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Technology Based Architectural Potentials in Future Sustainable Concrete Infrastructure

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ATINER started to publish this conference papers series in 2012. It includes only the papers submitted for publication after they were presented at one of the conferences organized by our Institute every year. The papers published in the series have not been refereed and are published as they were submitted by the author. The series serves two purposes. First, we want to disseminate the information as fast as possible. Second, by doing so, the authors can receive comments useful to revise their papers before they are considered for publication in one of ATINER's books, following our standard procedures of a blind review.

Dr. Gregory T. Papanikos
President
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Abstract

Driver experience and safety are two core parameters of daily transport and travelling by car. Driver experience is important to maintain drivers focus on the traffic and provide information. The information can be directly relevant to driving such as road works, tailbacks etc. This is 'need to know'- information which is traditionally communicated by signage. Infrastructure also communicates indirectly relevant 'nice to know' – information about e.g. weather conditions, surroundings and cultural heritage.

From an architectural point of view, concrete technology, as of today, offers a wide variety of options to produce very different expressions e.g. by using different formwork solutions (timber, steel, and plywood), finishing procedures, pigmentation etc. Solutions which to some extent are thought into existing projects. However, recent developments in concrete manufacturing will increase the architectural potential of concrete structures even further. Solutions, which will improve safety and overall driver experience. This paper will focus on two specific developments; namely CAD-CAM manufacturing of free form concrete formwork, and embedment of light transmitters into concrete.

These technologies are demonstrated through experimental mock ups where pros and cons will be studied and discussed. The results from these physical mock-ups are used directly in CAD modeling to illustrate and discuss ideas for their implementation in infrastructural concrete. Ideas focusing on overall road aesthetics and integration into landscape surroundings, integrated road graphics (static and dynamic imaging), road acoustics, and road lightning and reflections. As an example; driving through tunnels or noise regulated highways can be tiresome and dull. The concrete structure will often be perceived as a repetitious structure going on and on, which enhance the monotonic driving experience. New integrated solutions to concrete surfaces for infrastructure may help to overcome this and enhance both our driver experience and safety.

Key Words: Infrastructure, Concrete, Architecture, Robotic, Formwork, Optic, Fibre, Road, Acoustic, Traffic, Noise.

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INTRODUCTION

Infrastructure is an important part of daily life, travel, business and leisure (Fig. 1). Mobility in Denmark is based on a combination of train and automotive infrastructure traffic, with a high level of coherent solutions covering spatial and component design and resulting in better road architecture and improved driver safety. Originally the crash barrier, that straightens out the cars direction was invented in Denmark in mid 1930s and after WW2 further developed and brought to market worldwide.[1]

The crash barrier design concept derives from automotive design due to the average size and car platform. Automotive industry spends large sums on research and development, compared to infrastructure enterprises, so technology transfer is natural and linking the two industries is a potential.

Industrial robots are originally developed for Computer Aided Manufacturing (CAM) of cars (from 1950s). According to literature industrial robots can be utilized within construction of infrastructure and buildings.[2] This development is realistic due to the last decade evolution of Computer Aided Design (CAD) in construction and due to contemporary rich variety of larger size robots featuring high payload, lower price, user friendly interface and high degree of flexibility.

Concrete is increasingly used within infrastructure due to its low price, high durability and endless form possibilities. A high performing building culture is established resulting in a general picture of high quality infrastructure. However, recent developments in concrete manufacturing indicate that it is possible to evolve architectural potential in concrete structures, aiming for innovative solutions to improve safety and overall driver experience.

This paper will focus on two specific developments; namely CAD-CAM robotic manufacturing of free form concrete formwork, and embedment of light transmitters into concrete. The experiments employ the latest concrete technology combined with architectural approach covering both spatial design and component design, aiming at our sense of vision, sense of hearing and sense of space.

