Corrosion and tribocorrosion of biomaterials manufactured using traditional and advanced technologies
- Study of corrosion and the protection of cultural heritage buildings
- Degradation of materials in the disposal of intermediate and low-level radioactive waste

Major items of equipment:

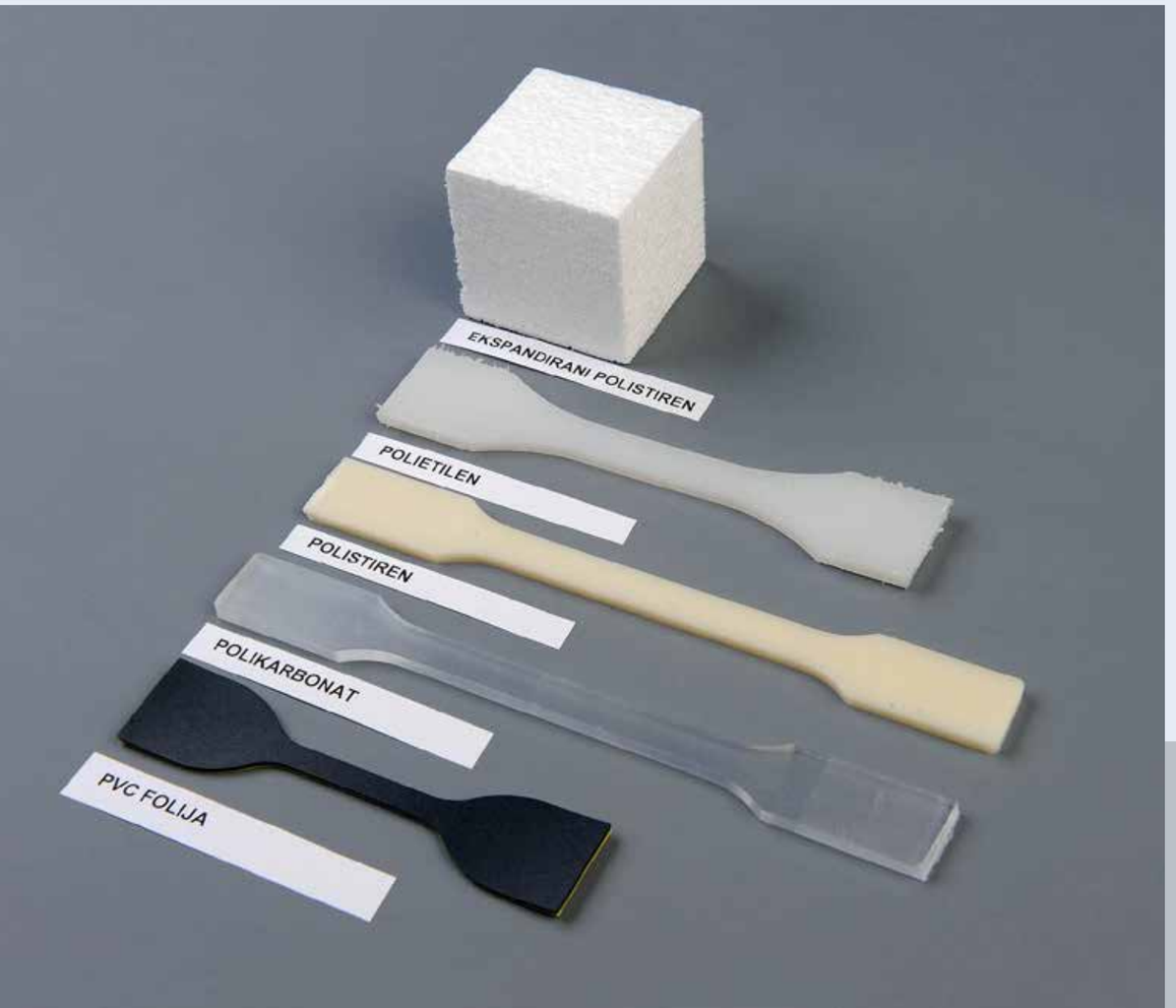
- MicroXCT-400 Micro Tomograph manufactured by Xradia (USA)
- X-ray diffraction analyser (XRD), manufactured by Emperyan (PANalytical, Netherlands)
- Cormet (Finland) SSRT Autoclave for static and dynamic load tests at elevated pressure and temperature
- TRIBOTECHNIC (France) tribometer equipped with a corrosion cell (i.e. a pin on disc, reciprocal tribometer)
- SpectroMAXx optical emission spectrometer (OES) for the chemical analysis of metals manufactured by SPECTRO Analytical Instruments (Germany)
- Zwick Z2500Y universal testing machine with a nominal maximum load capacity of 2500 KN manufactured by ZwickRoell (Germany)
- EOL (Japan) 5500LV and JSM-IT500LV scanning electronic microscopes for low vacuum analyses with an OXFORD (GB) EDS analyser
- LabRAM HR800 Raman spectrometer manufactured by Horiba Jobin Yvon (France)

Head of the laboratory: *Tadeja Kosec, PhD (Chem.) • E-mail: kovine@zag.si*



Laboratory for Polymers

The Laboratory for Polymers combines experts and researchers in the areas of polymers and functional materials in construction. Our work includes testing, investigation and development of advanced materials and construction products as well as polymer-based composites. We work closely with the Slovenian industry and individuals having first-hand problems and questions related to polymer-based products. We pay close attention to modern trends in construction and carefully monitor the development of novel polymer materials and materials science. In our work we are proud to use state-of-the-art equipment that enables us to perform the broadest possible spectrum of various research and examinations.



