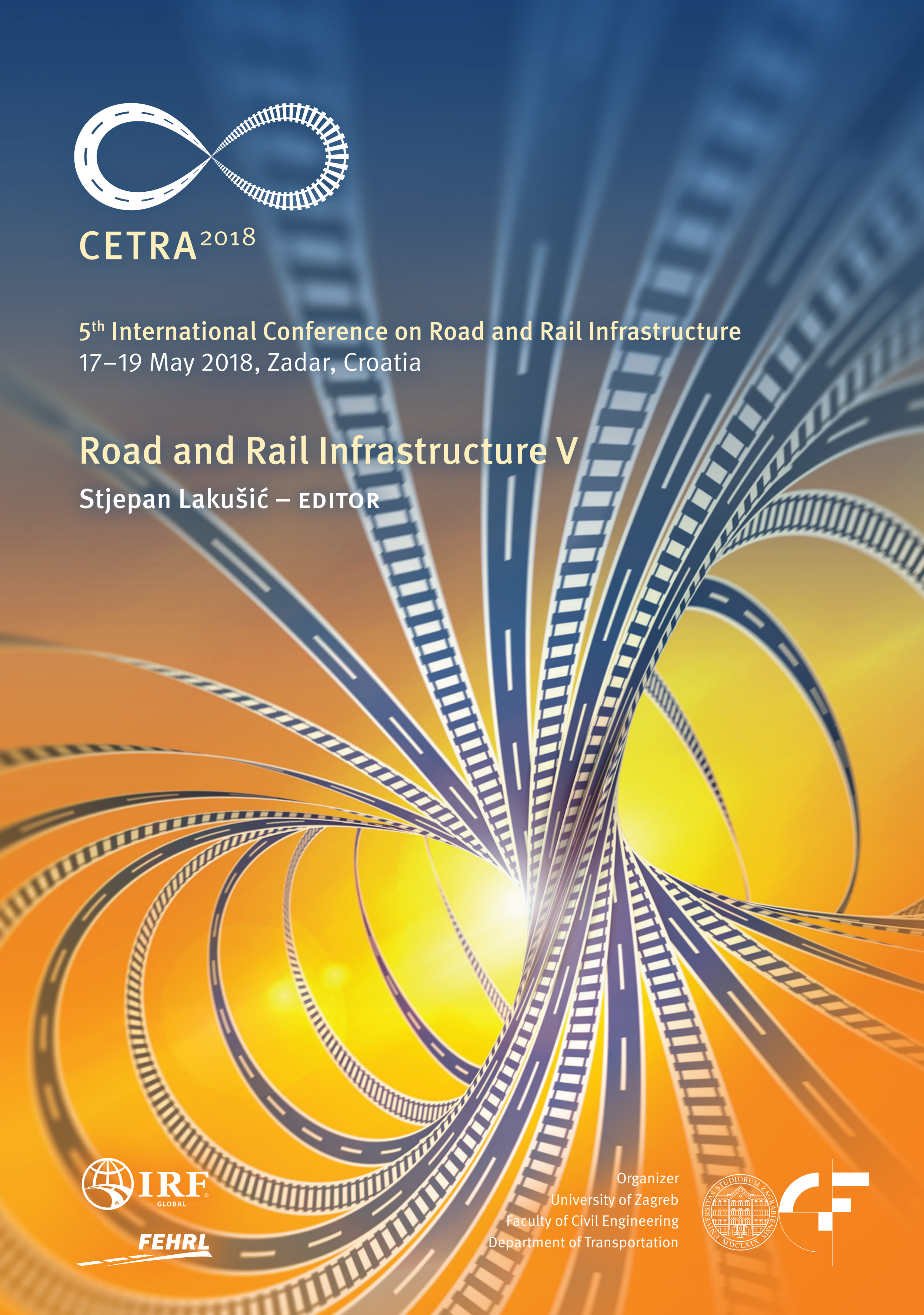

CETRA2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

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NEW MATERIALS AND TECHNOLOGIES USED IN CIVIL INFRASTRUCTURE

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Abstract

The end of the previous and the beginning of the current century have witnessed the investment of considerable funds into the research in construction industry with the aim of improving and modernising the profession so that it becomes environmentally sustainable. The paper gives examples of the use of 3D technology in printing concrete for infrastructure facilities in Europe and the world. The examples of innovative solutions in infrastructure facilities have been listed, such as the use of nanoengineering and multifunctional composite materials with superior mechanical properties and durability. Road safety, durability, profitability and sustainability can be improved by using nanotechnology and nanomaterials. The paper also brings the examples of trial segments of smart and solar roads and highways, as well as kinetic roads in Europe, China and USA.