EXPERIMENTS

The three experiments described are all carried out at The High Tech Laboratory at Danish Technological Institute (DTI) employing latest technology to reveal new architectural potentials targeted at future concrete infrastructure. The notion, architectural potentials, covers following aspects: aesthetics, acoustics, function, safety and sustainability. The first two experiments pursue and demonstrate images embedded in infrastructures

[1] «Crash barrier history, Dansk Auto-Værn A/S».
[2] Thrane, Andersen, og Mathiesen, «The use of robots and self-compacting concrete for unique concrete structures».

concrete surfaces: First, by applying ornament to the concrete surface, second, by embedding information technology into a smooth freely formed concrete surface. The third experiment pursues to reduce noise pollution at high ways and demonstrates a potential improvement of the overall design solution.

Experiment 1: Embedded imaging

The experiment was carried out at DTI initiated by cooperation with Henning Larsen Architects in 2008. Later its potentials were further investigated.

MOTIF: PROMOTE AESTHETIC VALUE LAYER TO EXISTING FORMWORK SYSTEMS

The motivation was to investigate architectural potentials within existing building praxis, and find alternative solutions to the plane, smooth concrete surface well known in building and infrastructure.

HYPOTHESIS: ORNAMENTAL REVIVAL IS A POTENTIAL WITHIN CONCRETE INFRASTRUCTURE

The experimental idea was to use industrial robot milling to fabricate form inlays that should be inexpensive to fabricate and be compatible with existing formwork systems. The CAD-CAM fabrication should provide a high degree of form freedom, and form inlays should result in new industrial ornamentation, embedded in the concrete surface itself – like carved in stone.

COURSE: DESIGN AND PRODUCTION OF PROTOTYPE

Based on a black and white image with high level of contrast, a 3D geometry was generated using a 3D modeling software. In this technique a specific height is given depending of the intensity of black. Afterwards the 3D image was provided with a raster pattern where every second raster band was substituted with a reference plane. In this way the image is “hidden” in varying depth of the relief in the concrete. The greater the distance between the reference plane and the terrain bottom the darker the shadows between the vertical tracks occur.

The 3D “image” was milled into a block of polyurethane using a plane tool attached on the industrial robot at DTI. Hereafter this milled form inlay was placed in a formwork and casted with self-compacting concrete. This process was repeated a number of times manufacturing prototypes in different sizes.

RESULTS: AUTOMATICALLY GENERATED ENTITIES CREATES ORNAMENTAL ENTIRETIES

The results are a number of concrete panels of size varying from 10 x 20 centimetres up to 1 x 1.5 metres, and a relief depth from 6 up to 25 millimetres. Commonly it is noticed that images arise and appear due to raster bands created by shadows cast in the concrete ornament. The embedded ornament can either be an added relief (Fig. 1, left) or a lowered relief (Fig. 1, right).

The apperance is obviously very dependant on light direction and diffusion. It is also observed that embedded imaging concrete surfaces are responsive to weather conditions: Imaging on a wet surface appears more strong and contrastive, than the imaging on a dry surface (Fig. 3). The reason for this phenomenon has not been discovered.

Embedded Imaging is conceived as new industrial ornament, where entities of fine details create an entire concrete surface with figurative or informative appearance. This new technology represents new architectonic potentials.

Experiment 2: Optic fibre concrete surface

The experiment was carried out 2010-2012 at DTI in cooperation with Dupont Lightstone, who holds the world patent "*Display system intergrateable into a building structure"* covering the information technology embedded in concrete.[1] The strategic motive of the cooperation was to use DTIs experience of CAD-CAM manufacturing of free form concrete formwork, with Dupont Lightstones experience with embedment of light transmitting information technology into concrete

MOTIF – INFORMATION TECHNOLOGY CAN BE INTEGRATED IN INFRASTRUCTURE

The experimental idea was to apply embedded information technology on freely formed concrete surfaces and to upscale potential application by using new fabrication methods. Thereby it will be possible to integrate signage and live images into concrete surfaces of infrastructure.

HYPOTHESIS: ROBOTICS IS CORE IN NEW FORMWORK TECHNOLOGY FOR INFRASTRUCTURE

Optic fibres can through a cost-efficient robotic process be embedded in freely formed concrete surfaces, resulting in innovative solutions for infrastructure.