Activities:

- Testing of polymer products such as pipes, geotextiles, sealants, rubber, adhesives, foils, coatings, paints, etc.
- Determination of the properties of facade systems and their components: insulation materials, renders, reinforcement and finishing coats.
- Testing of road marking materials, road marking performance, delineator posts and retroreflective sheeting for traffic signs
- Control of the quality and installation of polymer construction materials
- Expert assessments, opinions and studies of the properties of polymer materials
- Testing of packagings according to ADR for certification purposes, periodical inspections of intermediate bulk containers (IBCs)

Research and development:

- Research and development of functional materials for use in construction
- Mesoporous materials for use in indicators/sensors and selective photocatalysis
- Photocatalytic materials for the energy harvesting from sunlight, water and air purification and for self-cleaning surfaces
- Wood modification for fire protection and enhancement of durability
- New materials and procedures for protection and consolidation of cultural heritage monuments
- Composites based on renewable and environmentally-friendly fibres (cellulose and, basalt fibres)
- Development of new methods for the assessment of the properties of materials and the monitoring of physical and chemical processes
- Materials and procedures aimed at increasing a healthy living environment

Major items of equipment:

- ZWICK Z030 and ZWICK Z100 universal testing machines
- DMA/SDTA 1+ dynamic mechanical analyser, Mettler Toledo
- Zehtner ZRM 6014 and ZRS 6060 retroreflectometers and the Konica Minolta CM-2500c spectrometer
- Equipment for thermal analysis: TG/DTA STA 409 Luxx
- Accelerated ageing chambers (Q-SUN XE-3 in Q-UV manufactured by Q-Lab; temperature-humidity chamber KK-340 CHLT, Kambič)
- Gas chromatography device with mass spectrometry: GC/MS 7890B, Agilent
- NanoBrook Omni particle sizer and zeta potential analyser, Brookhaven Instruments
- SEM and FE-SEM scanning electrone microscopes (Jeol JSM LV5500, Jeol JSM-IT500LV, Zeiss ULTRA PLUS) with OXFORD EDS analyser
- X-ray computed microtomography system MicroXCT400 with an environmental chamber

Head of the laboratory: *Assistant professor Andrijana Sever Škapin, PhD (Chem) • E-mail: polimeri@zag.si*

Laboratory for Cements, Mortars and Ceramics

The Laboratory for Cements, Mortars and Ceramics provides technical and expert support in the fields of various mineral binders, mortars, ceramics and certain secondary raw materials. We cooperate with all branches of industry as well as with the representatives of institutes and faculties operating in our field of work. The laboratory unites experts and researchers from various complementary areas (chemistry, construction and geology). We are actively engaged in national and European projects and associations such as RILEM, COST, Nanocem …We present the results of our work at domestic and foreign conferences and in scientific publications and monographs.

Activities:

- Investigation of mineral binders, mineral additives, mortars, chemical additives for concrete, cement adhesives and injection grout
- Investigation of ceramic tiles and brick products
- Testing of road de-icing salt
- Determination of the chemical aggressiveness of water for concrete
- Determination of slipperiness of floors
- Petrographic-mineralogical tests of construction materials
- Micro-tomographic analyses of construction and other materials
- Technical assessments, opinions, education

Research and development:

- Low-carbon cements and hydration processes
- Alkali activated materials
- Chemical resistance of mineral construction materials to aggressive media
- Usability of secondary raw materials in the construction materials industry (mainly in mortars and the brick-making industry)

Major items of equipment:

- ARL PERFORM X WD XRF spectrometer for materials and minerals analysis
- TA Instruments TAM Air 3 and TAM Air 8 isothermal calorimeters
- Micromeritics ASAP 2020 gas adsorber
- Micromeritics Hg AutoPore IV 9510 porosimeter
- X-ray diffraction analyser (XRD), manufactured by Emperyan (PANalytical, Netherlands)
- XRadia Micro-XCT-400 microtomography system
- JEOL 5500 LV scanning electronic microscope with an OXFORD EDS analyser
- JEOL JSM IT500 scanning electronic microscope with an OXFORD EDS analyser
- Carl Zeiss Axio confocal-metallographic microscope

Head of the laboratory: *Vilma Ducman, PhD (Chem.) • E-mail: veziva@zag.si*

Laboratory for Thermal Performance and Acoustics

Researchers and experts of the Laboratory for Thermal Performance and Acoustics combine knowledge in the area of heat, moisture and sound transfer in building physics, energy efficiency and renewable energy sources as well as life cycle analyses of construction products, the environmental impact of construction products and sustainable evaluation of buildings.
We are active in national and international research projects and provide broad professional-technical support in the construction process and in the assurance of compliance with legislative requirements in the construction industry.

