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EXTERNAL INSTITUTIONS

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R3Direct

EXTERNAL TUTOR

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AMSHI

Executive summary

According to United Nations demographic forecasts, by 2050 more than 70 per cent of the world's population will live in cities. The urban heat island phenomenon, i.e. the increase in temperature in densely built-up urban areas compared to the surrounding suburban and rural ones, will affect the majority of the world's population and its mitigation will be crucial to maintain acceptable living conditions, also in light of worsening climate change.
The AMSHI project aims at contributing to the effort to mitigate this phenomenon, by designing a self-locking paving block with a low degree of embodied energy for public spaces that, thanks to its porosity, composition and colour characteristics, can contribute to reduce the urban heat island effect.
The main stakeholders with whom we collaborated, in addition to the professors and tutors who assisted us during the research and development phases of the block, were the municipality of Savona, which chose to test the block in the area in front of the university, and two companies. The first, Ferrari BK, is specialised in the production of traditional out-door paving blocks for over 50 years. The second, R3direct, is a Tuscan company spe-cialised in 3D printing, with which we collaborated to work on the moulds for the finishing layer of the blocks. Our role, in addition to active design, was to mediate between the differ-ent parties. We have visited the companies two times to see their production methods up close and to better understand the block engineering process that we later had to use.
To design a feasible solution from an economical and industrial point of view, the block that we have been called to design had to meet standards that not only concern thermal performance, but also ease of production, low cost, environmental sustainability, simplicity of installation and execution, and good aesthetic appearance that allows it to be used in central and prestigious urban contexts.
The objectives to be pursued, therefore, on which the preliminary research and design work was based, are listed below:
Thermal performance: the block must be able to guarantee a high level of porosity that contributes to maintain a good level of thermo-hygrometric comfort. The albedo, i.e. the reflective power of the surface, is also important in order not to absorb energy from the solar radiation as it would later be released in the form of heat. To understand the effects of the urban heat island, we carried out a measurement campaign in Savona, supplemented by a questionnaire that we had some of the city's inhabitants fill out, to understand their degree of dissatisfaction with the microclimatic conditions.
Sustainability: the block must have a low embodied energy level, i.e. a low impact in the use of limited resources of the environment.
The initial idea was to use geopolymer-based binders instead of traditional cement. However, the high costs of the materials and their hazardousness during production made us opt for a more traditional solution using a standard cement as a binder. The level of embodied energy compared to traditional concrete binders was achieved using recycled aggregates.
Mechanical strength: the ratios of recycled aggregate to primary aggregate were optimised through mechanical strength tests in the laboratories of the Politecnico di Torino. The block will be used for pavements operating under a limited flow of light-weight vehicles, and there-fore comply with specific mechanical characteristics.
Urban quality: the blocks, used for paving public spaces, should contribute to urban regeneration, not only from the point of view of thermo-hygrometric comfort, but also from the point of view of accessibility and quality of public spaces. We researched and studied some good examples of urban regeneration at all scales to understand which elements and characteristics are the most relevant for urban regeneration in general and for the specific design of the paving block. The choice of colours was based on a study of the recurring colours in the aesthetic identity of the city of Savona. Starting from a single block, thanks to its shape and the controlled randomisation of the colours, it was possible to obtain a great variety in the designs.
Industrialisation and scalability of the product: To mitigate the urban heat island effect, large public surfaces need to be changed. It is therefore important that the blocks are produced through an industrial process as simplified as possible. For this reason, we had to make several adjustments to the original design of the block to simplify the production process and make it possible, without failing to meet all the above-mentioned objectives.

Once we had established the design and composition of the paving block (the main objective of the project), the possible colour combinations, and carried out the mechanical tests, we were carried out the masterplan design for the product test on the area indicated by the municipality of Savona. We had to maintain the number of parking spaces present for the university's needs, but we optimised the composition of the routes and the position of vehicular traffic.