COURSE: FABRICATION DESIGN, PROTOTYPES, TEST AND EVALUATION

The experimental process undertaken was complex and multifarious (Fig. 4). It is described earlier in literature[2], and can be outlined by six steps:

1. Find pixels pattern connecting two dimensional image source and three dimensionally freely formed concrete surface.
2. Develop formwork system and fabrication strategies.
3. Set up fabrication line composed by robotic and manual processes.
4. Fabricate formwork and cast concrete.
5. Remove formwork and finish surfaces of prototype.
6. Test and evaluate prototypes *and* fabrication.

Last step was carried out with quantitative and qualitative methods in order to cover reason fabrication and to demonstrate architectural appearance of this hitherto unseen concrete surface.

[1]Dupont, «Display system intergrateable into a building structure».
[2]Greisen, «Robot Manufactured Formwork for Doubly Curved Concrete Surfaces with Precisely Embedded Optical Fibres Displaying Live Images», 142.

RESULTS: IMAGE FREEDOM, AMBIENT TECHNOLOGY AND SMOOTH APPEARANCE

Evaluation showed that fabrication is complex but feasible. The final three prototypes demonstrated concrete surfaces are capable of showing any live and still images, such as decoration (Fig. 5, left) or information (Fig. 5, right). Highlights occurs on surface parts facing directly towards the viewer due to the light leaving the optical fibre in prolongation of its directions and the optical fibre being cast in right angle to the surface, resulting in a transparent appearance. Unlit pixels disappear in the surface due to camouflaging of the coarse aggregate, resulting in ambient technology and a smooth appearance (Fig. 6).

Experiment 3: Acoustic Crash Barrier

The experiment was carried out 2012 as an iterative process at DTI in cooperation with Dansk Autoværn and Danish Road Directory. DTI represents future fabrication possibilities, Dansk Autoværn represents producer, vendor, erection and assembly on site, and finally, Danish Road Directory represents customer, maintenance and end user.

MOTIF: IMPROVE NOISE REDUCTION SOLUTION AND SAFETY AT HIGHWAYS

The motivation was to create more aesthetic, functional and durable concrete solutions for highway infrastructure, specifically was aimed at: Reduce traffic noise inconvenience, improve safety, flexibility and erection speed and reduce price and environmental footprint by using the crash barrier as foundation for noise walls.

HYPOTHESIS: NEW CONCRETE FORMWORK TECHNOLOGIES ADDS VALUE TO INFRASTRUCTURE

The experimental idea was to utilize CAD-CAM manufacturing, industrial robot milling of free form concrete formwork to create next generation of concrete crash barriers.

COURSE: ITERATION, DESIGN AND PROTOTYPE FABRICATION

Point of departure was existing crash barrier praxis and the new potentials of robot manufactured concrete formwork. A concept was developed and this concept ran through a number of iterations and modifications (Fig. 7). The chosen final design solution features a larger active noise absorption area, and a connection detail making it possible to mount noise walls *from behind* of the crash barrier. This detail improves work environment remarkably.

A prototype was fabricated by employing the industrial robot and industrial mixing plant at DTI and using existing reinforcement and connection systems (Fig. 8). Employment of these industrial fabrication techniques demonstrated potential actual fabrication being possible to implement and upscale. It was clearly demonstrated that the formwork was clean and intact.

RESULTS: DIGITAL MODEL AND PHYSICAL PROTOTYPE

The results cover CAD models describing the design solution and one physical concrete crash barrier element. This element is compatible which the existing system. It can be fitted into a crash barrier graduation and the proposed design solution has the possibility to work as noise wall foundation due to the improved connection detail (Fig. 9).

The acoustic absorption embedded in the crash barrier, is closer to the noise source (engine, wheels and asphalt), and will potentially reduce traffic noise pollution. Thereby it will reduce the need for noise barriers, baffles or other traditional noise abatement or improve the acoustic environment.

Furthermore the experiment demonstrates that the pattern of the noise absorbing areas and the robot fabrication can be a part of the concrete design, by being placed to emphasize infrastructure as an architectural space.