Activities:

- Investigation, measurement and testing of building-physics properties of construction products
- Numerical calculations of heat transfer, water transfer and water vapour diffusion in construction elements and numerical energy calculations of buildings
- Numerical calculations of sound propagation in buildings and the environment
- In situ measurement of building-physics properties and parameters in buildings
- Assessments, expert opinions, expert studies in the field of building physics
- Life cycle analyses of construction products and buildings
- Sustainable evaluation of buildings
- Education

Research and development:

- Renewable materials in construction
- Sound emissions of construction and mechanical elements
- Impact of construction materials and products on healthy living
- Construction materials and products in relation to durability and energy efficiency of buildings
- Multifunctional elements of the building envelope
- Concepts of energy renovation of buildings with the incorporation of renewable energy sources
- Sustainable life cycle analyses of products and processes
- Sustainable evaluation of buildings

Major items of equipment:

- Chamber for the measurement of thermal properties of construction elements in dynamic conditions
- Hygrothermal chamber for the testing of building-physics properties of façade components
- Calorimetric chamber with artificial sun modules for the measurement of thermal properties of construction elements
- Device for the testing of windows and doors (Holten)
- Cannon for the testing of the resistance of construction elements to hail
- Standardised laboratory chambers for the measurement of sound insulation and sound absorption of materials and structures
- Measurement chains for the measurement of sound insulation, sound absorption, ambient noise in buildings, noise emissions of road and rail transport as well as in situ measurement of the acoustic properties of noise barriers
- Numerical software TRNSYS, GaBi, Delphin, PHYSIBEL, WinISO, Predictor-LimA, ACOUBAT Sound, ACOUSYS, DIRAC

Head of the laboratory: *Sabina Jordan, PhD (Arch.) • E-mail: toplota@zag.si*

Fire Laboratory and Fire Engineering

We have been performing the testing of fire characteristics of products and structures for the construction and shipbuilding industries for more than 50 years. We perform standard and non-standard research-development tests in the area of fire. We are also active in the area of the assessment of environmental performance of the construction products over the life cycle of products as part of the issuance of environmental product declarations (EPD) and as part of our work in the area of research. We are members of the European Group of Organisations for Fire Testing (EGOLF) as well as other international bodies such as EOTA. We participate also in CEN. We also perform analyses of sites where a fire occurred and building fire safety studies.

Activities:

- Testing of fire characteristics of various products for construction and shipbuilding
- Performance of modified, non-standard targeted tests for Slovenian and European industry
- Production of expert opinions on the fire characteristics of various products, fire safety problems and causes as well as the spread of fire and on the inspection and assessment of structures damaged by fire
- Testing in the area of toxicity and ecotoxicity of smoke gases
- Production of environmental (LCA) and costs (LCC) analyses
- Production of guidelines and pilot systems for the renovation of buildings with elevated radon concentrations in the air

Research and development:

- Research into the behaviour of wood and wood-polymer composites in a fire in terms of the initial stages of a fire (response to a fire)
- High-strength concrete (UHPFRC) in a fire
- Research into elevated fire risk, construction materials, products and wood structures as well as other natural materials
- Research in the area of the effect of smoke gasses on people and the environment
- Systems for the building of a house using siding made of thermally insulated concrete forms made of expanded polystyrene with added graphite
- Evaluation of the life cycle of products made of recycled and other materials
- Development of guidelines for the renovation of buildings to mitigate the harmful effects of radon