Keywords: 3D printing, nanoengineering, smart road, solar road, kinetic road

1 Introduction

Globalisation processes, the emergence of the world market, the concern about the environment and the wish to fulfil the requirements for sustainable development have encouraged the need to invest into research in the field of civil engineering, too. In that, the cooperation between commercial companies and scientific research sector ensures the creation of new solutions which correspond to market needs. In this way the new knowledge turns into economic advantage. Because of the competition, innovation enables construction companies to grow. Growth is not only necessary for individual construction companies but also for the entire construction industry, which would be a driving force of the entire economy. Considering the competitiveness of construction companies and the economy as a whole, it is of crucial importance to promote and invest in innovation. Blayse i Manley [1] conclude that also in the past innovation was one of the sources of productivity and economy. Integrated approach, within the basic factors and a number of relevant elements, is essential for the successful implementation of innovation in a construction company [2]. When implementing innovation in construction industry by using digital technology it is important to know which factors will influence innovation [3] and determine the competitive advantages of the company applying them.

This paper gives an overview of the application of 3 D technology in printing concrete for infrastructure facilities in Europe and the world, it gives the examples of innovative solutions offered by nanoengineering and multifunctional composite materials with superior mechanical properties and durability, and gives the examples of trial segments of smart and solar roads and highways in Europe, China and USA.

DOI: https://doi.org/10.5592/CO/CETRA.2018.944

2 3D Concrete printing technologies in infrastructure facilities

The development of 3D construction technology has been encouraged by the foreseen reduced duration of construction and labour costs, by simplified logistics, by the increased geometrical freedom in construction, by the need to recycle construction waste, by the need to store secondary materials from various industries and by the developing industry of concrete additives. It can be said that the idea of 3D printing used for constructing full size buildings is still at its beginning. However, there is a considerable potential for its use. 3D technology was first used in constructing buildings [4], and in [5] states that 3D concrete printing technology as one of ten most important innovations in construction industry in the field of facility building. According to [6], the first printed bike bridge in the world was opened in December 2017 in Gemert in the Netherlands (Figure 1) [6-8]. Although this 3D printed bridge was constructed from pre-fabricated elements, developers anticipate future scenarios where a bridge will be 3D printed on the site.

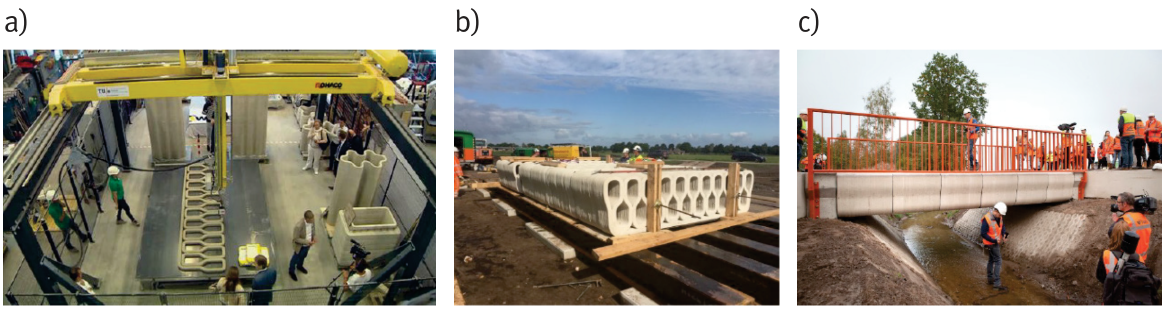

Figure 1 3D concrete technology, a) concreting bike bridge beams [6], b) beams ready for transport [6], c) bike bridge in the Netherlands made by 3D concrete technology [8]

As the result from a 15 years experience in 3D printing, the pedestrian bridge in Madrid (Figure 2a) [9, 10] was built in 2016 from fiber reinforced concrete. The pedestrian bridge, 12 m long and 1.75 m wide, was 3D printed from fiber reinforced concrete.