DISCUSSION and CONCLUSIONS

The results demonstrated by the three experiments shows that robot based CAM-technologies provide hitherto unseen possibilities and new industrial building *techniques*. These techniques can be combined and connected to existing infrastructure building techniques and lead to new building technology. We will discuss to which extent these new technologies are relevant to future infrastructure, by reflecting Vitruvius' three core elements of architecture: Durability (*Firmitas)*, convenience or functionality (*Utilitas)* and beauty (*Venustas*).[1] These, so called *departments*, are not distinct from each other, because architecture is a unified whole, but they offer a framework to understand the entities.

DURABILITY AND SUSTAINABILITY [*FIRMITAS*]

The resulting fact that the formwork can be reused as formwork or recycled as material is crucial to prove these new technologies relevant to infrastructure. They are a sustainable answer to an old, but sturdy paradox: *"Reinforced concrete can be cast into almost any shape, but how do you build a formwork of this size to pour it into? Standard formwork systems are customizable to a certain degree, but they cannot handle doubly curved surfaces"*[2]

These technologies are in keeping with contemporary tendencies on fabrication[3] and mass customization[4]; the so called *new industrialization* which connection to architecture and tectonics is condensed in the following quote: *"We do not reject the concept of hierarchy, but rather use it in a new way… we are using organizational principles that promote communication across scales"*.[5]

We conclude that robot based fabrication of formwork can be an efficient and sustainable way to achieve smarter solutions with a smaller environmental

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[1] Morgan, *Vitruvius*, p. 17.
[2] Scheurer, «Size Matters: Digital Manufacturing in Architecture», p. 63.
[3] Glynn, Sheil, og Skavara, *Fabricate: Making Digital Architecture*.
[4] Ryborg Jørgensen og CINARK, *Arkitektur & Mass customization*.
[5] Reiser og Umemoto, *Atlas of Novel Tectonics*, p. 50.

footprint, richer architecture with doubly curved geometries and to improve the concrete surface with outstanding relief or embedded technology.

FUNCTIONALITY, CONVENIENCE AND SAFETY [*UTILITAS*]

Convenient functions such as acoustics absorption, innovative connection details, and robust information technology was integrated in the experimental concrete solutions.

Design freedom was obtained was improved compared to previous solutions, because the design phase (CAD) is linked to the fabrication phase (CAM). *Flexibility* was kept because any connection system, reinforcement or acoustic absorption product can be implemented. *Safety* for workers was increased, because the mounting will be undertaken from behind the crash barrier.

The functions derive from details which at conveniently and automatically generated through CAD-CAM processes, and therefore the technology is a cost-efficient method to add a value layer to existing formwork technologies, and integrate imaging into concrete surfaces of infrastructure.

AESTHETICS [*VENUSTAS*]

Concrete itself as infrastructure is very durable, but the durability of concretes aesthetics can be questioned, because concrete not always grow old gracefully. In general ornament and relief helps aesthetic aging of concrete surfaces for two reasons; first, distribution of water happens more controlled and evenly, and second, the ornamental patterns play down the traces of age.

Ornament creating embedded images will therefore potentially create more aesthetic infrastructure simply because the relief ages gracefully *and* because the relief makes it possible to add a long lasting image layer. The motif of this image layer must be chosen very carefully, for it must have a long lasting connection to the built infrastructure (Fig. 10). It is a true ornament like carved in stone, not a decoration.

The driver perceives the so called *road space* from the moving car,[1] and literature also proves that the drivers visual field of becomes more narrow at higher speeds.[2] The visual fields centre is the vanishing point ahead of the driver, where all road space lines meet and vanish. The pattern obtained in the acoustic crash barrier aims towards this centre of visual field, and therefore we conclude that it emphasizes the movement of the car, and emphasizes the driver experience of infrastructure as an architectural road space.

Optical fibres are a feasible technology to make concrete surfaces display images and thereby offer new architectonic and spatial possibilities. Scale, size and information density are crucial factors in the challenge of bringing these new possibilities into architectural praxis.