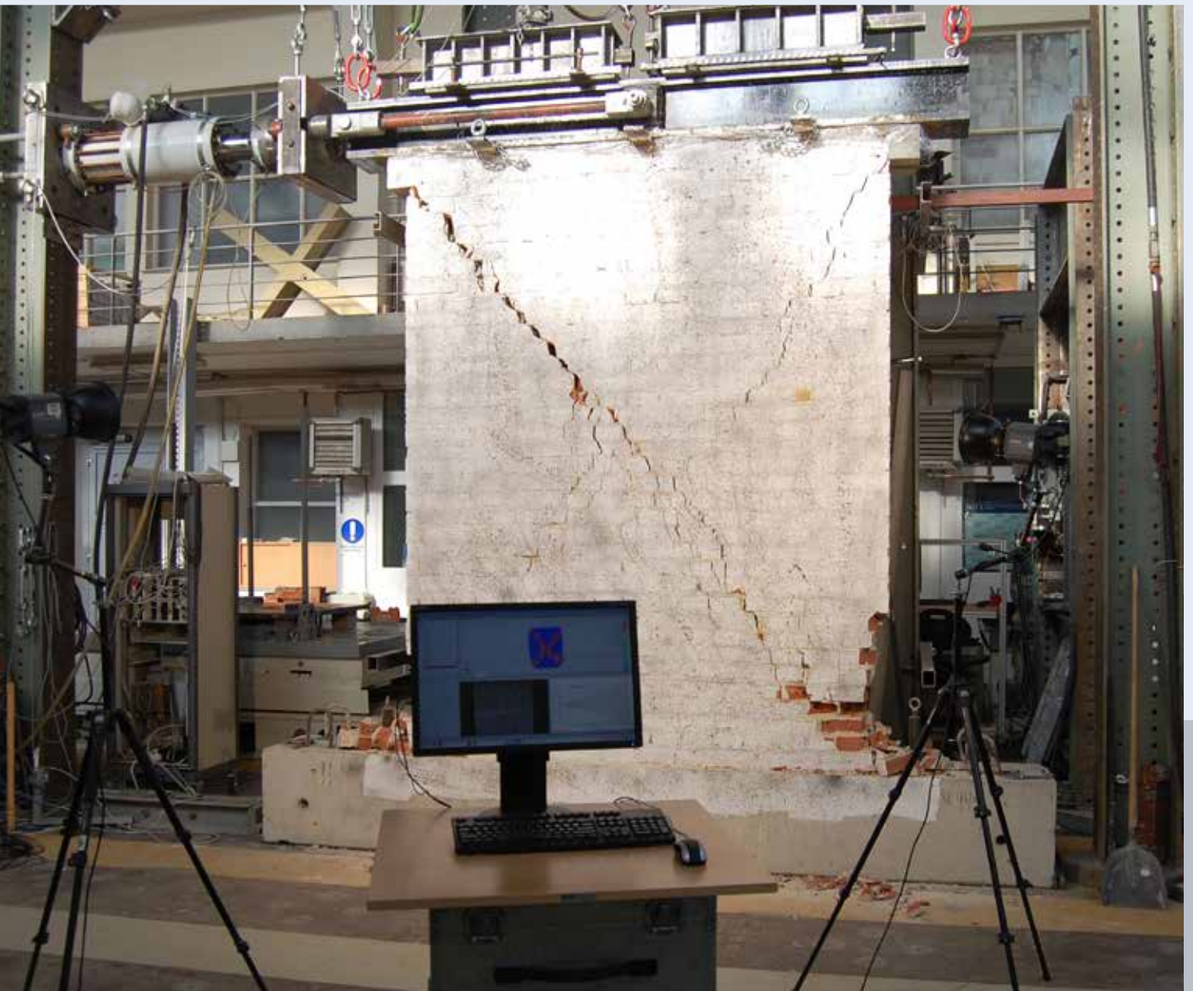
Major items of equipment:

- Cone calorimeter with a chamber for combustion in a controlled atmosphere
- FTIR gas analyser for smoke gas toxicity measurement
- Measurement system for full scale facade and other fire experiments with the measurement of temperatures, heat radiation, pressures and air speed
- Smoke chamber with connection to FTIR for the determination of the toxicity of smoke of burning materials for rail vehicles and ship equipment
- Apparatus for the testing of the response of construction materials to fire (SBI, non-combustibility, isoperibolic bomb calorimeter, small flame test apparatus, flooring)
- Vertical furnace 3 m × 3 m and horizontal furnace 4 m × 3 m for fire resistance testing

Head of the laboratory: *Friderik Knez, univ. dipl. fiz. • E-mail: pozarni.laboratorij@zag.si*

Section for Buildings and Earthquake Engineering

The Section for Buildings and Earthquake Engineering employs 4 experts for the broad field of buildings and their load-bearing structures. We perform the most demanding expert assessments, status assessment and evaluations of load bearing capacity as well as in situ and laboratory tests in this area and also participate in the preparation of technical approvals. As part of our long-standing, recognised and successful research work, we cooperate with researchers at home and abroad, provide the industry with support in development and are active in professional organisations.



Activities:

- Inspections of the state of existing building structures
- Laboratory and in situ examinations of structural elements, assemblies and structures
- Calculative analyses and assessments of seismic risk
- Load testing of various civil building structures
- Geodetic and other technical monitoring
- Cooperation in the preparation of standards and technical assessments in the confirmation of compliance
- Expert services and expert opinions

Research and development:

- Behaviour of buildings and civil engineering structures in the case of seismic loads
- Effectiveness of systems for aseismic strengthening of building structures
- Earthquake resistance of new structural elements and systems
- Experimental and analytical methods

Major items of equipment:

- Single-component shaking table with a 1.97 x 3.2 m platform (maximum payload: 5000 kg, maximum acceleration: 5 g)
- Servo-hydraulic testing system with a set of 2-way actuators with capacity from 40 kN to 1000 kN
- Measurement equipment and data acquisition systems
- Optical system for the measurement of displacements and deformation
- Testing equipment for destructive and semi-destructive in situ tests

Head of the Section: *Marjana Lutman, MSc (Civ.Eng.) • E-mail: marjana.lutman@zag.si*

Section for Bridges and Engineering Structures

We provide technical and professional support in the area of bridging and other civil engineering structures. We perform laboratory and in situ tests, measurements and analyses related to the safety and durability of civil engineering structures. We are developing a system for vehicle weighing in motion over bridges and cooperate with various infrastructure operators. We are intensively engaged in international cooperation.