After that, we focused on better defining the first 200-square-meter area to be built, designing the colour composition of the individual blocks through computational design, which allowed us to efficiently and immediately produce multiple options that could be compared. This design method also made it possible to calculate in advance the exact number of blocks to be produced based on colour. Future developments in the project will involve industrial production of the 18,900 blocks and subsequent installation by operators. A new measurement campaign, this time carried out on the new paving, will be able to empirically demonstrate how the AMSHI paving block is a valid solution for urban heat island mitigation, as well as a potential more sustainable alternative to traditional asphalt pavements.

Key Words

Urban Heat Island, Self-locking paving block, Sustainability, Thermal comfort

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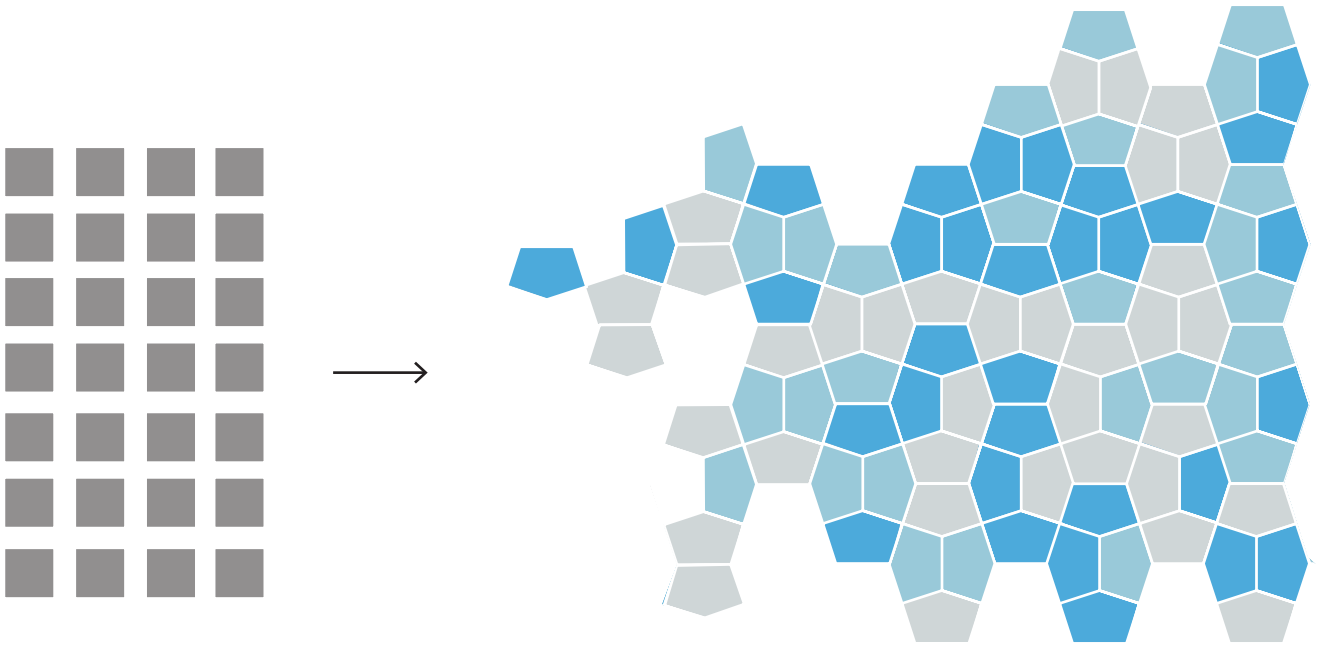
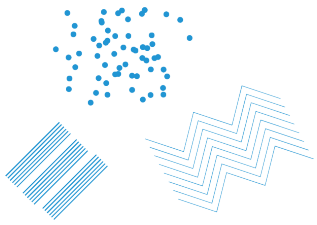
Advanced Solution for mitigating the impact of HEAT ISLAND on urban roads