The Netherlands is planning to build the first 3D printed bridge across Amsterdam canal (Figures 2b and 2c) by using robotic printers which can draw steel structures in 3D. Specially designed robotic arms heat the metal at temperature of 1.500 °C in order to carefully weld the structure by droplet, while using the computer software for drawing a sophisticated design.

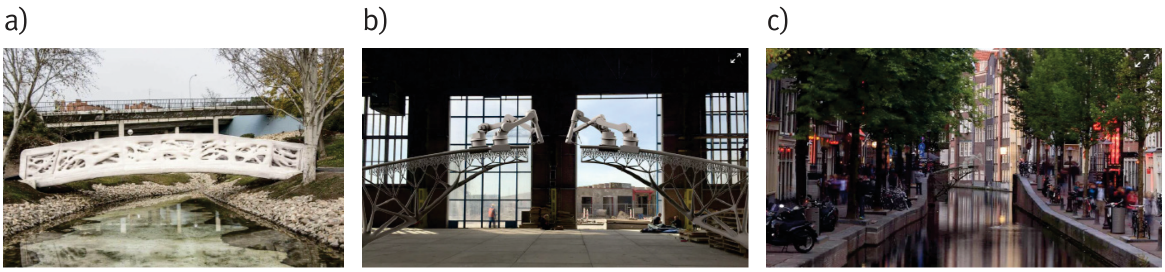

Figure 2 3D printed bridges a) The pedestrian bridge in Madrid [9] b) computer animation of 3D printing of the steel bridge in Amsterdam, in a laboratory [11], c) on the canal [11]

Students at the Institute for Advanced Architecture of Catalonia, Barcelona, have built a robotic 3D printer which can build structures from sand and binder. This technology can be used for building temporary shelters or bridges [12], as shown in Figure 3a [13].

The printing robot requires very little energy, because it only uses solar energy, and the binder is eco friendly, made from LEED certified components. Unlike other 3D printers, robotic arms move in many directions and printing can be done on vertical surfaces. 3D printed structures are the part of university series “Shanghai Digital Future”, whose aim is to demonstrate future technologies in architecture, urban planning and other fields. With the purpose of creating 3D pedestrian bridges, the staff at Tongji University used robots and a custom 3D printing module and they finally built two bridges in order to check the reliability (and repeatability) of the process (Figure 3b) [14].

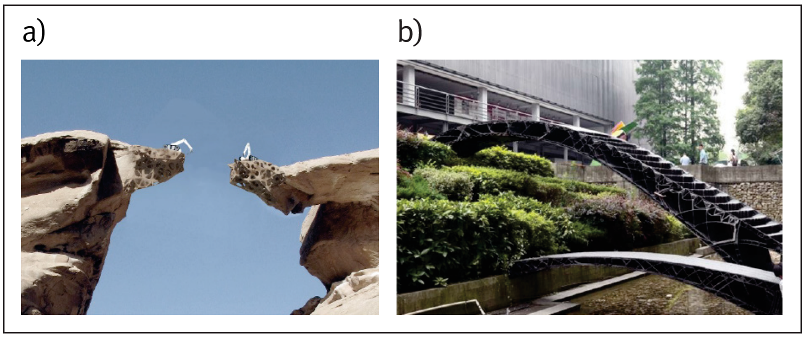

Figure 3 a) 3D printed bridge from sand and binder [13], b) First pedestrian bridges in China across the Shanghai river on Tongji University premises [14]

3 Nanoengineering bringing innovative solutions

Most innovative solutions would not be possible without innovative materials produced by nanoengineering. Nanoengineering uses nano particles and nano techniques to produce multifunctional composite materials mostly based on cement of superior mechanical properties and durability, which simultaneously have modified properties such as low electrical resistance, self-sensing, self-cleaning, high ductility, self-control of cracking etc. Concrete, for instance, can be nanomodified if it contains nano particles and/or nano tubes [5]. The application of nanotechnology on pavement structures is shown in Table (1) [5, 15].
Combining concrete of a very high strength with Carbon Nano Tubes (CTNs) can produce materials of a very high resistance to compression and tension and their application can ensure a load capacity with a very low use of and/or no use of reinforced concrete. The example of the above is the patented material Ductal® [16] and the pedestrian-bike bridge in France built from it (Figure 4) [17]. The bridge, a total length of 69 m consists of fifteen identical segments of 4.6 m length produced as pre-fabricated elements in a concrete plant.