Activities:

- Initial, regular, main, detailed and special visual inspections of bridges and inspections of bridge bearings and expansion joints
- Static and dynamic laboratory tests of individual bridge structure elements under short and long-term loads
- In situ tests, including load testing of bridges and other civil engineering structures
- Vibration measurements in residential, industrial and infrastructural structures
- Numerical modelling and analysis of the safety of existing bridging structures for various types of loads (traffic, seismic, erosion)
- Analyses and modelling of real life traffic loads for the assessment of the safety of existing bridges
- Planning and setup of the monitoring systems for the engineering structures

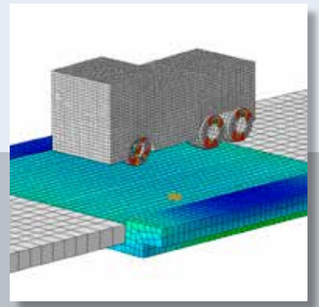
Research and development:

- Development of new methods and procedures in the area of safety and durability of bridge structures and weighing of vehicles in motion
- Development of methodology for the determination of damage state condition of bridging structures
- Development of applications for the inspection of bridging structures and software for the weighing of vehicles in motion
- Modelling of traffic loads, assessment of the state of bridging structures
- Active participation in domestic and foreign research and applied projects
- Cooperation with domestic and foreign universities and institutes

Major items of equipment:

- System for the measurement of the response of bridging structures under traffic loads
- System for the measurement of vibrations with speed and acceleration sensors
- Structure analysis software
- Software for the analysis of the behaviour of bridges in connection with the weighing of vehicles in motion over bridges

Head of the Section: *Andrej Anžlin, PhD (Civ. Eng.) • E-mail: mostovi@zag.si*



Section for Metal and Polymer Structures

The Section for Metal and Polymer Structures brings together researchers and experts with many years of experience in various areas of civil and mechanical engineering. We work with the industry and companies facing problems or issues in the Section's areas of expertise. We develop and introduce new testing methods in the area of non-standard tests.

Activities:

- In-situ measurements, inspections and assessment of the state of building and civil engineering structures and structural elements (steel bridges, columns, overhead transmission lines, etc.)
- Consulting, guidance, processing and analysis of the results of various laboratory tests, examinations and measurements of structural assemblies and elements in construction products
- External quality control of the execution of steel structures, ground anchors, soil nails and rock bolts on infrastructural constructions (motorways, roads, railways, hydroelectric power plants, etc.)
- Preparation of expert assessments, opinions and expert studies based on inspections, supervisions and/or submitted documentation
- Special multiannual inspections
- Magnetic rope testing on cableway and mining installations
- Technical and professional support in the introduction of new technologies and regulations in the area of metal and polymer structures and construction products

Research and development:

- New methods and technologies for the testing of metal and polymer structures in terms of their behaviour under static and dynamic loads
- Testing the load-bearing capacity and assessment of the state of prestressed ground anchors, soil nails and rock bolts
- Assessment, monitoring, repair and strengthening of existing structures

Major items of equipment:

- An electro-magnetic wire rope tester (AMC ROPE22AX and AMC ROPE 60AX with the AMC IASH data acquisition unit) manufactured by NDT Technologies
- Rope tension meter for the measurement of tension forces in steel cables under tension (manufactured by Sensy)
- Set for the performance of pull out tests of geotechnical anchor rods

Head of the Section: *Iztok Klemenc, PhD (Civ. Eng.) • E-mail: SM630@zag.si*

Section for Timber Structures

At the Section for Timber Structures in addition to research activities we collaborate with the domestic and foreign industry or companies in the area of development and testing of wood-based products. As experts we are involved in the preparation of technical assessments, approvals and certification. We participate in the research projects and introduce new testing methods.

Activities:

- Technical and professional support in the introduction of new technologies and regulations in the area of timber structures
- In situ inspections and assessment of timber structures and structural elements
- Various types of laboratory tests, tests and measurements of structural assemblies, elements and wood-based construction products
- Assessments, opinions, expert studies, inspections and control inspections, quality control
- Education

Research and development:

- Strength grading of structural timber
- (Non-destructive) methods of inspection and assessment of timber structures
- Innovative structures made of wood-based materials
- Development of innovative joints in wooden structures
- Use of waste wood material as raw material for new products
- Improvement of mechanical, physical and sustainable properties of woo

Major items of equipment:

- Structural timber strength grading device (Brookhuis Timber Grader MTG)
- Drill resistance measurement system (IML Resi PowerDrill)

Head of the Section: *Tomaž Pazlar, PhD (Civ. Eng.) • E-mail: lesene.konstrukcije@zag.si*

Laboratory for Structures

The Laboratory for Structures uses modern test and measurement equipment enabling the setup of the most demanding mechanical tests of structural elements with static and dynamic loading. Professional implementation of tests is ensured by the interdisciplinary team with competences covering various technical disciplines. The activities performed by the laboratory also include in situ inspections and tests of structures where cutting edge non-destructive methods are applied.