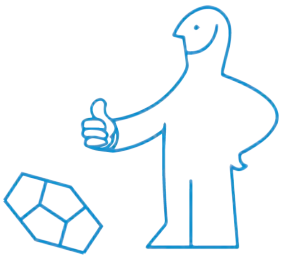
Traditional Self-locking Pavement

AMSHI solution

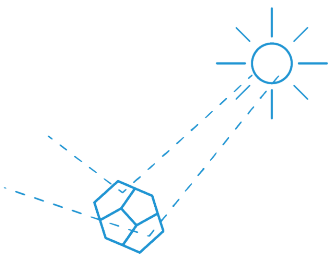
different textures



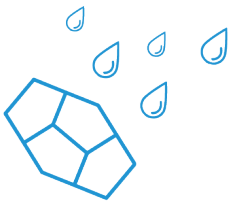
easy installation



high albedo



more porous



great variety

recycled materials

3D printed

context rooted

Project description written by the Principal Academic Tutor

The AMSHI project aims to (i) investigate innovative solutions for urban paving, (ii) outline a new production process for paving blocks that includes locally sourced secondary raw materials, and (iii) monitor on-site application before and after installation to evaluate the environmental performance of the proposed solution. The standard approach to determining the micro-climatic effects of cool pavement materials on the Urban Heat Island (UHI) effect is to measure the difference in surface temperatures and their effect on thermal comfort conditions. Here, a combination of field experimental campaigns (with probes to measure the surface temperature and thermal comfort conditions), the use of satellite data to measure the land surface temperature, and the simulations with QGIS tools is proposed to have a complete information about the UHI effect at local, district and urban scale. Furthermore, AMSHI includes activities related to the use of materials at a reduced Portland cement content and including secondary raw materials (i.e. secondary raw materials selection, mix-design, lab testing), and the environmental assessment of the proposed innovative technology as per the use of the Life-Cycle Assessment (LCA) technique. AMSHI includes current production analysis to guide paving block research addressing to a gap in current paving block production. In fact, currently, there is no product that can be created on a large scale, easy to find, and with low costs but with characteristics that can be used in valuable urban contexts, such as urban centres and the streets of historic centres at costs that the administrations can face. The experiments start from the study of a precise historical context in which a new strategy can be adopted. The prototyping of the solution using three-dimensional printers made in "plasmix" is used for small-scale production and intended for the limited industrial production used in the implementation on the pilot site on which to carry out ex-post measurements. The current production of blocks is carried out by pouring standard cement mixtures into metal moulds; the blocks are mechanically vibrated for compaction, then removed vertically and dried. The design of blocks that require complex demoulding has an impact on production times which must be measured to evaluate feasibility and commercialization. The 3D moulds, made with recycled plastic that responds to vibration resistance tests, constitute the blocks that will also be tested under the effect of static and dynamic forces.

Team description by skill

The AMSHI team has six members: four architects and two engineers. To best exploit the multidisciplinary backgrounds, everyone in the team was always informed about the activities being carried out and could give their input. In many activities, a significant part of the work was carried out by the people with the most relevant background; in others – e.g. the interaction with the companies FerrariBK and R3Direct to improve the first designs of the paving block – the whole team acted together.

Alessandra Bruno was the Team Controller, managing the communication between the team and the tutors and the internal works of the team. Gianpaolo Bevilacqua and Matteo Latella, the two engineers, focused on the aspects related to the material, its LCA, but also the manufacturability of the paving block. Francesca De Cola developed the first masterplan of the test site, handled most of the team presentations, and together with Matteo Deval was responsible for the analysis of the local conditions in Savona. Matteo Deval also developed the computational design aspects of the final masterplan. Pietro Mariani carried out the analysis of many urban regeneration case studies with Alessandra; he also focused on an implementation of the pavement which was relevant for the local context in Savona.

Goal

The AMSHI project's main goal is to develop an interlocking concrete pavement to counteract the Urban Heat Island (UHI), to be eventually tested in a pilot site in Savona. Contemporarily, this new pavement is specifically designed to be better inserted in the local context, create a high-quality pub-lic space, and use secondary raw materials, to reduce the environmental impact of new construc-tions.
There are several possible interventions to mitigate the UHI, which should be used in synergy, with the most important being: increasing vegetation, using cool or green roofs, and using cool pave-ments. Pavements in cities typically occupy double the surface area of buildings, so they are a key ar-ea to act on and this project is focused only on them. However, it is essential to keep in mind that cool pavements are only a part of the general solution.
Finally, the designed pavement must be feasible from an economical and industrial point of view, be-cause its benefits can be reaped only if it becomes widely adopted. This means that the performance of this design must be similar to the ones of existing pavements, and it must be able to be manufac-tured with existing industrial processes and equipment.
Therefore, the multiple objectives to be pursued with this pavement are: 1) improve the thermal comfort of urban roads; 2) have a low life cycle impact; 3) guarantee the needed mechanical strength for an urban pavement; 4) contribute to the quality of the urban space; 5) be industrially and commercially viable and scalable.