Resolution of the approximately 3000 pixels achieved are similar to existing digital signage, but it is low compared to the resolution at hand in smart devices, such as mobile phones and GPSs. Optic fibre concrete surfaces must

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[1] Egebjerg og Simonsen, *Byen, vejen og landskabet - Motorvej til fremtiden*, 47.
[2] Tunnard og Pushkarev, *Man-made America*, p. 173.

not only be comprehended as traditional information technology, but also as a new ‘transparent’ architecture, because it has the important feature that the information technology is hidden when not in use, leaving an smooth aesthetic surface.

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FIGURES

Figure 1. *Highway, Copenhagen Ring 3. 2012. New Jersey crash barrier system (left) and 3-4 meter high noise walls (right)*

Figure 2. *Embedded Imaging as new industrial ornament, concrete surfaces and details*

Figure 3. *Embedded Imaging responding on weather conditions*

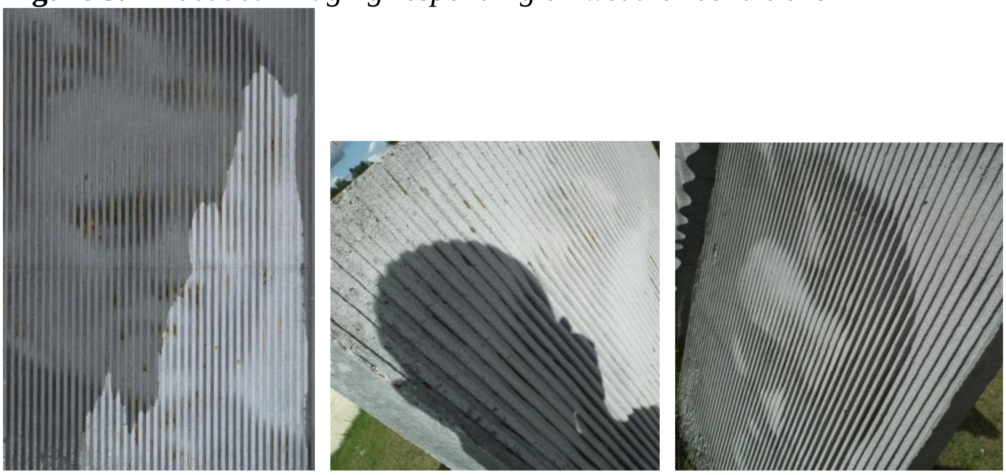

Figure 4. *Fabrication proces of optic fibre concrete*

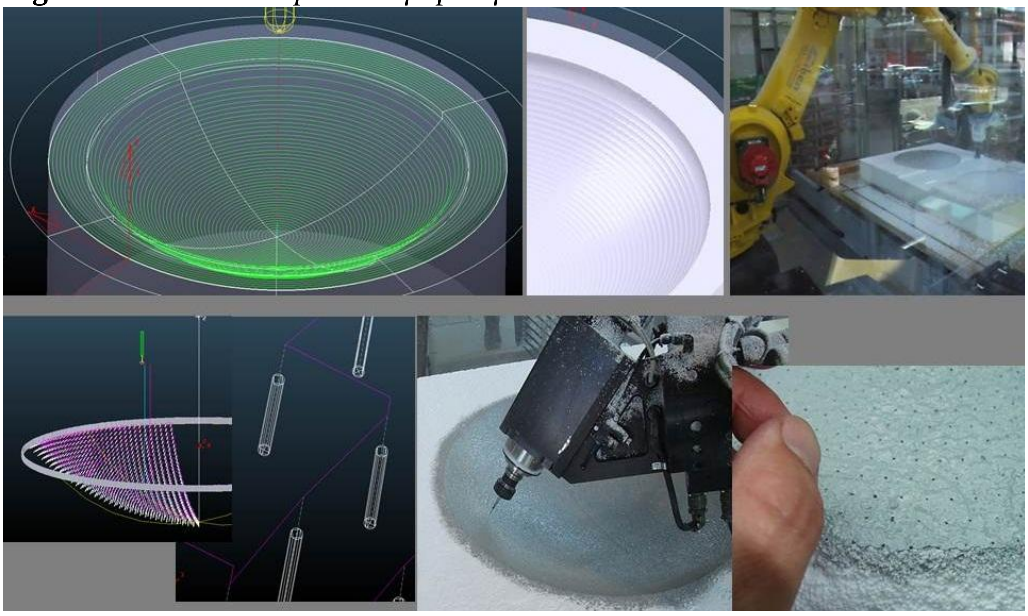

Figure 5. *Optic fibre concrete surface showing different images*

Figure 6. *Information technology being integrated into concrete surface and being 'silent' when not in use*