Activities:

- Performance of various static and dynamic tests of structural elements; maximum static loads of up to 5000 kN can be applied as well dynamic loads of up to 1000 kN at frequencies of up to 100 Hz
- In situ inspections of structures comprising geodetic measurements of displacements and deformations as well as in situ sampling of materials
- Non-destructive tests of structural elements

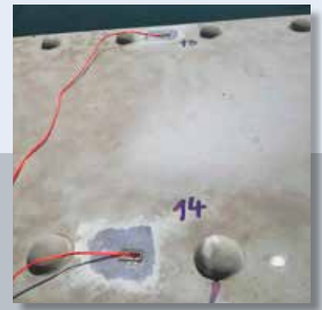
Research and development:

- Development of measurement methods in the area of structural element testing
- Introduction of non-destructive methods for the evaluation of structural health
- Development of optical methods for non-contact measurement of displacements and deformations

Major items of equipment:

- 14 m × 26 m test floor with a load-bearing capacity of 1000 kN/m^2
- 10 x 10 m reaction floor
- 6 m × 7 m bi-directional reaction wall
- Modular system of steel reaction frames
- Highly flexible servo-hydraulic system MTS FlexTest 100 allowing simultaneous loading with up to 8 hydraulic cylinders with loads ranging from 16 to 1000 kN
- Single-component shaking-table
- ZWICK universal static testing machine
- MTS Bionix dynamic testing machine with the option of combined axial torsional loading
- GOM Aramis optical measurement systems for non-contact measurements of displacements and deformations with standard and high speed cameras
- Numerous non-destructive test methods; the newer ones including the GPR measurement system, ultrasound and impact-echo.

Head of the laboratory: *Uroš Ristić, MSc (Civ. Eng.) • E-mail: uros.ristic@zag.si*



Section for Geotechnics

Using modern equipment and with the help of experienced experts, the Section can provide technical and professional support in the area of earthworks and geotechnical monitoring. Our experts carry out national and international research and development projects and actively participate at conferences both in Slovenia and abroad. We perform comprehensive quality control of materials and executed earthworks in the construction of road and railway connections as well as earth dams. We perform geomechanical soil surveys, while we perform static and dynamic stability analyses of geotechnical structures in case of more demanding building projects.

Activities:

- Geomechanical soil investigations for buildings, civil engineering structures and tunnels
- Geomechanical laboratory investigations
- Geomechanical in situ investigations
- External control of earthworks and the road surface structure
- Technical monitoring of structures such as earth dams, tunnels and roads
- PIT tests (pile integrity tests)
- Expert analyses of the condition of roads on the basis of visual inspections and road surface structure tests
- Research into the usability of recycled materials for geotechnical and road surface structures

Research and development:

- Investigations into the dynamic behaviour of soils in earthquake conditions or due to traffic loads
- Geomechanical investigations into suction under triaxial loading conditions
- Geomechanical investigations into the shear characteristics of cracked bedrock
- Geomechanical investigations into the shear characteristics of unbound material
- Introduction of laser scanning when studying the roughness of cracks
- Use of geosynthetics in road and railway infrastructure
- Stability of road infrastructure under different climatic conditions
- Use of recycled materials in geotechnical structures

Major items of equipment:

- Dynamic torsion tri-axial apparatus
- Bishop-Wesley tri-axial cell equipped for measurements of suction, small strains and shear wave velocity
- ATOS optical scanner for the measurement of crack roughness
- Large-size direct shear test apparatus for unbound materials and rock testing
- Large-size tri-axial shear test apparatus for unbound material testing
- Hoek tri-axial apparatus for rock testing
- Apparatus for the determination of the water permeability of geosynthetics
- Automated oedometer for large loads

Head of the laboratory: *Assistant Professor Karmen Fifer Bizjak, PhD (Geology) • E-mail: karmen.fifer@zag.si*

Section for Road Maintenance and Management

The staff of the Section for Road Maintenance and Management provides technical and professional support in the field of asset management and road maintenance as well as of the properties of road surfaces: longitudinal and transverse unevenness, wet skidding resistance, macro-texture and bearing capacity. The staff employ contactless measurement methods in the area of transport infrastructure and its surroundings; to determine and assess their initial state and form, to monitor changes as well as to determine the state and changes in the natural environment. The staff of the Section actively collaborate with Slovenian and international experts through involvement in a number of research projects, as well as are active in professional associations, at conferences and meetings.