Table 1 Summary of nanoparticles and its application [15]

Nanoparticles	Application areas
Nano-silica (SiO_2)	· Replaces part of the cement to densify the concrete and gain early strength · Improving pavement surface characteristics
Micro silica (silica fume)	· Increase compressive strength and flexural strength in concrete
Carbon nanotubes (SWCNTs or MWCNTs)	· Increase compressive strength and flexural strength in concrete · It can be utilized self-sensing concrete for monitoring the structural conditions
Nano phosphorus	· Improving road visibility
Nano TiO_2	· Self-cleaning of concrete pavement
Polymer fibre matrix using nanosilica	· Self-structural health monitoring system in repairs & rehabilitation
High performance steel using copper nanoparticles	· In bridges for corrosion resistance & better weld ability
Nanotechnology enabled sensors	· To monitor and control temperature, moisture, smoke, noise, stresses, vibrations, cracks and corrosion

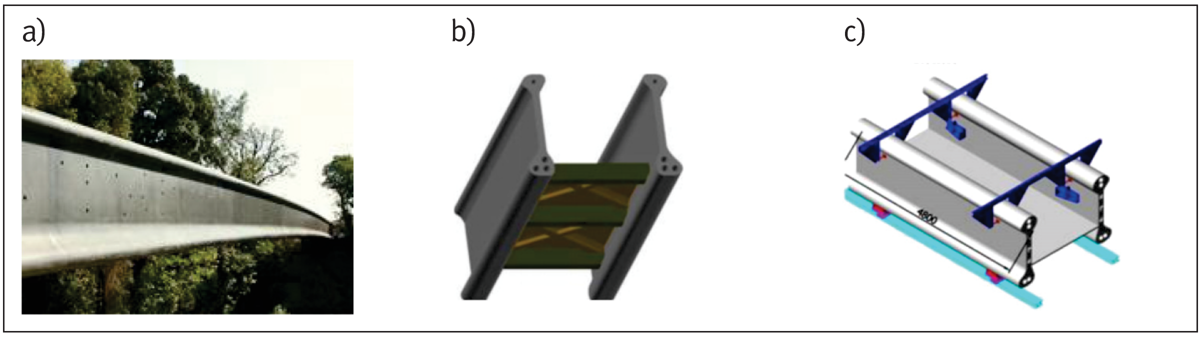

Figure 4 Pedestrian bridge Pont du Diable, a) A view of the beam [16], b) and c) 3D views [17]

Cracks in plain concrete are usual because of relatively small tensile strength. Cracks enable liquids and gases to introduce potentially harmful substances into concrete. If microcracks spread along the cross-section and reach the reinforcement, not only concrete can be damaged, but the reinforcement, too. It is therefore important to control the width of the cracks and repair them as soon as possible. Research institutions are intensively working on finding the efficient method of self-healing of cracks in various construction materials (Table 2) [18]. Cracks in concrete can be prevented by using micro-organisms, a type of bacteria that stimulate the formation of calcium carbonate [19, 20]. The bacteria spores built in the concrete matrix in the shape of micro capsules or in the super absorbent polymer, SAP, after the crack opens, start to settle $CaCO_3$. The bacteria on the fresh surfaces of cracks become active when in contact with water. In this process the bacteria cells will be covered with a layer of calcium carbonate, which results in the crack filling [20 – 23]. Self-healing of cracks on roads is an innovative technology which is being developed at the University of Bath, Cardiff University, and the University of Cambridge, based on the technology described above [19 – 23] and in [24]. However, it should be emphasised that the method of crack healing depends on the type and cause of the crack [25].