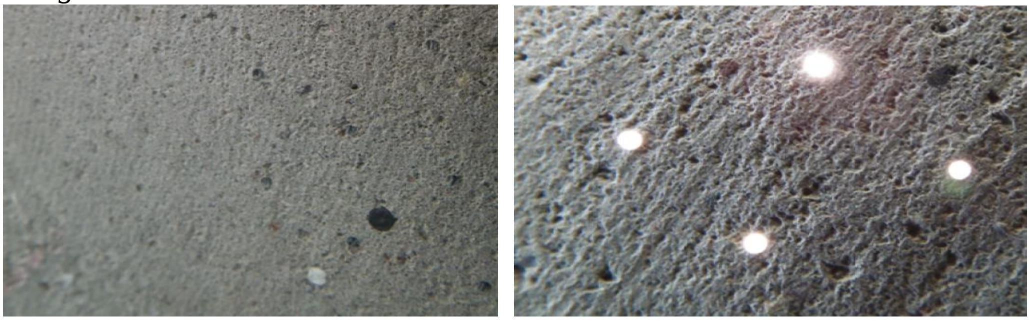

Figure 7. *Concept for next generation crash barrier with integrated noise wall and silencer module*

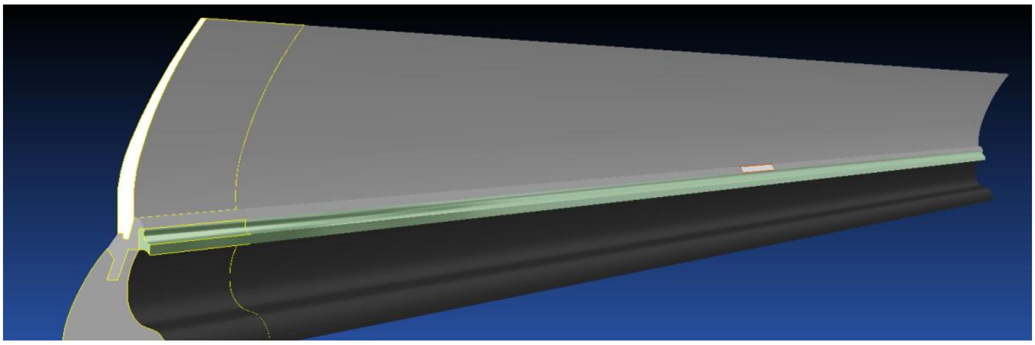

Figure 8. *Final design solution for acoustic crash barrier*

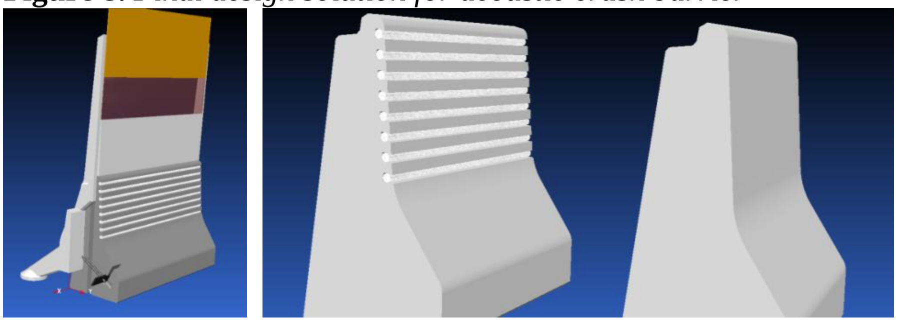

Figure 9. *Fabrication and concrete prototype of crash barrier element*

Figure 10. *Visualization of embedded imaging applyed (Photomontage)*