Activities:

- Measurements of the properties of road surfaces and pavement structures: unevenness, wet skidding resistance, macro-texture, bearing capacity
- Management of transport infrastructure, impact of the road infrastructure on the environment, optimisation of traffic energy consumption and GHG emissions
- Laser scanning for detection of transport infrastructure, built and natural environment and changes of their location and form
- Preparation of expert studies and consulting in own fields of work for the managers of road networks and other investors in the field of road management
- Inclusion of the results of field measurements in road management systems, enabling better use of the funds available for road maintenance
- Inclusion of new knowledge and research equipment into daily work
- International cooperation with researchers and experts from the fields of work

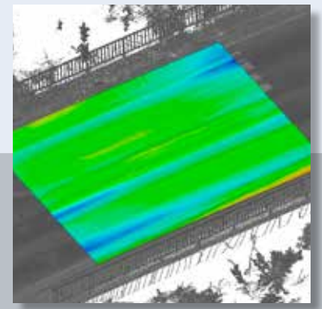
Areas of research and development:

- Asset management and management of roads
- Methods and equipment for measurement of the properties of road surfaces and pavement structures
- Traffic safety
- Impacts of road construction and maintenance on the environment
- Contactless laser measurement methods for the detection and monitoring of infrastructure, structures and the environment
- Digitalisation and management of data related to infrastructure

Relevant equipment:

- SCRIMTEX device for measurements of the wet skidding resistance and macro-texture of road and airfield surfaces
- ZAG-VP device for measurements of the longitudinal profile and the determination of the unevenness of road and airfield surfaces
- Laser scanner

Head of the Section: *Darko Kokot, MSc (Civ.Eng.) • E-mail: darko.kokot@zag.si*



Laboratory for Asphalts and Bitumen-Based Products

The Laboratory for Asphalts and Bitumen-Based Products brings together experts with many years of experience in various areas of road construction and chemistry. In addition to research work, we also work closely with the industry and perform in situ and laboratory tests for both investors and asphalt contractors. In the area of non-standardized tests of bitumen and asphalt, we develop and introduce new test methods. We perform over 80 standardized tests of bitumen, asphalt and waterproofing, 35 of which are accredited.

Activities:

- In situ measurements, supervision and assessments of executed asphalt and waterproofing works
- Compiling of expert opinions
- Quality control of executed works on national and international level
- Demanding testing of bitumen, asphalt and bitumen waterproofing
- Practical and expert support at possible implementation of reclaimed asphalt granulate

Research and development:

- Effects of ageing on original pavement and and polymer-modified bitumens
- Effect of the type and properties of asphalt on resistance to fatigue and to low temperatures
- Effect of asphalt compaction on its durability
- Use of waste products in asphalt
- Relations between bitumen properties and asphalt mix behaviour

Major items of equipment:

- Rolling thin-film oven test apparatus (RTFOT) for determination of short-term bitumen ageing
- Pressure Ageing Vessel (PAV) for accelerated bitumen ageing
- Bending Beam Rheometer (BBR) for determination of bitumen flexural creep stiffness
- Dynamic shear rheometer for DSR and MSCRT tests
- Device for testing of asphalt behaviour at low temperatures (TSRST)
- Four-point bending test device (4PBT) for asphalt fatigue and stiffness tests
- Gyratory compactor

Head of the laboratory: *Mojca Ravnikar Turk, MSc (Civ.Eng.) • E-pošta: mojca.turk@zag.si*

Laboratory for Metrology

The Laboratory for Metrology performs calibration and control of measurement and test equipment at the laboratory of the ZAG and at the clients' premises. The Laboratory is accredited by Slovenian Accreditation (SA) in accordance with SIST EN ISO/IEC 17025 standard for calibration of measurement equipment in the areas of force, torque, pressure, hardness, testing machines, pendulum impact testing machines, weighing scales, temperature and others. As the leading Slovenian calibration laboratory in the areas of force and hardness, it provides the traceability of test devices for a broad range of users ranging from scientific research institutions to industry, both in Slovenia and abroad. Laboratory members cooperate with foreign national metrology institutes and universities and are members of international metrology organisations, contributing to the development of metrology at the international level.

Market activities:

- Maintenance of reference standards for force and hardness
- Calibration of measurement and test equipment (mechanical quantities, length, temperature)
- Organisation of inter-laboratory comparisons
- Inspection of measurement and test devices and metrological maintenance
- Provision of education in the area of metrology
- Participation in international metrology associations in the drafting of guidelines and standards

Research and development:

- Development of reference standards
- Research in the area of force and hardness calibration
- Research and development of measurement instrumentation
- Analysis and improvement of measurement uncertainty of calibration procedures

Major items of equipment:

- Primary reference calibration machines for the force of up to 1000 N and 20 kN, uncertainty of force measurement – 0.01%
- Reference machines for the force from 0.1 N to 1 MN – pressure (600 kN – tension)
- Calibration machines for the force of up to 5 MN
- Transfer standards transducers for the force of up to 1 MN
- Precision measurement amplifiers for strain gauge transducers
- Reference hardness machine with hardness reference blocks

Head of the laboratory: *Miha Hiti, PhD. (Elec. Eng.) • E-mail: metrologija@zag.si*

Certification Service

As a certification body, ZAG's Certification Service (CB ZAG) focuses on continuous improvement of the quality of its services. For this purpose, it has established a quality management system that meets the requirements of the EN ISO/IEC 17065 standard. The effectiveness of the system is confirmed by the internationally recognised accreditation certificate No. CP-002 issued by Slovenian Accreditation. In accordance with provisions of EU Regulation No. 305/2011 (the Construction Products Regulation), CB ZAG is a notified certification body with the identification number NB 1404 allotted by the European Commission. CB ZAG has also been appointed as a certification body for all technical specifications laid down by Article 5 of the Slovenian Construction Products Act (ZGPro-1). The core of the Service is an interdisciplinary team of five employees cooperating with more than 30 experts from other departments ofZAG and with various laboratories at home and abroad.