Understanding the problem

The Urban Heat Island (UHI) is the increase of temperature in the urban centres compared to the suburban and rural areas, which can easily be 3–5 °C higher. Its causes are linked to urban morphol-ogy (height and distribution of buildings, the orientation of roads, etc.) and, especially, to the mate-rials used both for buildings and for pavements, which absorb sunlight and heat up, and the lack of vegetation that could help in cooling down the area thanks to evapotranspiration.
There are several negative effects associated with the UHI. Some of the most significant are on the social aspect, as the UHI causes general thermal discomfort and can lead to heat-related illnesses and deaths, and the economic costs that incur due to the increased expense for public health and civil protection, but also for damage recovery from extreme weather events that are made more likely by the higher air temperatures.
We carried out a study of the local conditions in Savona: first a general analysis of the built environ-ment and the socio-economic conditions, then a specific analysis of the UHI phenomenon. Data col-lected remotely (Land Surface Temperature from satellite measurements and weather station data) was used to obtain a general picture and choose (together with Savona municipality) the pilot site for the installation of the innovative pavement. Later, we went to Savona to carry out measurements of the local environmental conditions (temperature, humidity, wind speed, etc.) to assess the inten-sity of the UHI phenomenon both in the pilot site before the intervention and in other reference sites with varying surfaces (asphalt or concrete pavement, or green areas) and urban density.
UHI is a significant problem that will become worse with global warming, and it will affect more and more people with the increasing urbanization of the global population. The growing urban popula-tion also presents the need for high-quality urban spaces and low-impact materials for new con-structions.
Traditional concrete used in interlocking pavers (and in the construction industry in general) has a relatively high impact on the environment due to the production of Portland cement and the large consumption of natural aggregates, in terms of greenhouse gas emissions, energy consumption, and many other areas. There are several proposals to reduce the impact of concrete both using recycled aggregates instead of natural ones or alternative binders such as geo-polymers and other alkali-activated binders or cement with low clinker content (which is the most impactful component and can be partially substituted with recycled cementitious materials such as fly ash or blast furnace slag).

Finally, traditional interlocking pavers are typically built with a one-size-fits-all approach, with many new constructions being completely detached from the local context and having little aesthetic val-ue. Instead, we conducted a thorough investigation of the typical local pavement shapes and col-ours, as well as of some of the landmarks and views of the city centre.

Exploring the opportunities

The AMSHI project represents a significant step forward in the transformation of our cities into more sustainable and pleasurable spaces. The main goal of this project is to mitigate the urban heat island phenomenon, making our cities more liveable also during the hottest summers.
However, the opportunities arising from the AMSHI project do not stop here. The use of recycled aggregates to make paving bricks promotes a reduction of environmental and energy impact during the production process. This not only preserves natural resources, but also contributes to the reduction of carbon emissions, supporting efforts to combat climate change.

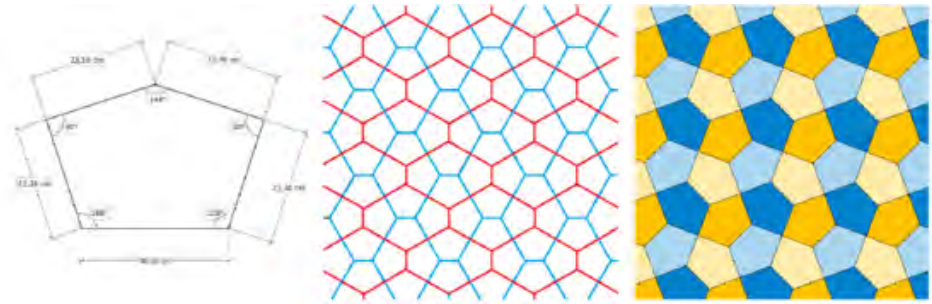
In addition, the urban areas where the pavement change takes place can be revitalized, thus improving the aesthetics, accessibility and quality of the place. These improvements could in this way attract new investment and development in the surrounding areas, increasing the vitality of the community.
Finally, the choice of brick colors was designed to reflect the distinctive characteristics of the site, helping to integrate this pavement more into the urban context and preserve the local identity, enhancing the overall experience of residents and visitors.