Table 2 Materials with successful self-healing technology applied [18]

Material	Healing mechanism
Polymer	Healing agent encapsulation
Concrete	Bacteria
	Hollow fibres
	Micro encapsulation
	Expansive agents and mineral admixtures
Asphalt	Nanoparticles
	Steel fibres – induction heating
	Rejuvenator encapsulation
Coatings	Healing agents (resin) encapsulation
Composites	Memory alloys
Metals and alloys	Press and sinter powder metallurgy

4 Trial segments of smart, solar and kinetic roads

A number of innovative solutions for roads have been developed. Only three examples of innovation in road construction will be presented here, so called smart, solar and kinetic roads [26, 27]. A good example of smart roads are bike lanes which in their final layer have solar LED lights (Figure 5a) or roads marked with colour collecting light at daylight and reflecting it at night (Figure 5b).

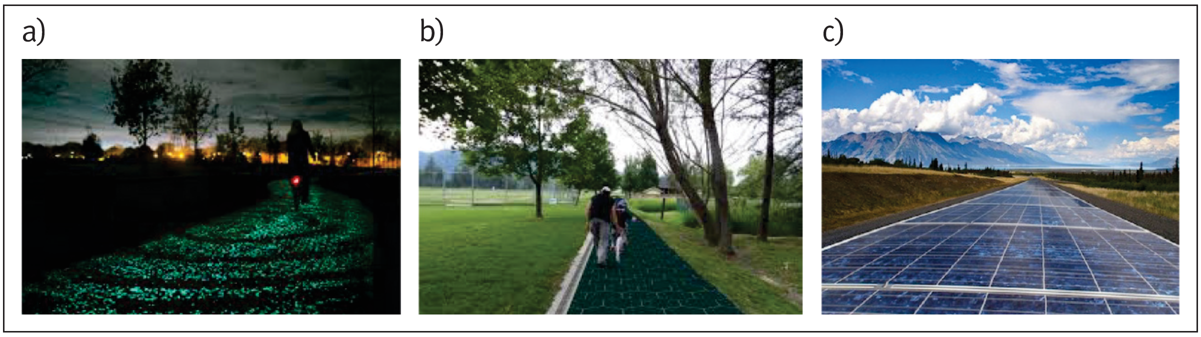

Figure 5 a) Smart road–bike lane [26] b) Bike lane with solar cells [28], b) Highway with solar cells [29]

Research into road colours that react to temperature is also under way, with the aim to warn drivers to drive more carefully, that is, to adjust their speed to road temperature. Since highways take a lot of space, so- called solar roads are being planned, which in their system have a finishing layer made of solar cells which can take heavy loads (Figure 5c) [28, 29].

Solar roads are systems consisting of interconnected hexagonal panels made of tempered glass which have been tested for impact and tensile loads. The panels have built-in photovoltaic cells which collect solar energy [29]. Federal Highway Administration, USA, General Electric and Google have shown interest in further investigation into the efficiency of road solar systems.

A 70 m long trial segment of a solar road was built in the Netherlands in 2014, on a bike lane between two Amsterdam suburbs (Figure 6) [30-32]. It is planned to build 100 m, of which one part will have a solar system, and the other will be paved with plain concrete, in order to examine the range of impacts on one and the second part of the lane.

Figure 6 Solar road: a) the trial segment of a solar road [30], b) the first photovoltaic pilot zone in China, in the city of Jinan, Shandong district [31], c) solar power highway [32]

One of the most polluted cities in China, Jinan, has bad quality air which has been proved to be the cause of the 6 % increase in death rate. For this reason, the first photovoltaic pilot zone of 160 m in length was built in Jinan, the capital of Shandong district in China (Figure 6b) [31]. The road, suitable for pedestrians and cars, and even for trucks, is equipped with photovoltaic modules which generate electric power by collecting solar energy. The system can also heat the road surface, helping to remove ice and snow. Experts believe that in near future photovoltaic roads will also power electric vehicles and exchange information on vehicles, and thus offer technological basis for autonomous ride. Two kilometers of solar road are also being built in China (Figure 6c) [32], with the plan to use road solar panels to supply the surrounding towns with electric power. Chinese engineers use three layers to build photovoltaic highways. The top layer is made of transparent concrete. Then follow solar panels, which absorb sun rays while well protected from the impact of the surroundings. Below the solar panels there is the insulating layer which prevents the impacts from below. This pilot project also offers the automatic thawing of snow.