Activities:

- Product certification and factory production control certification in the field of mandatory and voluntary construction products certification
- Certification of other products in both regulated and voluntary field
- Voluntary certification of various processes and services
- Voluntary certification of executed works

Development of new schemes:

- Cooperation in preparing and upgrading of legislation, standardisation and conformity assessment procedures
- Consideration of needs, wishes and problems of manufacturers, traders and retailers as well as buyers of construction products, building designers and building contractors and designing of ZAG's tailor made certification schemes

Important milestones:

- 1996 – ZAG's Certification Service is established
- 1998 – First certificates of conformity issued
- 2003 – CB ZAGbecomes accredited according to the EN 45011 standard (CP-002)
- 2004 – ZAG attains the status of an EU notified body No. 1404, according to the Construction Products Directive 89/106/EEC (CPD); CB ZAG assumes the role of the representative of Slovenia in the Advisory Group of Notified Bodies (AG GNB)
- 2006 – CB ZAG takes over the leadership of the National Mirror Group of Conformity Assessment Bodies
- 2013 – Scope of ZAG's activities as notified body No. 1404 is extended according to the EU Construction Products Regulation No. 305/2011 (CPR)
- 2015 – accreditation scope is upgraded to the EN ISO/IEC 17065 standard
- 2016 – the scope of accreditation is extended by the accreditation for the purposes of notification according to EU Construction Products Regulation No. 305/2011 (CPR)

Head of the Service: *Marjan Japelj, B.Sc. (Phys.) • E-mail: certifikati@zag.si*

Service for Technical Assessments and Approvals

The Service for Technical Assessments and Approvals (the Service) performs activities for the granting of Slovenian Technical Approval, European Technical Assessments (ETA) and Environmental Product Declarations (EPD).
In 2003, ZAG was appointed as the Body for Technical Approvals and thus acquired the right to issue ***Slovenian Technical Approvals*** *(STS) and* ***European Technical Approvals*** *(ETA).*
With the entry into force of Regulation No. On 305/2011, ZAG was appointed as Technical Assessment Body in 2013, thereby acquiring the right to prepare and issue European Technical Assessments (ETAs). Since 2013, the Service has also been issuing ***Environmental Product Declarations*** *(EPD). We believe that the EPD will come to represent one of the main market advantages for a construction product manufacturer as a result of national requirements in many European countries.*

Activities:

- **Slovenian Technical Approval (STS)**
  An STS is granted based on a request submitted by a manufacturer that places a construction product on the market of the Republic of Slovenia, whereby the product is not included in the harmonised technical specification under the Construction Products Act (ZGPro-1).
- **European Technical Assessment (ETA)**
  An ETA is issued based on a request submitted by a manufacturer of a construction product that places the construction product on the markets of EU Member States. The basis for the issue of an ETA is the European Assessment Document (EAD) prepared by the Technical Assessment Body (TAB) and confirmed by the European Organisation for Technical Assessment (EOTA) and the European Commission.
- **Environmental Product Declaration (EPD)**
  An EPD outlines the product description and emissions associated with the product over its entire life cycle. An EPD is based on the results of the life cycle assessment (LCA) and represents a complex but necessary and reliable basis for sustainable construction.

Membership:

- **EOTA** – European Organisation for Technical Assessments
- **ECO PLATFORMA** – association of European organisations that issue Environmental Product Declarations

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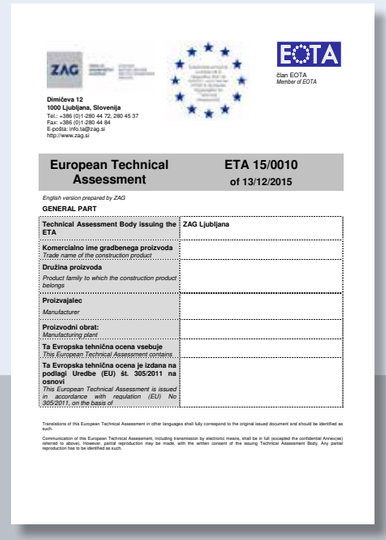

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EOTA
Član EOTA
Member of EOTA

European Technical Assessment — **ETA 15/0010** of 13/12/2015

English version prepared by ZAG

GENERAL PART

Technical Assessment Body issuing the ETA	**ZAG Ljubljana**
Komercialno ime gradbenega proizvoda *Trade name of the construction product*	
Družina proizvoda *Product family to which the construction product belongs*	
Proizvajalec *Manufacturer*	
Proizvodni obrat: *Manufacturing plant*	
Ta Evropska tehnična ocena vsebuje *This European Technical Assessment contains*	
Ta Evropska tehnična ocena je izdana na podlagi Uredbe (EU) št. 305/2011 na osnovi *This European Technical Assessment is issued in accordance with regulation (EU) No 305/2011, on the basis of*	

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