Generating a solution

The main goal of the AMSHI project is to create a self-locking block with properties aimed at mitigating the heat island phenomenon in urban centers. It was mainly based on the historical context of Savona but can be modified for use in different contexts. The block is a porous block, to drain the water that settles on top, and is composed of recycled aggregates, thus reducing environmental impacts during production.
The design and block shape was based on the requirements of the available machinery, the Ferrari BK production method and the installation efficiency of it. The characteristics considered to be met are:

- Minimization of linear seams that are too long.
- Minimization of block types to be printed.
- Use of angles preferably not less than 90 degrees.
- Easy to place for operators.

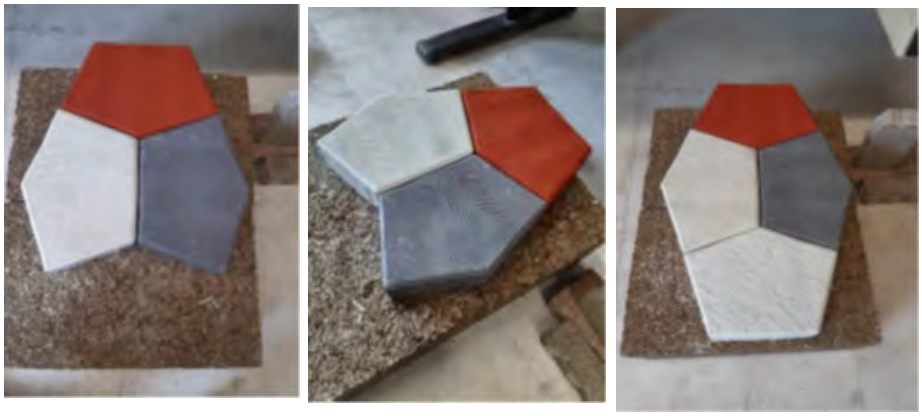
The shape, size and compositional scheme chosen as a result of the above considerations is as follows:



Block shape, block sizing, and compositional scheme.

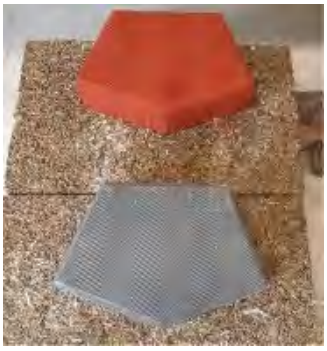
The color of the pavement is of fundamental importance, as it characterizes the albedo, i.e. the amount of light absorbed and not reflected by the surface. A high albedo means a low percentage of solar energy absorbed and consequently less heating of the pavement during the day.

The selection criterion was based on the investigation of the colours of the pavements and façades of Savona's historic centre. The grey and reddish colours were chosen so as not to create a contrast with the urban context, despite their low albedo.



Final finishing and colour tests carried out by R3Direct.

For the realisation of our product, the moulding of the texture takes place thanks to the contribution of the company R3Direct, with whom we worked on the image that will be realized in negative on the mould, into which the solid wood compound is poured to take shape.



Selected finish for solid block construction.

Through the catalogues provided by ferrari BK, a surface finish was selected that, simply by rotating the piece, is able to create different patterns and spaces, in order to further reduce the repetitiveness of the mould, improving the aesthetic but also the functional qualities. The final block minimizes the variations in shape as much as possible, still having a variety of possible designs, and can be manufactured through the known techniques and equipment already present, bringing at the same time innovation and sustainability with respect to traditionally produced pavements. Although this block was developed specifically to the municipality of Savona, minimal variations in color and finish, which are the least demanding changes in this production process, make it adaptable to many different spaces and uses. Through research linked to the context, it is possible to adapt the block with any surrounding space.

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