The following innovative solution for roads is kinetic ramps which, when cars pass over them, collect the dispersed kinetic energy and turn it into electric power [33 -36]. Ramps function as

panels or rollers on roads (Figures 7 a) and b)) [33, 34]. When a car puts pressure on panels they move up and down while a specially designed mechanism starts a generator which can produce alternative or direct current. More energy is generated if vehicles drive slowly or are of higher weight when they pass over the built-in elements (panels or rollers) [36, 37]. Efficient use of kinetic ramps is described in [38, 39].
In London (Figure 8a) [40], as well as in Las Vegas, USA, (Figure 8b) [41], a pedestrian lane was built where electric power is produced by walking, (Figure 8a) [40]. Thus kinetic energy which we generate by walking or running can be put to useful purposes.

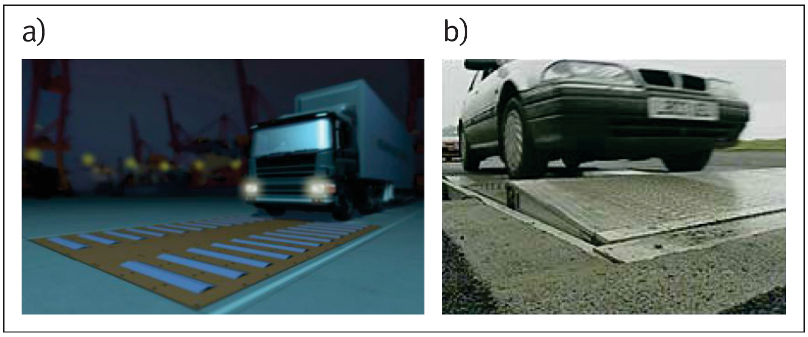

Figure 7 Kinetic ramp, a) view of a kinetic ramp made of rollers built on a road [33], b) kinetic ramp, panel shaped [34]

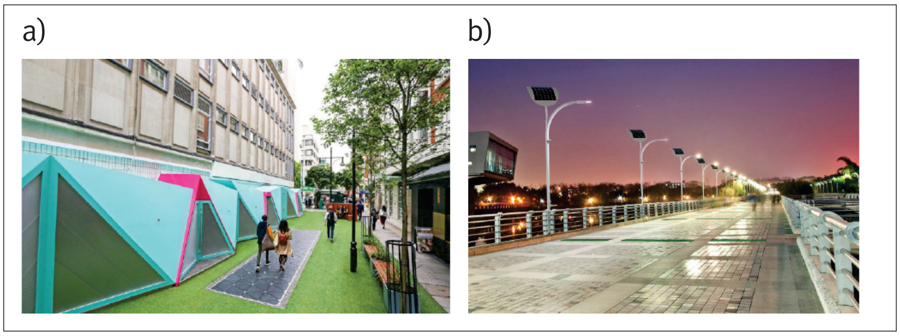

Figure 8 Pedestrian lane with a built-in kinetic system for production of electric power, a) in London [40], b) in Las Vegas [41]

5 Conclusion

Construction industry is currently facing two opposing issues: it has to fulfil the growing need for infrastructure facilities, and at the same time it is expected to reduce its own impact on the environment. Development of new materials is essential for dealing with this challenge. The traditional engineering know-how is not enough for the development of sustainable materials, since other areas, like economy and ecological engineering, have become the important aspects of sustainable development. For this reason the innovations in concrete production should have a heterogeneous approach to engineering of new materials and should integrate into their development process the know-how from other areas. Companies can benefit from the cooperation with universities and research institutions since they create and offer knowledge, and the financial aspect should be also taken into consideration. All this is presented here in order to emphasise that it is a long way from an idea to implementation, particularly in the field of civil engineering, known as a very conservative area which accepts new technologies with difficulty. However, the demand for sustainable development, which is inevitable in the 21st century, has united all participants, from researchers to builders.

References

[1] Blayse, A., Manley, K.: Key influences on construction innovation, CONSTRUCTION INNOVATION, 4 (2004) 3, pp. 143-154, doi:10.1108/14714170410815060

[2] Šuman, N., Semič El-Masri, M.: The Integrated Approach for Introducing Innovation in Construction Industry, ORGANIZATION, TECHNOLOGY AND MANAGEMENT IN CONSTRUCTION, 5 (2013) 2, pp. 834-843, doi:10.5592/otmcj.2013.2.2

[3] Fromm, A.: 3 D Printing zementgebundener Formteile, Disertation, Kassel University, 2014, 334 pp

[4] Bjegović, D., Banjad Pečur, I., Štirmer, N.: Obrazovanje i znanost kao pokretači razvoja, Hrvatski graditeljski forum 2015 – Izazovi u graditeljstvu 3, pp 138-162, Zagreb, Croatia, 4th December 2015.

[5] Bjegović, D., Štirmer, N.: Theory and technology of concrete, University of Zagreb, Faculty of Civil Engineering, 2015., ISBN 978-953-6272-77-8, pp. 999 (in Croatian)

[6] Full-scale 3D printed concrete bicycle bridge destined for Gemert, Netherlands is underway, http://www.3ders.org/articles/20170907-massive-3d-printed-bicycle-bridge-is-delivered-to-gemert-netherlands-by-truck.html, 24.02.2018.

[7] Hernandez, A.: 3D printed reinforced concrete cyclist bridge opens in the Netherlands, https://techaeris.com/2017/10/18/3d-printed-cyclist-bridge-netherlands/

[8] World's first' 3D printed bike bridge opens in Brabant, http://www.dutchnews.nl/news/archives/2017/10/worlds-first-3d-printed-bike-bridge-set-to-open-in-brabant/, 24.02.2018.

[9] Xie, J.: World's first 3D-printed footbridge installed in Spain, https://www.curbed.com/2017/1/24/14376476/3d-printed-bridge-spain, 24.02.2018.

[10] Koslow, T.: World's First 3D Printed Pedestrian Brodge Completed in Madrid, https://all3dp.com/3d-printed-pedestrian-bridge/, 24.02.2018.

[11] Dutch startup plans first 3D printed steel bridge to span Amsterdam canal, https://www.theguardian.com/technology/2015/jun/17/dutch-startup-plans-first-3d-printed-steel-bridge-to-span-amsterdam-canal, 24.02.2018.

[12] Kulik, A., Shergill, I., Novikov, P.: Stone Spray Robot, https://www.dezeen.com/2012/08/22/stone-spray-robot-by-anna-kulik-inder-shergill-and-petr-novikov/, 24.02.2018.

[13] Amazing 3D Printed Bridge From Sand and Bonding Agent, http://3dprintboard.com/showthread.php?2183-Amazing-3D-Printed-Bridge-From-Sand-and-Bonding-Agent

[14] Bridge over river Shanghai: Tongji University unveils China's 1st 3D printed pedestrian bridges, http://www.3ders.org/articles/20170719-bridge-over-river-shanghai-tongji-university-unveils-chinas-1st-3d-printed-pedestrian-bridges.html

[15] Patel, D. A., Mishra, C.B.: Nano Material for Highway Infrastructure, International Conference on Research and Innovations in Science – ICRISET2017, pp 321–328, Anand, India, 17-19 February 2017, Engineering &Technology, Kalpa Publications in Civil Engineering, Volume 1, 2017

[16] A propos de Ductal®, http://www.ductal-lafarge.fr/wps/portal/ductal/fr/1_3-Ductal_in_a_word, 26.02.2018.

[17] Behloul, M., Ricciotti, R., Ricciotti, R.F., Pallot, P., Leboe, J.: Ductal® Pont du Diable footbridge, France, (Chapter), Tailor Made Concrete Structures, (eds) Walraven & Stoelhorst, Taylor & Francis Group, London, pp. 335-340, 2008, ISBN 978-0-415-47535-8

[18] Tabakovic, A., Schlangen, E.: Self-Healing Technology for Asphalt Pavements, (Chapter), Self-healing Materials, Advances in Polymer Science, vol 273, eds: Hager, M., van der Zwaag, S., Schubert, U., Springer Cham, pp. 285-306, 2015, doi: 10.1007/12_2015_335

[19] Self Healing Materials – An Alternative Approach to 20 Centuries of Materials Science, ed. van der Zwaag, S., Springer, 2007, 385 pp, ISBN 978-1-4020-6250-6

[20] Qian, C., Chen, H., Ren, L., Luo, M.: Self-healing of early age cracks in cement-based materials by mineralization of carbonic anhydrase microorganism, FRONTIERS IN MICROBIOLOGY, 6 (2015) 1225, doi: 10.3389/fmicb.2015.01225

[21] Self-healing of concrete, https://www.ugent.be/ea/structural-engineering/en/research/magnel/research/research3/selfhealing, 24.02.2018.

[22] Wang, J., Van Tittelboom, K., De Belie, N., Verstraete, W.: Use of silica gel or polyurethane immobilized bacteria for self-healing concrete, CONSTRUCTION AND BUILDING MATERIALS, 26 (2012) 1, pp 532-540, doi: 10.1016/j.conbuildmat.2011.06.054

[23] Vijay, K., Murmu, M., Deo, S.V.: Bacteria based self healing concrete – A review, CONSTRUCTION AND BUILDING MATERIALS, 152 (2017) 15, pp 1008-1014, doi:

[24] Daftardar, I.: Science of the Self-Healing Roads: Roads That Repair Themselves!, https://www.scienceabc.com/innovation/say-goodbye-bumpy-rides-self-healing-roads.html, 24.02.2018.

[25] Andrei, M.: Self-repairing concrete might build the future, https://www.zmescience.com/research/inventions/self-repairing-concrete-04042015/, 24.02.2018.

[26] Lofgren, K.: Twinkling Solar Bike Path Inspired by Vincent van Gogh's Starry Night Opens in the Netherlands | Inhabitat – Sustainable Design Innovation, Eco Architecture, Green Building, http://snip.ly/bwVk#http://inhabitat.com/roosegaarde-studios-bike-path-is-a-twinkling-road-inspired-by-van-gogh/

[27] Smart Highway, The intelligent and interactive roads of tomorrow, http://www.smarthighway.net/, 24.02.2018.

[28] Roads that generate electricity, http://www.thepowerreport.com/the-power-report/roads-that-generate-electricity/

[29] Kermeliotis, T.: Solar-powered roads: Coming to a highway near you? https://guerrillaworldpress.wordpress.com/2014/05/14/solar-powered-roads-coming-to-a-highway-near-you/, 24.02.2018.

[30] Hruska, J.: The Netherlands has laid the world's first solar road – we go eyes-on to investigate, http://www.extremetech.com/extreme/194313-the-netherlands-has-laid-the-worlds-first-solar-road-we-go-eyes-on-to-investigate, 24.02.2018.

[31] China opens first trial photovoltaic road, http://english.ningbo.gov.cn/art/2017/10/14/art_926_847292.html, 24.02.2018.

[32] Weaver, J.F.: China is building solar roadways – 'transparent concrete' atop solar cells that charge driving cars, http://www.popularmechanics.com/technology/infrastructure/a14479240/china-is-building-a-solar-power-highway, 24.02.2018.

[33] The Electro-Kinetic Road Ramp, Environmentally Friendly Engineering, http://www.myninjaplease.com/?p=3466, 24.02.2018.

[34] Driving Force: Harvesting Kinetic From Passing Cars, Energy http://webecoist.momtastic.com/2009/09/09/driving-force-harvesting-kinetic-energy-from-passing-cars/, 24.02.2018.

[35] Ilahi, T., Afroz, A., Khan, M.U., Zafar, A., Bakht, K., Altaf, S.: Generating Electricity through Harnessing of Kinetic Energy Using a Ramp, INTERNATIONAL JOURNAL OF MODELING AND OPTIMIZATION, 3 (2013) 6, pp. 520-522, doi: 10.7763/IJMO.2013.V3.333

[36] Biswal, J.: Power generation from speed breakers, https://www.slideshare.net/biswajitcet13/power-generation-from-speed-breakers, 24.02.2018.

[37] Noor, F., Jiyaul, M.: Production of electricity by the method of road power generation, International Journal of Advances in Electrical and Electronics Engineering, Volume 1, Number 1, pp. 9-14, 2016

[38] Islam, Md.S., Rahman, S.K., Jyoti, J.S.: Generation of Electricity Using Road Transport Pressure, International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 3, 2013, pp. 520-525.

[39] A New Smart Thing Has Come: The Smart Street! Welcome!, http://theawesomedaily.com/a-new-smart-thing-has-come-the-smart-street-welcome/, 4

[40] Meet the streetlights that are powered by footsteps, http://luxreview.com/article/2016/11/meet-the-streetlights-that-are-powered-by-footsteps, 24.02.2018.